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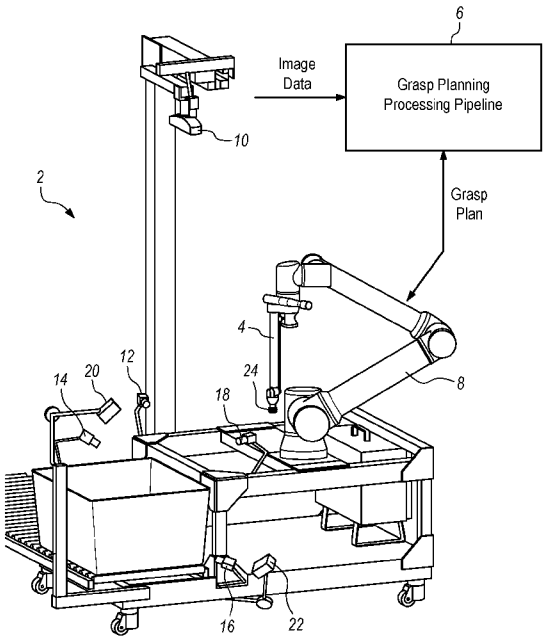


FIG. 1

(57) Abstract: One approach is directed to a robotic package handling system, comprising a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information.

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ROBOTIC PACKAGE HANDLING SYSTEMS AND METHODS

FIELD OF THE INVENTION:

[0001] This invention relates generally to the field of robotics, and more specifically to a new and useful system and method for planning and adapting to object manipulation by a robotic system. More specifically the present invention relates to robotic systems and methods for managing and processing packages.

BACKGROUND:

[0002] Many industries are adopting forms of automation. Robotic systems, and robotic arms specifically, are increasingly being used to help with the automation of manual tasks. The cost and complexity involved in integrating robotic automation, however, are limiting this adoption.

[0003] Because of the diversity of possible uses, many robotic systems are either highly customized and uniquely designed for a specific implementation or are very general robotic systems. The highly specialized solutions can only be used in limited applications. The general systems will often require a large amount of integration work to program and setup for a specific implementation. This can be costly and time consuming.

[0004] Further complicating the matter, many potential uses of robotic systems have changing conditions. Traditionally, robots have been designed and configured for various uses in industrial and manufacturing settings. These robotic systems generally perform very repetitive and well-defined tasks. The increase in e-commerce, however, is resulting in more demand for forms of automation that must deal with a high degree of

changing or unknown conditions. Many robotic systems are unable to handle a wide variety of objects and/or a constantly changing variety of objects, which can make such robotic systems poor solutions for the product handling tasks resulting from e-commerce. Thus, there is a need in the robotics field to create a new and useful system and method for planning and adapting to object manipulation by a robotic system. This invention provides such new and useful systems and methods.

SUMMARY

[0005] One embodiment is directed to a system and method for planning and adapting to object manipulation by a robotic system functions to use dynamic planning for the control of a robotic system when interacting with objects. The system and method preferably employ robotic grasp planning in combination with dynamic tool selection. The system and method may additionally be dynamically configured to an environment, which can enable a workstation implementation of the system and method to be quickly integrated and setup in a new environment.

[0006] The system and method are preferably operated so as to optimize or otherwise enhance throughput of automated object-related task performance. This challenging problem can alternatively be framed as increasing or maximizing successful grasps and object manipulation tasks per unit tasks. For example, the system and method may improve the capabilities of a robotic system to pick objects from a first region (e.g., a bin), moving the object to a new location or orientation, and placing the object in a second region.

[0007] In one particular variation, the system and method employ the use of selectable and/or

interchangeable end effectors to leverage dynamic tool selection for improved manipulation of objects. In such a multi-tool variation, the system and method may make use of a variety of different end effector heads that can vary in design and capabilities. The system and method may use a multi-tool with a set of selectively activated end effectors as shown in FIGURE 7 and FIGURE 8. In another variation, the system and method may use a changeable end effector head wherein the in-use end effector can be changed between a set of compatible end effectors.

[0008] By optimizing throughout, the system and method can enable unique robotic capabilities. The system and method can rapidly plan for a variety of end effector elements and dynamically make decisions on when to change end effector heads and/or how to use the selected tool. The system and method preferably account for the time cost of switching tools and the predicted success probabilities for different actions of the robotic system.

[0009] The unique robotic capabilities enabled by the system and method may be used to allow a wide variety of tools and more specialized tools to be used as end effectors. These capabilities can additionally, make robotic systems more adaptable and easier to configure for environments or scenarios where a wide variety of objects are encountered and/or when it is beneficial to use automatic selection of a tool. In the e-commerce application, there may be many situations where the robotic system is used for a collection of objects of differing types such as when sorting returned products or when consolidating products by workers or robots for order processing.

[0010] The system and method is preferably used for grasping objects and performing at least one object manipulation task. One preferred sequence of object manipulation tasks can include grasping an object (e.g., picking an object), moving the object to a new position, and placing the object, wherein the robotic system of the system and method operates as a pick-and-place system. The system and method may alternatively be applied to a variety of other object processing tasks such as object inspection, object sorting, performing manufacturing tasks, and/or other suitable tasks. While, the system and method are primarily described in the context of a pick-and-place application, the variations of the system and method described herein may similarly be applied to any suitable use-case and application.

[0011] The system and method can be particularly useful in scenarios where a diversity of objects needs to be processed and/or when little to no prior information is available for at least a subset of the objects needing processing.

[0012] The system and method may be used in a variety of use cases and scenarios. A robotic pick-and-place implementation of the system and method may be used in warehouses, product-handling facilities, and/or in other environments. For example, a warehouse used for fulfilling shipping orders may have to process and handle a wide variety of products. The robotic systems handing these products will generally have no 3D CAD or models available, little or no prior image data, and no explicit information on barcode position. The system and method can address such challenges so that a wide variety of products may be handled.

[0013] The system and method may provide a number of potential benefits. The system and method are not

limited to always providing such benefits, and are presented only as exemplary representations for how the system and method may be put to use. The list of benefits is not intended to be exhaustive and other benefits may additionally or alternatively exist.

[0014] As one potential benefit, the system and method may be used in enhancing throughput of a robotic system. Grasp planning and dynamic tool selection can be used in automatically altering operation and leveraging capabilities of different end effectors for selection of specific objects. The system and method can preferably reduce or even minimize time spent changing tools while increasing or even maximizing object manipulation success rates (e.g., successfully grasping an object).

[0015] As another potential benefit, the system and method can more reliably interact with objects. The predictive modeling can be used in more successfully interacting with objects. The added flexibility to change tools can further be used to improve the chances of success when performing an object task like picking and placing an object.

[0016] As a related potential benefit, the system and method can more efficiently work with products in an automated manner. In general, a robotic system will perform some processing of the object as an intermediary step to some other action taken with the grasped object. For example, a product may be grasped, the barcode scanned, and then the product placed into an appropriate box or bin based on the barcode identifier. By more reliably selecting objects, the system and method may reduce the number of failed attempts. This may result in a faster time for handling objects thereby yielding an increase in efficiency for processing objects.

[0017] As another potential benefit, the system and method can be adaptable to a variety of environments. In some variations, the system and method can be easily and efficiently configured for use in a new environment using the configuration approach described herein. As another aspect, the multi-tool variations can enable a wide variety of objects to be handled. The system and method may not depend on collecting a large amount of data or information prior to being setup for a particular site. In this way, a pick-and-place robotic system using the system and method may be moved into a new warehouse and begin handling the products of that warehouse without a lengthy configuration process. Furthermore, the system and method can handle a wide variety of types of objects. The system and method is preferably well suited for situations where there is a diversity of variety and type of products needing handling. Although, instances of the system and method may similarly be useful where the diversity of objects is low.

[0018] As a related benefit, the system and method may additionally learn and improve performance over time as it learns and adapts to the encountered objects for a particular facility.

[0019] Another embodiment is directed to a robotic package handling system, comprising a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure positioned in geometric proximity to the distal portion of the robotic arm; a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to

the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; and wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly defining a first inner capture chamber configured such that conducting the grasp of the targeted package comprises pulling into and at least partially encapsulating a portion of the targeted package with the first inner capture chamber when the vacuum load is controllably activated adjacent the targeted package.

[0020] Another embodiment is directed to a robotic package handling system, comprising a robotic arm comprising a distal portion and a proximal base portion an end effector coupled to the distal portion of the robotic arm; a place structure positioned in geometric proximity to the distal portion of the robotic arm; a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive

the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; and wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing device, the first suction cup assembly defining a first inner chamber, a first outer sealing lip, and a first vacuum-permeable distal wall member which are collectively configured such that upon conducting the grasp of the targeted package with the vacuum load controllably activated, the outer sealing lip may become removably coupled to at least one surface of the targeted package, while the vacuum-permeable distal wall member prevents over-protrusion of said surface of the targeted package into the inner chamber of the suction cup assembly.

[0021] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure positioned in geometric proximity to the distal portion of the robotic arm; a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

[0022] a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the

first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; and wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package when the vacuum load is controllably activated adjacent the targeted package; and wherein before conducting the grasp, the computing device is configured to analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device, the neural network trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure.

[0023] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure positioned in geometric proximity to the distal portion of the robotic arm; a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned

and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; and wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package when the vacuum load is controllably activated adjacent the targeted package; wherein the system further comprises a second imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector to estimate the outer dimensional bounds of the targeted package by fitting a 3-D rectangular prism around the targeted package and estimating L-W-H of said rectangular prism, and to utilize the fitted 3-D rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector; and wherein the first computing system is configured to operate the robotic arm and end effector to place the targeted package upon the place structure in a specific position and orientation relative to the place structure.

[0024] Another embodiment is directed to a system, comprising: a robotic pick-and-place machine comprising an actuation system and a changeable end effector system configured to facilitate selection and switching between a plurality of end effector heads; a sensing system; and a grasp planning processing pipeline used in control of the robotic pick-and-place machine.

[0025] Another embodiment is directed to a method for robotic package handing, comprising: a. providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly defining a first inner capture chamber; and b. utilizing the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein conducting the grasp of the targeted package comprises pulling into and at least partially

encapsulating a portion of the targeted package with the first inner capture chamber when the vacuum load is controllably activated adjacent the targeted package.

[0026] Another embodiment is directed to a method for robotic package handling, comprising: a. providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and b. utilizing the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing device, the first suction cup assembly defining a first inner chamber, a first outer sealing lip, and a first vacuum-permeable distal wall member which are collectively configured such that upon conducting the grasp of the targeted package with the vacuum load controllably activated, the outer sealing lip may become removably coupled to at least one surface of the targeted package,

while the vacuum-permeable distal wall member prevents over-protrusion of said surface of the targeted package into the inner chamber of the suction cup assembly.

[0027] Another embodiment is directed to a method for robotic package handling, comprising: a. providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and b. utilizing the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package when the vacuum load is controllably activated adjacent the targeted package; and wherein before conducting the grasp, the computing device is configured to analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted

package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device, the neural network trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure.

[0028] Another embodiment is directed to a method for robotic package handling, comprising: a. providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and b. utilizing the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package when the vacuum load is controllably activated adjacent the targeted package; c. providing a

second imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector to estimate the outer dimensional bounds of the targeted package by fitting a 3-D rectangular prism around the targeted package and estimating L-W-H of said rectangular prism, and to utilize the fitted 3-D rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector; and d. utilizing the first computing system to operate the robotic arm and end effector to place the targeted package upon the place structure in a specific position and orientation relative to the place structure.

[0029] Another embodiment is directed to a method, comprising: a. collecting image data of an object populated region; b. planning a grasp which is comprised of evaluating image data through a grasp quality model to generate a set of candidate grasp plans, processing candidate grasp plans and selecting a grasp plan; c. performing the selected grasp plan with a robotic system; and d. performing an object interaction task.

[0030] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to

the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; wherein before conducting the grasp, the first computing system is configured to analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device, the neural network trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure. The first computing system may be further configured to analyze the plurality of candidate grasps based a continuous learning configuration of the neural network wherein data from a set of known and actual experiences is utilized to further train the neural network. The set of known and actual experiences may be based upon prior operation of the particular robotic arm of the system. The set of

known and actual experiences may be based upon prior operation of a different robotic arm similar to the particular robotic arm of the system. The different robotic arm similar to the particular robotic arm of the system may be substantially identical to the particular robotic arm of the system. The first computing system may be configured to analyze the plurality of candidate grasps based upon a kinematic reach of the robotic arm and end effector. The first computing system may be configured to analyze the plurality of candidate grasps based upon a location of labeling information of the targeted package based upon the image information from the first imaging device. The first computing system may be configured to analyze the plurality of candidate grasps based upon a location of barcode labeling information of the targeted package based upon the image information from the first imaging device. The first computing system may be configured to analyze the plurality of candidate grasps based upon a location of labeling information of the targeted package based upon the image information from the first imaging device, and to select an execution grasp that does not have the end effector covering the barcode labeling information. The subject system embodiments above, as well as each below, may each also be directed to the following additional features:

[0031] The system further may comprise a frame structure configured to fixedly couple the robotic arm to the place structure. The pick structure may be removably coupled to the frame structure. The place structure may comprise a placement tray. The placement tray may comprise first and second rotatably coupled members, the first and second rotatably coupled members being configured to form a substantially flat tray base

surface when in a first rotated configuration relative to each other, and to form a lifting fork configuration when in a second rotated configuration relative to each other. The placement tray may be operatively coupled to one or more actuators configured to controllably change an orientation of at least a portion of the placement tray, the one or more actuators being operatively coupled to the first computing system. The pick structure may comprise an element selected from the group consisting of: a bin, a tray, a fixed surface, and a movable surface. The pick structure may comprise a bin configured to define a package containment volume bounded by a bottom and a plurality of walls, as well as an open access aperture configured to accommodate entry and egress of at least the distal portion of the robotic arm. The first imaging device may be configured to capture the image information pertaining to the pick structure and one or more packages through the open access aperture. The first imaging device may comprise a depth camera. The first imaging device may be configured to capture color image data. The first computing system may comprise a VLSI computer operatively coupled to the frame structure. The first computing system may comprise a network of intercoupled computing devices, at least one of which is remotely located relative to the robotic arm. The system further may comprise a second computing system operatively coupled to the first computing system. The second computing system may be remotely located relative to the first computing system, and the first and second computing systems are operatively coupled via a computer network. The first computing system may be configured such that conducting the grasp comprises analyzing a plurality of candidate grasps to select an execution

grasp to be executed to remove the targeted package from the pick structure. Analyzing a plurality of candidate grasps may comprise examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package. Analyzing a plurality of candidate grasps may comprise examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach orientations. Analyzing a plurality of candidate grasps may comprise examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach positions. The first suction cup assembly may comprise a first outer sealing lip, and wherein a sealing engagement with a surface comprises a substantially complete engagement of the first outer sealing lip with the surface. Examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package may be conducted in a purely geometric fashion. The first computing system may be configured to select the execution grasp based upon a candidate grasps factor selected from the group consisting of: estimated time required; estimated computation required; and estimated success of grasp. The first suction cup assembly may comprise a bellows structure. The bellows structure may comprise a plurality of wall portions adjacently coupled with bending margins. The bellows structure may comprise a material selected from the group consisting

of: polyethylene, polypropylene, rubber, and thermoplastic elastomer. The first suction cup assembly may comprise an outer housing and an internal structure coupled thereto. The internal structure of the first suction cup assembly may comprise a wall member coupled to a proximal base member. The wall member may comprise a substantially cylindrical shape having proximal and distal ends, and wherein the proximal base member forms a substantially circular interface with the proximal end of the wall member. The proximal base member may define one or more inlet apertures therethrough, the one or more inlet apertures being configured to allow air flow therethrough in accordance with activation of the controllably activated vacuum load. The internal structure further may comprise a distal wall member comprising a structural aperture ring portion configured to define access to the inner capture chamber, as well as one or more transitional air channels configured to allow air flow therethrough in accordance with activation of the controllably activated vacuum load. The one or more inlet apertures and the one or more transitional air channels may be configured to function to allow a prescribed flow of air through the capture chamber to facilitate releasable coupling of the first suction cup assembly with the targeted package. The one or more packages may be selected from the group consisting of: a bag, a "poly bag", a "poly", a fiber-based bag, a fiber-based envelope, a bubble-wrap bag, a bubble-wrap envelope, a "jiffy" bag, a "jiffy" envelope, and a substantially rigid cuboid structure. The one or more packages may comprise a fiber-based bag comprising a paper composite or polymer composite. The one or more packages may comprise a fiber-based envelope comprising a paper composite or polymer composite. The one or more

packages may comprise a substantially rigid cuboid structure comprising a box. The end effector may comprise a second suction cup assembly coupled to the controllably activated vacuum load. The second suction cup assembly may define a second inner capture chamber configured to pull into and at least partially encapsulate a portion of the targeted package when the vacuum load is controllably activated adjacent the targeted package. The system further may comprise a second imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector. The first computing system and second imaging device may be configured to capture the one or more images such that outer dimensional bounds of the targeted package may be estimated. The first computing system may be configured to utilize the one or more images to determine dimensional bounds of the targeted package by fitting a 3-D rectangular prism around the targeted package and estimating the L-W-H of said rectangular prism. The first computing system may be configured to utilize the fitted 3-D rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector. The system further may comprise a third imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector. The second imaging device and first computing system may be further configured to estimate whether the targeted package is deformable by capturing a sequence of images of the targeted package during motion of the targeted package and analyzing deformation of the targeted

package within the sequence of images. The first computing system and second imaging device may be configured to capture and utilize the one or more images after the grasp has been conducted using the end effector to estimate whether a plurality of packages, or zero packages, have been yielded with the conducted grasp. The first computing system may be configured to abort a grasp upon determination that a plurality of packages, or zero packages, have been yielded by the conducted grasp. The end effector may comprise a tool switching head portion configured to controllably couple to and uncouple from the first suction cup assembly using a tool holder mounted within geometric proximity of the distal portion of the robotic arm. The tool holder may be configured to hold and be removably coupled to one or more additional suction cup assemblies or one or more other package interfacing tools, such that the first computing device may be configured to conduct tool switching using the tool switching head portion.

[0032] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and

command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the place structure comprises at least one substantially planar surface and one or more extrinsic dexterity geometric features extending away from the at least one substantially planar surface, the one or more extrinsic dexterity geometric features configured to provide counter-loading relative to movements of the targeted package via the robotic arm and end effector, to assist the robotic arm and end effector in manipulating the targeted package before the targeted package is released at the place structure. The one or more extrinsic dexterity geometric features may be selected from the group consisting of: a protruding wall; a protruding ramp; a protruding ramp/wall; a compound ramp; a compound wall; and a compound ramp/wall. The one or more extrinsic dexterity geometric features may comprise one or more controllably movable degrees of freedom to change shape operatively coupled to the first computing system. The first imaging device may be configured to provide image information pertaining to the place structure, and wherein based at least in part upon the image

information, the first computing system is configured to utilize a neural network to operate the robotic arm and end effector while conducting the grasp and contacting one or more aspects of the extrinsic dexterity geometric features to obtain a desired orientation of the targeted package upon release of the targeted package to the place structure. The neural network may be trained based at least in part upon synthetic imagery pertaining to synthetic packages and synthetic extrinsic dexterity geometric features.

[0033] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture stereo image information pertaining to the pick structure and one or more packages comprising pairs of images pertaining to the substantially same capture field but with different perspectives; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises

a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein before conducting the grasp, the first computing system is configured to geometrically map a three-dimensional volume around the targeted package based at least in part upon the stereo image information from the first imaging device, and analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device and informed by the stereo image information, the neural network trained at least in part using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure. The first imaging device may be configured to provide pairs of images with different perspectives selected to provide relative depth discernment, and is based, at least in part, upon the selected distance between the first imaging device and the targeted package. The neural network is trained using views developed from synthetic data wherein noise has been modelled into the rendered images. The neural network may be trained using views from real data selected to match a high-resolution imaging device sensor.

[0034] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the

robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; a centralized storage system configured to store event information pertaining to operations of the robotic arm, end effector, and first imaging device; and a user computing system operatively coupled to the centralized storage system; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the centralized storage system is configured to allow a user operating the user computing system to view event information pertaining to the image information from the first imaging device as well as data and meta-data pertaining to the event information through a user interface configurable by the user to facilitate sequential event

viewing pertaining to operation of the robotic arm and end effector. The centralized storage system may be configured to allow a user operating the user computing system to receive a user interface flag pertaining to an operational error, and to view an operational visual sequence pertaining to the event information associated with the operational error. The centralized storage system may be configured to allow a user operating the user computing system to receive one or more written reports pertaining to operation of the package handling system. The one or more written reports may comprise elements selected from the group consisting of: operating analytics data; event logging data; sort frequency data; and integrated facility data.

[0035] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more

packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; and an output distribution gantry configured to transport packages from the place structure to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the place structure, move the targeted package away from the place structure to a position adjacent to the output container, and cause the targeted package to be dropped into the output container; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry. The system further may comprise an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated

degrees of freedom. Each of the output containers of the array may be organized in a substantially co-planar configuration. The output distribution gantry may comprise an electromechanical coupler configured to controllably couple or decouple from a selected output container. The electromechanical coupler may comprise an output container grasper. The electromechanical coupler may comprise an electromechanically operated hook configured to be removably coupled to a selected output container. The place structure may be configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially orthogonal vertical configuration relative to the substantially gravity-level orientation of the place structure. The place structure imay be configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially parallel vertical configuration relative to the substantially gravity-level orientation of the place structure. The system further may comprise a barcode scanner operatively coupled to the first computing system and configured to scan one or more labels which may be present upon a targeted package. The place structure may comprise a conveyor configured to move a targeted package toward the output distribution gantry once released by the end effector. The output distribution gantry may be configured to controllably exit one or more contained packages utilizing a controllably-releasable door configuration. The output distribution gantry may comprise a rail system. The output distribution gantry may comprise a conveyor. The output distribution gantry may be configured to

controllably grasp a plurality of targeted packages at once. The system further may comprise a second output distribution gantry operatively coupled to the first output distribution gantry and configured to receive packages transferred from the first output distribution gantry.

[0036] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a first scanning device operatively coupled to the first computing system and configured to scan identifiable information which may be passed within a field of view of the first scanning device; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly

configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first computing system is configured to operate the first scanning device to capture identifying information pertaining to the targeted package by positioning and/or orienting the targeted package relative to the first scanning device such that the first scanning device field of view has geometric access to the identifiable information of the targeted package. The identifiable information may comprise a package label. The package label may comprise a barcode readable by the first scanning device. The first computing system may be configured to operate the robotic arm and end effector to pass the identifiable information of the targeted package into the field of view of the first scanning device. The first computing system may be configured to identify a location of the identifiable information on the targeted package utilizing the image information from the first imaging device. The first computing system may be configured to reorient and examine an aspect of the targeted package that is not viewable with the first imaging device when the first computing system has failed to find the identifiable information on the targeted package in an initial orientation relative to the first imaging device. The first computing system may be configured to read one or more aspects of the package label using optical character recognition.

[0037] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure

transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the pack-out module comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically couple packages for further separate processing. The pack-out module may comprise an element selected from the group consisting

of: a ramp; a chute; a diverter; an external wrapping system; a palletizing system; a wheeled cart; and a mobile robot.

[0038] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; wherein the first computing system is configured to release the grasp by controllably de-activating the vacuum load with the end effector in a release position and orientation from the end effector relative to the

place structure as influenced by the position and orientation of the end effector at the time of de-activating the vacuum load; and wherein the first computing system is configured to select a release position and orientation to accommodate a subsequent repositioning or reorientation of the targeted package away from the place structure. The subsequent repositioning or reorientation may be selected from the group consisting of: a push into a container; a drag into a container; a tip-reorientation to cause a rotational fall into a container; a coupling with move to another location; and a coupling with a reorientation to another location. The first computing system may be configured to select a release position and orientation of the targeted package based at least in part upon an additional factor of the targeted package selected from the group consisting of: a material property of the targeted package; a moment of inertia of the targeted package; dimensions of the targeted package; and location of labeling information of the targeted package.

[0039] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive

the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first computing system is configured to construct and execute a motion plan for repositioning and reorienting the targeted package when coupled to the end effector in a manner that minimizes disruption of the targeted package. The motion plan may be selected to minimize loading of the targeted package. The motion plan may be selected to minimize angular acceleration of the targeted package. The motion plan may be selected to minimize linear acceleration of the targeted package. The motion plan may be selected to minimize impact loading as a result of one or more collisions with other objects. The motion plan may be selected to minimize vibratory loading of the targeted package. The first computing system may be configured to utilize the image information from the first imaging device to identify labeling information present on the targeted package. The labeling information may be selected from the group consisting of: barcode information, address information, and shipping label information. The first computing system may be configured to construct and

execute the motion plan to position and orient the targeted package such that the labeling information is exposed for capture. The system further may comprise a barcode scanner, wherein the first computing system is configured to construct and execute the motion plan to position and orient the targeted package such that the labeling information is exposed for capture by the barcode scanner. The first computing system may be configured to utilize optical character recognition to gather information from the labeling information. The first computing system may be configured to select a release position and orientation to accommodate a subsequent repositioning or reorientation of the targeted package away from the place structure. The subsequent repositioning or reorientation may be selected from the group consisting of: a push into a container; a tip-reorientation to cause a rotational fall into a container; a coupling with move to another location; and a coupling with a reorientation to another location.

[0040] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and

command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first computing system is configured to receive loading information from the robotic arm, and to utilize the loading information and image information from the first imaging device to characterize one or more material properties of the targeted package. The loading information from the robotic arm may comprise kinematic data pertaining to operation of the robotic arm when the end effector has been utilized to conduct a grasp of the targeted package. The system further may comprise one or more load cells operatively coupled to the robotic arm and configured to determine loads associated with operation of the robotic arm. The one or more material properties of the targeted package may be selected from the group consisting of: moment of inertia; stability under acceleration; apparent stiffness of exterior structure; structural modulus of the targeted package. The first computing system may be configured to subject the targeted package to a characterizing loading treatment to assist in characterizing the one or more material properties of the targeted package. The characterizing loading

treatment may comprise a relatively high-impulse load application. The characterizing loading treatment may comprise an acceleration. The acceleration may be rotational. The characterizing loading treatment may comprise exposing at least a portion of the targeted package to a high-velocity stream of gas. The stream of gas may comprise high-velocity air from an aperture. The first imaging device may be configured to capture information pertaining to the behavior of the targeted package during the characterizing loading treatment. The characterizing loading treatment may comprise causing the targeted package to be moved relative to another surface. The characterizing loading treatment may comprise causing the targeted package to be re-oriented relative to another surface. While conducting the grasp with the robotic arm and end effector, the first computing system may be configured to pass the targeted package within a field of view of the first imaging device, and wherein image information pertaining to the targeted package as it is passed within the field of view of the first imaging device is utilized by the first computing system to fit a three-dimensional rectangular prism around the targeted package and estimate three side dimensions of the three-dimensional rectangular prism. The first computing system may be further configured to utilize the fitted three-dimensional rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector. The first computing system may be further configured to estimate the tightest possible three-dimensional rectangular prism around the targeted package. The first computing system may be further configured to construct a three-dimensional model of the targeted package. The first computing system may be

configured to utilize the image information from the first imaging device to capture barcode information from a targeted package. The barcode information may comprise an estimate of quality of the captured barcode information from the targeted package.

[0041] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a package input module operatively coupled to the first computing system and configured to provide a supply of packages to be transferred to the pick structure; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted

package and controllably activating the vacuum load; and wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a number of the one or more packages transiently coupled to the pick structure. The package input module may be configured to be operated by the first computing system to control the supply based at least in part upon image information from the first imaging device. The package input module may be configured to be able to automatically eject a targeted package based at least in part upon analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable. Analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable may be based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. The package input module may comprise a mechanical ejection element configured to controllably eject a targeted package into a separate routing to be subsequently re-processed. The mechanical ejection element may be selected from the group consisting of: a pusher, a diverter, an arm, and a multidirectional conveyor. The mechanical ejection element may be configured to be operated pneumatically or electromechanically. The first computing system may be configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector. The first computing system may be configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting

a grasp of a particular targeted package before the particular targeted package reaches the end effector based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. The system further may comprise a second imaging device positioned and oriented to capture image information pertaining to the package input module and one or more packages. The first computing system may be configured to utilize the image information from the first imaging device to determine whether a package jam has occurred. Analysis by the first computing system of the image information from the first imaging device whether a package jam has occurred may be based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. The first computing system may be configured to send a notification to one or more users upon determination that a package jam has occurred. The first computing system may be configured to automatically take one or more steps to resolve a package jam upon determination that a package jam has occurred. The one or more steps to resolve a package jam may be selected from the group consisting of: applying mechanical vibration, applying a load to move one or more targeted packages, and reversing movement of one or more targeted packages.

[0042] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned

and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container comprised to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first computing system is configured to estimate when the output container is at a desired level of fullness based at least in part upon an aggregated package volume determined at least in part based upon image information from the first imaging device acquired before the plurality of the one or more packages has entered the output container. The computing system may be configured to estimate when the output container is at a desired level of fullness based upon an additional input

selected from the group consisting of: an image of the output container; a weight of the output container; a shape of the output container. The first imaging device may be configured to capture image information pertaining to the output container. The computing system may be configured to utilize the image information from the first imaging device in determining whether a jam has occurred. The computing system may be configured to utilize a neural network to determine whether a jam has occurred, the neural network trained based upon imagery of one or more packages. The imagery of one or more packages is based at least in part upon synthetic imagery. The system further may comprise a second imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the output container. The computing system may be configured to utilize the image information from the second imaging device in determining whether a jam has occurred. The computing system may be configured to utilize a neural network to determine whether a jam has occurred, the neural network trained based upon imagery of one or more packages. The imagery of one or more packages may be based at least in part upon synthetic imagery.

[0043] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to

the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the pack-out module comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically place packages into a transport container in a manner selected to facilitate manual unloading at a plurality of destinations. The pack-out module may comprise an element selected from the group consisting of: a ramp; a chute; a diverter; an external wrapping system; a palletizing system; a robotic arm; and a mobile robot. The transport

container may be a delivery truck comprising a package enclosure, and wherein the pack-out module comprises a first conveyance module configured to controllably place packages into the package enclosure to facilitate a predetermined order of manual unloading at the plurality of destinations. The transport container may be a shipping container, and wherein the pack-out module comprises a first conveyance module configured to controllably place packages into the shipping container to facilitate a predetermined order of manual unloading at the plurality of destinations. The pack-out module may comprise a distal portion configured to be cantilevered into an entry door of the transport container. The pack-out module distal portion may comprise at least one local stability loading member configured to be controllably extended away from the pack-out module distal portion to be removably coupled to a portion of the transport container to stabilize the pack-out module distal portion relative to the transport container. The stability loading member may be configured to be primarily loaded in tension. The stability loading member may be configured to be primarily loaded in compression. The stability loading member may be configured to be primarily loaded in bending. The system further may comprise a second imaging device configured to capture image information regarding the transport container. The first computing system may be configured to conduct simultaneous localization and mapping pertaining to geometric features of the transport container. The second imaging device may be coupled to the pack-out module. The pack-out module may comprise a robotic arm configured to automatically place packages into the transport container. The robotic arm may be coupled to a movable

base to facilitate movement relative to the transport container. The movable base may comprise an element selected from the group consisting of: an electromechanically-movable base; a manually-movable base; and a rail-constrained movable base. The system further may comprise an output buffer structure coupled between the end effector and the pack-out module, the output buffer structure configured to contain packages output from the robotic arm and associated end effector before the pack-out module is able to automatically place the packages into the transport container.

[0044] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted

package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the pack-out module comprises a palletizing system having one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically place packages upon a pallet base. The pack-out module further may comprise an element selected from the group consisting of: a ramp; a chute; a diverter; a robotic arm; and a mobile robot. The pack out module further may comprise a coupling module configured to automatically couple packages placed upon the pallet base using an applied circumferential containment member. The pack-out module further may comprise a robotic arm configured to automatically place packages upon the pallet base. The robotic arm may be coupled to a movable base to facilitate movement relative to the pallet base. The movable base may comprise an element selected from the group consisting of: an electromechanically-movable base; a manually-movable base; and a rail-constrained movable base. The system further may comprise an output buffer structure coupled between the end effector and the pack-out module, the output buffer structure configured to contain packages output from the robotic arm and associated end effector

before the pack-out module is able to automatically place the packages upon the pallet base.

[0045] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein while conducting the grasp with the robotic arm and end effector, the first computing system is configured to pass the targeted package within a field of view of the first imaging device, and wherein image information pertaining to the targeted package as it is

passed within the field of view of the first imaging device is utilized by the first computing system to fit a three-dimensional rectangular prism around the targeted package and estimate three side dimensions of the three-dimensional rectangular prism. The first computing system may be further configured to utilize the fitted three-dimensional rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector. The first computing system may be further configured to estimate the tightest possible three-dimensional rectangular prism around the targeted package. The first computing system may be further configured to construct a three-dimensional model of the targeted package.

[0046] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a movable place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the movable place structure after release from the end effector, the output container configured to at least temporarily

contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; and an output distribution gantry coupled to the movable place structure and configured to transport packages from the movable place structure to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the movable place structure, move the targeted package away from the end effector to a position adjacent to the output container, and cause the targeted package to be dropped into the output container; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the movable place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the output distribution gantry comprises two or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry. The system further may comprise an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in

each of the output containers of the array through utilization of the two or more controllably actuated degrees of freedom. Each of the output containers of the array may be organized in a substantially co-planar configuration.

[0047] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a package input module operatively coupled to the first computing system and configured to be operated by the first computing system based at least in part upon the image information to mechanically process a plurality of incoming packages from a substantially disordered mechanical organization to provide a supply of packages to be transferred to the pick structure that is substantially singulated, and to prune away certain packages which do not become substantially singulated as a result of the mechanical process; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the

targeted package to be at least transiently coupled with the place structure; and wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load. The package input module may be configured to be operated by the first computing system to control the supply based at least in part upon a number of the one or more packages transiently coupled to the pick structure. The package input module may be configured to be operated by the first computing system to control the supply based at least in part upon the image information pertaining to the pick structure. The package input module may comprise one or more mechanical singulation elements configured to mechanically process and direct the substantially singulated supply of packages toward the pick structure. The one or more mechanical singulation elements may be selected from the group consisting of: a ramp sequence; a vibratory actuator; a belt; a coordinated plurality of belts; a ball sorter conveyor; a step sequence; a chute with one or more 90-degree turns; a mechanical diverter; a vertical mechanical filter; and a horizontal mechanical filter. The package input module may be configured to be operated by the first computing system to prune away certain packages which do not become substantially singulated as a result of the mechanical process using a diversion element configured to selectably divert one or more targeted packages. The diversion element may be a mechanical diverter. The diversion element may be a diversion conveyor. The package input module may be operatively coupled to the first computing system and

configured to be operated by the first computing system based at least in part upon the image information to mechanically process a plurality of incoming packages from a substantially disordered mechanical organization to provide a supply of packages to be transferred to the pick structure that is substantially singulated, to prune away certain packages which do not become substantially singulated as a result of the mechanical process, and to move toward singulation certain packages based upon the image information. The first computing system may be configured to move the certain packages toward singulation using one or more mechanical singulation elements configured to mechanically process these certain packages. The one or more mechanical singulation elements are selected from the group consisting of: a ramp sequence; a vibratory actuator; a belt; a coordinated plurality of belts; a ball sorter conveyor; a step sequence; a chute with one or more 90-degree turns; a mechanical diverter; a vertical mechanical filter; and a horizontal mechanical filter.

[0048] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive

the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a package input module operatively coupled to the first computing system and configured to provide a supply of packages to be transferred to the pick structure; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a rate at which the robotic arm and end effector are able to conduct a grasp from the pick structure and release a targeted package at the place structure. The first computing system may be configured to substantially match the rate at which the robotic arm and end effector are able to conduct a grasp from the pick structure and release a targeted package at the place structure with a supply rate provided to the pick structure by the package input module. The package input module may be configured to be able to automatically eject a targeted package based at least in part upon analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable. Analysis by the first computing system of the image

information from the first imaging device that the targeted package may be unpickable may be based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. Thye package input module may comprise a mechanical ejection element configured to controllably eject a targeted package into a separate routing to be subsequently re-processed. The mechanical ejection element may be selected from the group consisting of: a pusher, a diverter, an arm, and a multidirectional conveyor. The mechanical ejection element may be configured to be operated pneumatically or electromechanically. The first computing system may be configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector. The first computing system may be configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. The system further may comprise a second imaging device positioned and oriented to capture image information pertaining to the package input module and one or more packages. The first computing system may be configured to utilize the image information from the first imaging device to determine whether a package jam has occurred. Analysis by the first computing system of the image information from the first imaging device whether a package jam has occurred may be based upon a neural network. The neural network may be trained, at

least in part, based upon synthetic package imagery. The first computing system may be configured to send a notification to one or more users upon determination that a package jam has occurred. The first computing system may be configured to automatically take one or more steps to resolve a package jam upon determination that a package jam has occurred. The one or more steps to resolve a package jam may be selected from the group consisting of: applying mechanical vibration, applying a load to move one or more targeted packages, and reversing movement of one or more targeted packages.

[0049] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; a second imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the one or more packages from a second perspective that differs from a first perspective of the first imaging device; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or

more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first computing system is configured to utilize image information from the first imaging device and second imaging device in a sensor fusion configuration to estimate external dimensions of the targeted package. The first and second perspectives may be substantially orthogonal. The first and second perspectives may be substantially opposite. The first imaging device may have a measurement error pertaining to the targeted package that is substantially uncorrelated relative to a measurement error that the second imaging device has pertaining to the targeted package. The system further may comprise a third imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the one or more packages from a third perspective that differs from the first perspective of the first imaging device or the second perspective of the second imaging device. The first computing system may be configured to utilize the image information from the first imaging device and second imaging device to construct a three-dimensional model of the one or more packages. The first computing system may be configured to utilize the image information from the first imaging device and second imaging device to estimate one or more material properties of a targeted package. The one or more material properties of a

targeted package may be selected from the group consisting of: package stiffness, package bulk modulus, package rigidity, package exterior compliance, and estimated looseness of exterior package material. The first computing system may be configured to utilize a neural network to estimate the one or more material properties, the neural network trained utilizing imagery pertaining to a package exterior training dataset. The imagery may be based at least in part upon synthetic imagery. The first computing system may be configured to utilize the image information from the first imaging device and second imaging device to estimate a quality control variable pertaining to one or more targeted packages selected from the group consisting of: existence of package damage, existence of multiple packages bound together, and whether the end effector has successfully conducted a grasp. The first computing system may be configured to utilize a neural network to estimate the quality control variable, the neural network trained utilizing imagery pertaining to a package exterior training dataset. The imagery may be based at least in part upon synthetic imagery.

[0050] Another embodiment is directed to a robotic package handling system, comprising: a package input module configured to move a plurality of incoming packages in a primary advancement direction along a conveyance platform while also being configured to selectably move one or more targeted packages from the plurality away from the conveyance platform; a first imaging device positioned and oriented to capture image information pertaining to the conveyance platform and plurality of incoming packages; a first computing system operatively coupled to the package input module and the first imaging device, and configured to receive the

image information from the first imaging device and command movements of package input module based at least in part upon the image information; an output container configured to receive packages which may be moved away from the conveyance platform, the output container configured to at least temporarily contain a plurality of the one or more packages from the conveyance platform as they are moved by operation of the first computing system and package input module; and an output distribution gantry configured to transport packages from the conveyance platform to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been moved from the conveyance platform to a position adjacent to the output container, and cause the targeted package to be dropped into the output container; wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the package input module and output distribution gantry. The system further may comprise an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated degrees of freedom. Each of the output containers of the array may be organized in a substantially co-planar configuration. The package input module may comprise a bi-directional conveyor. The package input module may comprise an omnidirectional ball sorter conveyor. The package input module may comprise a mechanical diverter configured to selectably move one or more targeted

packages from the plurality away from the conveyance platform. The system further may comprise a guiding structure operatively coupled between the package input module and output distribution gantry, the guiding structure configured to mechanically guide the one or more targeted packages from the plurality away from the conveyance platform and to the output distribution gantry. The guiding structure may comprise an element selected from the group consisting of: a chute, a ramp, a funnel, and a conveyor. The output distribution gantry may be configured to be able to controllably removably couple to a selected output container and to remove the selected output container from the output distribution gantry.

[0051] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more

packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; an output distribution gantry configured to transport packages from the place structure to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the place structure, move the targeted package away from the place structure to a position adjacent to the output container, and cause the targeted package to be dropped into the output container; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry; and wherein the output distribution gantry is configured to be able to controllably removably couple to a selected output container and to remove the selected output container from the output distribution gantry. The system further may comprise an array of output containers organized in

proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated degrees of freedom. Each of the output containers of the array may be organized in a substantially co-planar configuration. The output distribution gantry may comprise an electromechanical coupler configured to controllably couple or decouple from a selected output container. The electromechanical coupler may comprise an output container grasper. The electromechanical coupler may comprise an electromechanically operated hook configured to be removably coupled to a selected output container. The place structure may be configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially orthogonal vertical configuration relative to the substantially gravity-level orientation of the place structure. The place structure may be configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially parallel vertical configuration relative to the substantially gravity-level orientation of the place structure. The system further may comprise a barcode scanner operatively coupled to the first computing system and configured to scan one or more labels which may be present upon a targeted package. The place structure may comprise a conveyor configured to move a targeted package toward the output distribution gantry once released by the end effector. The output distribution gantry may be configured to

controllably exit one or more contained packages utilizing a controllably-releasable door configuration.

[0052] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first suction cup assembly defines a first inner capture chamber configured such that conducting the grasp of the targeted package comprises pulling into and at least partially encapsulating a portion of the targeted package with the first inner capture chamber

when the vacuum load is controllably activated adjacent the targeted package.

[0053] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first suction cup assembly defines a first inner chamber, a first outer sealing lip, and a first vacuum-permeable distal wall member which are collectively configured such that upon conducting the grasp of the targeted package with the vacuum load

controllably actuated, the outer sealing lip may become removably coupled to at least one surface of the targeted package, while the vacuum-permeable distal wall member prevents over-protrusion of said surface o the targeted package into the inner chamber of the suction cup assembly.

[0054] Another embodiment is directed to a system comprising: a robotic pick-and-place machine comprising an actuation system and a changeable end effector system conrfigured to facilitate selection and switching between a plurality of end effector heads; a sensing system; and a grasp planning processing pipeline used in control of the robotic pick-and-place machine. The changeable end effector system may comprise a head selector integrated into a distal end of the actuation system, a set of end effector heads, and a head holding device, wherein the head selector attaches with one of the sets of end effector heads at a respective attachment face. The changeable end effector system further may comprise at least one magnet circumscribing a center of one of the head selector or end effector head to supply initial seating and holding of the end effector head. At least one of the head selector or each of the set of end effector heads may comprise a seal positioned along an outer edge of a respective attachment face. The head selector and the set of end effector heads may comprise complimentary registration structures. The head selector and the set of end effector heads may comprise a lateral support structure geometry selected to assist with grasping a compliant package. The set of end effector heads may comprise a set of suction end effectors. The actuation system may comprise an articulated arm.

[0055] Another embodiment is directed to a robotic package handling system, comprising: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the end effector is coupled to the distal portion of the robotic arm using a spring-biased end effector coupling assembly comprising a spring member configured to provide an engagement compliance when conducting the grasp between the end effector and the targeted package. The spring member may be configured to have a prescribed spring constant selected to provide

the engagement compliance. The spring-biased end effector coupling assembly may comprise an insertion axis constraining member configured to facilitate spring-biased insertion of the spring-biased end effector coupling assembly along an axis prescribed by the axis constraining member. The axis constraining member may comprise a linear bearing assembly configured to facilitate movement along a single axis of motion.

[0056] Another embodiment is directed to a robotic package handling method, comprising: providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure in geometric proximity to the distal portion of the robotic arm, a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises

engaging the targeted package and controllably activating the vacuum load; and wherein before conducting the grasp, the first computing system is configured to analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device, the neural network trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure. The first computing system may be further configured to analyze the plurality of candidate grasps based a continuous learning configuration of the neural network wherein data from a set of known and actual experiences is utilized to further train the neural network. The set of known and actual experiences may be based upon prior operation of the particular robotic arm. The set of known and actual experiences may be based upon prior operation of a different robotic arm similar to the particular robotic arm. The different robotic arm similar to the particular robotic arm may be substantially identical to the particular robotic arm. The first computing system may be configured to analyze the plurality of candidate grasps based upon a kinematic reach of the robotic arm and end effector. The first computing system may be configured to analyze the plurality of candidate grasps based upon a location of labeling information of the targeted package based upon the image information from the first imaging device. The first computing system may be configured to analyze the plurality of candidate grasps based upon a location of barcode labeling information of the targeted package based upon the image information from the first imaging

device. The first computing system may be configured to analyze the plurality of candidate grasps based upon a location of labeling information of the targeted package based upon the image information from the first imaging device, and to select an execution grasp that does not have the end effector covering the barcode labeling information. The subject method embodiments above, as well as each below, may each also be directed to the following additional features:

[0057] The method further may comprise providing a frame structure configured to fixedly couple the robotic arm to the place structure. The pick structure may be removably coupled to the frame structure. The place structure may comprise a placement tray. The placement tray may comprise first and second rotatably coupled members, the first and second rotatably coupled members being configured to form a substantially flat tray base surface when in a first rotated configuration relative to each other, and to form a lifting fork configuration when in a second rotated configuration relative to each other. The placement tray may be operatively coupled to one or more actuators configured to controllably change an orientation of at least a portion of the placement tray, the one or more actuators being operatively coupled to the first computing system. The pick structure may comprise an element selected from the group consisting of: a bin, a tray, a fixed surface, and a movable surface. The pick structure may comprise a bin configured to define a package containment volume bounded by a bottom and a plurality of walls, as well as an open access aperture configured to accommodate entry and egress of at least the distal portion of the robotic arm. The first imaging device may be configured to capture the image information pertaining to the pick

structure and one or more packages through the open access aperture. The first imaging device may comprise a depth camera. The first imaging device may be configured to capture color image data. The first computing system may comprise a VLSI computer operatively coupled to the frame structure. The first computing system may comprise a network of intercoupled computing devices, at least one of which is remotely located relative to the robotic arm. The method further may comprise a second computing system operatively coupled to the first computing system. The second computing system may be remotely located relative to the first computing system, and the first and second computing systems are operatively coupled via a computer network. The first computing system may be configured such that conducting the grasp comprises analyzing a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure. Analyzing a plurality of candidate grasps may comprise examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package. Analyzing a plurality of candidate grasps may comprise examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach orientations. Analyzing a plurality of candidate grasps may comprise examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach positions. The first suction cup

assembly may comprise a first outer sealing lip, and wherein a sealing engagement with a surface comprises a substantially complete engagement of the first outer sealing lip with the surface. Examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package may be conducted in a purely geometric fashion. The first computing system may be configured to select the execution grasp based upon a candidate grasps factor selected from the group consisting of: estimated time required; estimated computation required; and estimated success of grasp. The first suction cup assembly may comprise a bellows structure. The bellows structure may comprise a plurality of wall portions adjacently coupled with bending margins. The bellows structure may comprise a material selected from the group consisting of: polyethylene, polypropylene, rubber, and thermoplastic elastomer. The first suction cup assembly may comprise an outer housing and an internal structure coupled thereto. The internal structure of the first suction cup assembly may comprise a wall member coupled to a proximal base member. The wall member may comprise a substantially cylindrical shape having proximal and distal ends, and wherein the proximal base member forms a substantially circular interface with the proximal end of the wall member. The proximal base member may define one or more inlet apertures therethrough, the one or more inlet apertures being configured to allow air flow therethrough in accordance with activation of the controllably activated vacuum load. The internal structure further may comprise a distal wall member comprising a structural aperture ring portion configured to define access to the inner capture chamber, as well

as one or more transitional air channels configured to allow air flow therethrough in accordance with activation of the controllably activated vacuum load. The one or more inlet apertures and the one or more transitional air channels may be configured to function to allow a prescribed flow of air through the capture chamber to facilitate releasable coupling of the first suction cup assembly with the targeted package. The one or more packages may be selected from the group consisting of: a bag, a "poly bag", a "poly", a fiber-based bag, a fiber-based envelope, a bubble-wrap bag, a bubble-wrap envelope, a "jiffy" bag, a "jiffy" envelope, and a substantially rigid cuboid structure. The one or more packages may comprise a fiber-based bag comprising a paper composite or polymer composite. The one or more packages may comprise a fiber-based envelope comprising a paper composite or polymer composite. The one or more packages may comprise a substantially rigid cuboid structure comprising a box. The end effector may comprise a second suction cup assembly coupled to the controllably activated vacuum load. The second suction cup assembly may define a second inner capture chamber configured to pull into and at least partially encapsulate a portion of the targeted package when the vacuum load is controllably activated adjacent the targeted package. The method further may comprise a second imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector. The first computing system and second imaging device may be configured to capture the one or more images such that outer dimensional bounds of the targeted package may be estimated. The first computing system may be configured

to utilize the one or more images to determine dimensional bounds of the targeted package by fitting a 3-D rectangular prism around the targeted package and estimating the L-W-H of said rectangular prism. The first computing system may be configured to utilize the fitted 3-D rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector. The method further may comprise a third imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector. The second imaging device and first computing system may be further configured to estimate whether the targeted package is deformable by capturing a sequence of images of the targeted package during motion of the targeted package and analyzing deformation of the targeted package within the sequence of images. The first computing system and second imaging device may be configured to capture and utilize the one or more images after the grasp has been conducted using the end effector to estimate whether a plurality of packages, or zero packages, have been yielded with the conducted grasp. The first computing system may be configured to abort a grasp upon determination that a plurality of packages, or zero packages, have been yielded by the conducted grasp. The end effector may comprise a tool switching head portion configured to controllably couple to and uncouple from the first suction cup assembly using a tool holder mounted within geometric proximity of the distal portion of the robotic arm. The tool holder may be configured to hold and be removably coupled to one or more additional suction cup assemblies or one or more other package interfacing tools, such

that the first computing device may be configured to conduct tool switching using the tool switching head portion.

[0058] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the place structure comprises at least one substantially planar surface and one or more extrinsic dexterity geometric features extending away from the at least one

substantially planar surface, the one or more extrinsic dexterity geometric features configured to provide counter-loading relative to movements of the targeted package via the robotic arm and end effector, to assist the robotic arm and end effector in manipulating the targeted package before the targeted package is released at the place structure. The one or more extrinsic dexterity geometric features may be selected from the group consisting of: a protruding wall; a protruding ramp; a protruding ramp/wall; a compound ramp; a compound wall; and a compound ramp/wall. The one or more extrinsic dexterity geometric features may comprise one or more controllably movable degrees of freedom to change shape operatively coupled to the first computing system. The first imaging device may be configured to provide image information pertaining to the place structure, and wherein based at least in part upon the image information, the first computing system is configured to utilize a neural network to operate the robotic arm and end effector while conducting the grasp and contacting one or more aspects of the extrinsic dexterity geometric features to obtain a desired orientation of the targeted package upon release of the targeted package to the place structure. The neural network may be trained based at least in part upon synthetic imagery pertaining to synthetic packages and synthetic extrinsic dexterity geometric features.

[0059] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more

packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture stereo image information pertaining to the pick structure and one or more packages comprising pairs of images pertaining to the substantially same capture field but with different perspectives; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein before conducting the grasp, the first computing system is configured to geometrically map a three-dimensional volume around the targeted package based at least in part upon the stereo image information from the first imaging device, and analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device and informed by the stereo image information, the neural network trained at least in part using views developed from synthetic

data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure. The first imaging device may be configured to provide pairs of images with different perspectives selected to provide relative depth discernment, and is based, at least in part, upon the selected distance between the first imaging device and the targeted package. The neural network is trained using views developed from synthetic data wherein noise has been modelled into the rendered images. The neural network may be trained using views from real data selected to match a high-resolution imaging device sensor.

[0060] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; a centralized storage system configured to store event information pertaining to operations of the robotic arm, end effector, and first imaging device; and a user computing system operatively coupled to the centralized storage system; wherein the first computing

system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the centralized storage system is configured to allow a user operating the user computing system to view event information pertaining to the image information from the first imaging device as well as data and meta-data pertaining to the event information through a user interface configurable by the user to facilitate sequential event viewing pertaining to operation of the robotic arm and end effector. The centralized storage system may be configured to allow a user operating the user computing system to receive a user interface flag pertaining to an operational error, and to view an operational visual sequence pertaining to the event information associated with the operational error. The centralized storage system may be configured to allow a user operating the user computing system to receive one or more written reports pertaining to operation of the package handling system. The one or more written reports may comprise elements selected from the group consisting of: operating analytics data; event logging data; sort frequency data; and integrated facility data.

[0061] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base

portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; and an output distribution gantry configured to transport packages from the place structure to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the place structure, move the targeted package away from the place structure to a position adjacent to the output container, and cause the targeted package to be dropped into the output container; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry. The method further may comprise providing an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated degrees of freedom. Each of the output containers of the array may be organized in a substantially co-planar configuration. The output distribution gantry may comprise an electromechanical coupler configured to controllably couple or decouple from a selected output container. The electromechanical coupler may comprise an output container grasper. The electromechanical coupler may comprise an electromechanically operated hook configured to be removably coupled to a selected output container. The place structure may be configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially orthogonal vertical configuration relative to the substantially gravity-level orientation of the place structure. The place structure imay be configured to

have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially parallel vertical configuration relative to the substantially gravity-level orientation of the place structure. The method further may comprise providing a barcode scanner operatively coupled to the first computing system and configured to scan one or more labels which may be present upon a targeted package. The place structure may comprise a conveyor configured to move a targeted package toward the output distribution gantry once released by the end effector. The output distribution gantry may be configured to controllably exit one or more contained packages utilizing a controllably-releasable door configuration. The output distribution gantry may comprise a rail system. The output distribution gantry may comprise a conveyor. The output distribution gantry may be configured to controllably grasp a plurality of targeted packages at once. The method further may comprise providing a second output distribution gantry operatively coupled to the first output distribution gantry and configured to receive packages transferred from the first output distribution gantry.

[0062] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image

information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a first scanning device operatively coupled to the first computing system and configured to scan identifiable information which may be passed within a field of view of the first scanning device; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first computing system is configured to operate the first scanning device to capture identifying information pertaining to the targeted package by positioning and/or orienting the targeted package relative to the first scanning device such that the first scanning device field of view has geometric access to the identifiable information of the targeted package. The identifiable information may comprise a package label. The package label may comprise a barcode readable by the first scanning device. The first computing system may be configured to operate the robotic arm and end effector to pass the identifiable information of the targeted package into the field of

view of the first scanning device. The first computing system may be configured to identify a location of the identifiable information on the targeted package utilizing the image information from the first imaging device. The first computing system may be configured to reorient and examine an aspect of the targeted package that is not viewable with the first imaging device when the first computing system has failed to find the identifiable information on the targeted package in an initial orientation relative to the first imaging device. The first computing system may be configured to read one or more aspects of the package label using optical character recognition.

[0063] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further

separate processing; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the pack-out module comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically couple packages for further separate processing. The pack-out module may comprise an element selected from the group consisting of: a ramp; a chute; a diverter; an external wrapping system; a palletizing system; a wheeled cart; and a mobile robot.

[0064] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or

more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; wherein the first computing system is configured to release the grasp by controllably de-activating the vacuum load with the end effector in a release position and orientation from the end effector relative to the place structure as influenced by the position and orientation of the end effector at the time of de-activating the vacuum load; and wherein the first computing system is configured to select a release position and orientation to accommodate a subsequent repositioning or reorientation of the targeted package away from the place structure. The subsequent repositioning or reorientation may be selected from the group consisting of: a push into a container; a drag into a container; a tip-reorientation to cause a rotational fall into a container; a coupling with move to another location; and a coupling with a reorientation to another location. The first computing system may be configured to select a

release position and orientation of the targeted package based at least in part upon an additional factor of the targeted package selected from the group consisting of: a material property of the targeted package; a moment of inertia of the targeted package; dimensions of the targeted package; and location of labeling information of the targeted package.

[0065] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably

activating the vacuum load; and wherein the first computing system is configured to construct and execute a motion plan for repositioning and reorienting the targeted package when coupled to the end effector in a manner that minimizes disruption of the targeted package. The motion plan may be selected to minimize loading of the targeted package. The motion plan may be selected to minimize angular acceleration of the targeted package. The motion plan may be selected to minimize linear acceleration of the targeted package. The motion plan may be selected to minimize impact loading as a result of one or more collisions with other objects. The motion plan may be selected to minimize vibratory loading of the targeted package. The first computing system may be configured to utilize the image information from the first imaging device to identify labeling information present on the targeted package. The labeling information may be selected from the group consisting of: barcode information, address information, and shipping label information. The first computing system may be configured to construct and execute the motion plan to position and orient the targeted package such that the labeling information is exposed for capture. The method further may comprise providing a barcode scanner, wherein the first computing system is configured to construct and execute the motion plan to position and orient the targeted package such that the labeling information is exposed for capture by the barcode scanner. The first computing system may be configured to utilize optical character recognition to gather information from the labeling information. The first computing system may be configured to select a release position and orientation to accommodate a subsequent repositioning or reorientation of the

targeted package away from the place structure. The subsequent repositioning or reorientation may be selected from the group consisting of: a push into a container; a tip-reorientation to cause a rotational fall into a container; a coupling with move to another location; and a coupling with a reorientation to another location.

[0066] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably

activating the vacuum load; and wherein the first computing system is configured to receive loading information from the robotic arm, and to utilize the loading information and image information from the first imaging device to characterize one or more material properties of the targeted package. The loading information from the robotic arm may comprise kinematic data pertaining to operation of the robotic arm when the end effector has been utilized to conduct a grasp of the targeted package. The method further may comprise providing one or more load cells operatively coupled to the robotic arm and configured to determine loads associated with operation of the robotic arm. The one or more material properties of the targeted package may be selected from the group consisting of: moment of inertia; stability under acceleration; apparent stiffness of exterior structure; structural modulus of the targeted package. The first computing system may be configured to subject the targeted package to a characterizing loading treatment to assist in characterizing the one or more material properties of the targeted package. The characterizing loading treatment may comprise a relatively high-impulse load application. The characterizing loading treatment may comprise an acceleration. The acceleration may be rotational. The characterizing loading treatment may comprise exposing at least a portion of the targeted package to a high-velocity stream of gas. The stream of gas may comprise high-velocity air from an aperture. The first imaging device may be configured to capture information pertaining to the behavior of the targeted package during the characterizing loading treatment. The characterizing loading treatment may comprise causing the targeted package to be moved relative to

another surface. The characterizing loading treatment may comprise causing the targeted package to be re-oriented relative to another surface. While conducting the grasp with the robotic arm and end effector, the first computing system may be configured to pass the targeted package within a field of view of the first imaging device, and wherein image information pertaining to the targeted package as it is passed within the field of view of the first imaging device is utilized by the first computing system to fit a three-dimensional rectangular prism around the targeted package and estimate three side dimensions of the three-dimensional rectangular prism. The first computing system may be further configured to utilize the fitted three-dimensional rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector. The first computing system may be further configured to estimate the tightest possible three-dimensional rectangular prism around the targeted package. The first computing system may be further configured to construct a three-dimensional model of the targeted package. The first computing system may be configured to utilize the image information from the first imaging device to capture barcode information from a targeted package. The barcode information may comprise an estimate of quality of the captured barcode information from the targeted package.

[0067] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more

packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a package input module operatively coupled to the first computing system and configured to provide a supply of packages to be transferred to the pick structure; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a number of the one or more packages transiently coupled to the pick structure. The package input module may be configured to be operated by the first computing system to control the supply based at least in part upon image information from the first imaging device. The package input module may be configured to be able to automatically eject a targeted package based at least in part upon analysis by the

first computing system of the image information from the first imaging device that the targeted package may be unpickable. Analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable may be based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. The package input module may comprise a mechanical ejection element configured to controllably eject a targeted package into a separate routing to be subsequently re-processed. The mechanical ejection element may be selected from the group consisting of: a pusher, a diverter, an arm, and a multidirectional conveyor. The mechanical ejection element may be configured to be operated pneumatically or electromechanically. The first computing system may be configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector. The first computing system may be configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. The method further may comprise providing a second imaging device positioned and oriented to capture image information pertaining to the package input module and one or more packages. The first computing system may be configured to utilize the image information from the first imaging device to determine whether a package jam has occurred. Analysis by the first computing

system of the image information from the first imaging device whether a package jam has occurred may be based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. The first computing system may be configured to send a notification to one or more users upon determination that a package jam has occurred. The first computing system may be configured to automatically take one or more steps to resolve a package jam upon determination that a package jam has occurred. The one or more steps to resolve a package jam may be selected from the group consisting of: applying mechanical vibration, applying a load to move one or more targeted packages, and reversing movement of one or more targeted packages.

[0068] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the

output container comprised to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first computing system is configured to estimate when the output container is at a desired level of fullness based at least in part upon an aggregated package volume determined at least in part based upon image information from the first imaging device acquired before the plurality of the one or more packages has entered the output container. The computing system may be configured to estimate when the output container is at a desired level of fullness based upon an additional input selected from the group consisting of: an image of the output container; a weight of the output container; a shape of the output container. The first imaging device may be configured to capture image information pertaining to the output container. The computing system may be configured to utilize the image information from the first imaging device in determining whether a jam has occurred. The computing system may be configured to utilize a neural network to determine

whether a jam has occurred, the neural network trained based upon imagery of one or more packages. The imagery of one or more packages is based at least in part upon synthetic imagery. The method further may comprise providing a second imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the output container. The computing system may be configured to utilize the image information from the second imaging device in determining whether a jam has occurred. The computing system may be configured to utilize a neural network to determine whether a jam has occurred, the neural network trained based upon imagery of one or more packages. The imagery of one or more packages may be based at least in part upon synthetic imagery.

[0069] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector,

automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the pack-out module comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically place packages into a transport container in a manner selected to facilitate manual unloading at a plurality of destinations. The pack-out module may comprise an element selected from the group consisting of: a ramp; a chute; a diverter; an external wrapping system; a palletizing system; a robotic arm; and a mobile robot. The transport container may be a delivery truck comprising a package enclosure, and wherein the pack-out module comprises a first conveyance module configured to controllably place packages into the package enclosure to facilitate a predetermined order of manual unloading at the plurality of destinations. The transport container may be a shipping container, and wherein the pack-out module comprises a first conveyance module configured to controllably place

packages into the shipping container to facilitate a predetermined order of manual unloading at the plurality of destinations. The pack-out module may comprise a distal portion configured to be cantilevered into an entry door of the transport container. The pack-out module distal portion may comprise at least one local stability loading member configured to be controllably extended away from the pack-out module distal portion to be removably coupled to a portion of the transport container to stabilize the pack-out module distal portion relative to the transport container. The stability loading member may be configured to be primarily loaded in tension. The stability loading member may be configured to be primarily loaded in compression. The stability loading member may be configured to be primarily loaded in bending. The method further may comprise providing a second imaging device configured to capture image information regarding the transport container. The first computing system may be configured to conduct simultaneous localization and mapping pertaining to geometric features of the transport container. The second imaging device may be coupled to the pack-out module. The pack-out module may comprise a robotic arm configured to automatically place packages into the transport container. The robotic arm may be coupled to a movable base to facilitate movement relative to the transport container. The movable base may comprise an element selected from the group consisting of: an electromechanically-movable base; a manually-movable base; and a rail-constrained movable base. The system further may comprise an output buffer structure coupled between the end effector and the pack-out module, the output buffer structure configured to contain packages output from the robotic arm and

associated end effector before the pack-out module is able to automatically place the packages into the transport container.

[0070] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp

comprises engaging the targeted package and controllably activating the vacuum load; and wherein the pack-out module comprises a palletizing system having one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically place packages upon a pallet base. The pack-out module further may comprise an element selected from the group consisting of: a ramp; a chute; a diverter; a robotic arm; and a mobile robot. The pack out module further may comprise a coupling module configured to automatically couple packages placed upon the pallet base using an applied circumferential containment member. The pack-out module further may comprise a robotic arm configured to automatically place packages upon the pallet base. The robotic arm may be coupled to a movable base to facilitate movement relative to the pallet base. The movable base may comprise an element selected from the group consisting of: an electromechanically-movable base; a manually-movable base; and a rail-constrained movable base. The method further may comprise providing an output buffer structure coupled between the end effector and the pack-out module, the output buffer structure configured to contain packages output from the robotic arm and associated end effector before the pack-out module is able to automatically place the packages upon the pallet base.

[0071] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric

proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein while conducting the grasp with the robotic arm and end effector, the first computing system is configured to pass the targeted package within a field of view of the first imaging device, and wherein image information pertaining to the targeted package as it is passed within the field of view of the first imaging device is utilized by the first computing system to fit a three-dimensional rectangular prism around the targeted package and estimate three side dimensions of the three-dimensional rectangular prism. The first computing system may be further configured to utilize the fitted three-

dimensional rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector. The first computing system may be further configured to estimate the tightest possible three-dimensional rectangular prism around the targeted package. The first computing system may be further configured to construct a three-dimensional model of the targeted package.

[0072] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a movable place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the movable place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; and an output distribution gantry coupled to the movable place structure and configured to transport packages from the movable place structure to the output

container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the movable place structure, move the targeted package away from the end effector to a position adjacent to the output container, and cause the targeted package to be dropped into the output container; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the movable place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the output distribution gantry comprises two or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry. The method further may comprise providing an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the two or more controllably actuated degrees of freedom. Each of the output containers of the array may be organized in a substantially co-planar configuration.

[0073] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a package input module operatively coupled to the first computing system and configured to be operated by the first computing system based at least in part upon the image information to mechanically process a plurality of incoming packages from a substantially disordered mechanical organization to provide a supply of packages to be transferred to the pick structure that is substantially singulated, and to prune away certain packages which do not become substantially singulated as a result of the mechanical process; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; and wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled

to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load. The package input module may be configured to be operated by the first computing system to control the supply based at least in part upon a number of the one or more packages transiently coupled to the pick structure. The package input module may be configured to be operated by the first computing system to control the supply based at least in part upon the image information pertaining to the pick structure. The package input module may comprise one or more mechanical singulation elements configured to mechanically process and direct the substantially singulated supply of packages toward the pick structure. The one or more mechanical singulation elements may be selected from the group consisting of: a ramp sequence; a vibratory actuator; a belt; a coordinated plurality of belts; a ball sorter conveyor; a step sequence; a chute with one or more 90-degree turns; a mechanical diverter; a vertical mechanical filter; and a horizontal mechanical filter. The package input module may be configured to be operated by the first computing system to prune away certain packages which do not become substantially singulated as a result of the mechanical process using a diversion element configured to selectably divert one or more targeted packages. The diversion element may be a mechanical diverter. The diversion element may be a diversion conveyor. The package input module may be operatively coupled to the first computing system and configured to be operated by the first computing system based at least in part upon the image information to mechanically process a plurality of incoming packages from a substantially disordered mechanical organization

to provide a supply of packages to be transferred to the pick structure that is substantially singulated, to prune away certain packages which do not become substantially singulated as a result of the mechanical process, and to move toward singulation certain packages based upon the image information. The first computing system may be configured to move the certain packages toward singulation using one or more mechanical singulation elements configured to mechanically process these certain packages. The one or more mechanical singulation elements are selected from the group consisting of: a ramp sequence; a vibratory actuator; a belt; a coordinated plurality of belts; a ball sorter conveyor; a step sequence; a chute with one or more 90-degree turns; a mechanical diverter; a vertical mechanical filter; and a horizontal mechanical filter.

[0074] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a package input module operatively

coupled to the first computing system and configured to provide a supply of packages to be transferred to the pick structure; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a rate at which the robotic arm and end effector are able to conduct a grasp from the pick structure and release a targeted package at the place structure. The first computing system may be configured to substantially match the rate at which the robotic arm and end effector are able to conduct a grasp from the pick structure and release a targeted package at the place structure with a supply rate provided to the pick structure by the package input module. The package input module may be configured to be able to automatically eject a targeted package based at least in part upon analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable. Analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable may be based upon a neural network. The neural network may be trained, at least in part, based

upon synthetic package imagery. Thye package input module may comprise a mechanical ejection element configured to controllably eject a targeted package into a separate routing to be subsequently re-processed. The mechanical ejection element may be selected from the group consisting of: a pusher, a diverter, an arm, and a multidirectional conveyor. The mechanical ejection element may be configured to be operated pneumatically or electromechanically. The first computing system may be configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector. The first computing system may be configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. The method further may comprise a second imaging device positioned and oriented to capture image information pertaining to the package input module and one or more packages. The first computing system may be configured to utilize the image information from the first imaging device to determine whether a package jam has occurred. Analysis by the first computing system of the image information from the first imaging device whether a package jam has occurred may be based upon a neural network. The neural network may be trained, at least in part, based upon synthetic package imagery. The first computing system may be configured to send a notification to one or more users upon determination that a package jam has occurred. The first computing

system may be configured to automatically take one or more steps to resolve a package jam upon determination that a package jam has occurred. The one or more steps to resolve a package jam may be selected from the group consisting of: applying mechanical vibration, applying a load to move one or more targeted packages, and reversing movement of one or more targeted packages.

[0075] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; a second imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the one or more packages from a second perspective that differs from a first perspective of the first imaging device; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup

assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first computing system is configured to utilize image information from the first imaging device and second imaging device in a sensor fusion configuration to estimate external dimensions of the targeted package. The first and second perspectives may be substantially orthogonal. The first and second perspectives may be substantially opposite. The first imaging device may have a measurement error pertaining to the targeted package that is substantially uncorrelated relative to a measurement error that the second imaging device has pertaining to the targeted package. The method further may comprise providing a third imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the one or more packages from a third perspective that differs from the first perspective of the first imaging device or the second perspective of the second imaging device. The first computing system may be configured to utilize the image information from the first imaging device and second imaging device to construct a three-dimensional model of the one or more packages. The first computing system may be configured to utilize the image information from the first imaging device and second imaging device to estimate one or more material properties of a targeted package. The one or more material properties of a targeted package may be selected from the group consisting of: package stiffness, package bulk modulus, package rigidity, package exterior compliance, and

estimated looseness of exterior package material. The first computing system may be configured to utilize a neural network to estimate the one or more material properties, the neural network trained utilizing imagery pertaining to a package exterior training dataset. The imagery may be based at least in part upon synthetic imagery. The first computing system may be configured to utilize the image information from the first imaging device and second imaging device to estimate a quality control variable pertaining to one or more targeted packages selected from the group consisting of: existence of package damage, existence of multiple packages bound together, and whether the end effector has successfully conducted a grasp. The first computing system may be configured to utilize a neural network to estimate the quality control variable, the neural network trained utilizing imagery pertaining to a package exterior training dataset. The imagery may be based at least in part upon synthetic imagery.

[0076] Another embodiment is directed to a robotic package handling method, comprising providing: a package input module configured to move a plurality of incoming packages in a primary advancement direction along a conveyance platform while also being configured to selectably move one or more targeted packages from the plurality away from the conveyance platform; a first imaging device positioned and oriented to capture image information pertaining to the conveyance platform and plurality of incoming packages; a first computing system operatively coupled to the package input module and the first imaging device, and configured to receive the image information from the first imaging device and command movements of package input module based at least in part upon the image information; an output container

configured to receive packages which may be moved away from the conveyance platform, the output container configured to at least temporarily contain a plurality of the one or more packages from the conveyance platform as they are moved by operation of the first computing system and package input module; and an output distribution gantry configured to transport packages from the conveyance platform to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been moved from the conveyance platform to a position adjacent to the output container, and cause the targeted package to be dropped into the output container; wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the package input module and output distribution gantry. The method further may comprise providing an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated degrees of freedom. Each of the output containers of the array may be organized in a substantially co-planar configuration. The package input module may comprise a bi-directional conveyor. The package input module may comprise an omnidirectional ball sorter conveyor. The package input module may comprise a mechanical diverter configured to selectably move one or more targeted packages from the plurality away from the conveyance platform. The method further may comprise providing a guiding structure operatively coupled between the

package input module and output distribution gantry, the guiding structure configured to mechanically guide the one or more targeted packages from the plurality away from the conveyance platform and to the output distribution gantry. The guiding structure may comprise an element selected from the group consisting of: a chute, a ramp, a funnel, and a conveyor. The output distribution gantry may be configured to be able to controllably removably couple to a selected output container and to remove the selected output container from the output distribution gantry.

[0077] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector;

an output distribution gantry configured to transport packages from the place structure to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the place structure, move the targeted package away from the place structure to a position adjacent to the output container, and cause the targeted package to be dropped into the output container; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry; and wherein the output distribution gantry is configured to be able to controllably removably couple to a selected output container and to remove the selected output container from the output distribution gantry. The method further may comprise providing an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output

containers of the array through utilization of the one or more controllably actuated degrees of freedom. Each of the output containers of the array may be organized in a substantially co-planar configuration. The output distribution gantry may comprise an electromechanical coupler configured to controllably couple or decouple from a selected output container. The electromechanical coupler may comprise an output container grasper. The electromechanical coupler may comprise an electromechanically operated hook configured to be removably coupled to a selected output container. The place structure may be configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially orthogonal vertical configuration relative to the substantially gravity-level orientation of the place structure. The place structure may be configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially parallel vertical configuration relative to the substantially gravity-level orientation of the place structure. The method further may comprise a barcode scanner operatively coupled to the first computing system and configured to scan one or more labels which may be present upon a targeted package. The place structure may comprise a conveyor configured to move a targeted package toward the output distribution gantry once released by the end effector. The output distribution gantry may be configured to controllably exit one or more contained packages utilizing a controllably-releasable door configuration.

[0078] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic

arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first suction cup assembly defines a first inner capture chamber configured such that conducting the grasp of the targeted package comprises pulling into and at least partially encapsulating a portion of the targeted package with the first inner capture chamber when the vacuum load is controllably activated adjacent the targeted package.

[0079] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the first suction cup assembly defines a first inner chamber, a first outer sealing lip, and a first vacuum-permeable distal wall member which are collectively configured such that upon conducting the grasp of the targeted package with the vacuum load controllably actuated, the outer sealing lip may become removably coupled to at

least one surface of the targeted package, while the vacuum-permeable distal wall member prevents over-protrusion of said surface o the targeted package into the inner chamber of the suction cup assembly.

[0080] Another embodiment is directed to a method comprising providing: a robotic pick-and-place machine comprising an actuation system and a changeable end effector system conrfigured to facilitate selection and switching between a plurality of end effector heads; a sensing system; and a grasp planning processing pipeline used in control of the robotic pick-and-place machine. The changeable end effector system may comprise a head selector integrated into a distal end of the actuation system, a set of end effector heads, and a head holding device, wherein the head selector attaches with one of the sets of end effector heads at a respective attachment face. The changeable end effector method further may comprise providing at least one magnet circumscribing a center of one of the head selector or end effector head to supply initial seating and holding of the end effector head. At least one of the head selector or each of the set of end effector heads may comprise a seal positioned along an outer edge of a respective attachment face. The head selector and the set of end effector heads may comprise complimentary registration structures. The head selector and the set of end effector heads may comprise a lateral support structure geometry selected to assist with grasping a compliant package. The set of end effector heads may comprise a set of suction end effectors. The actuation system may comprise an articulated arm.

[0081] Another embodiment is directed to a robotic package handling method, comprising providing: a robotic arm comprising a distal portion and a proximal base

portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load; and wherein the end effector is coupled to the distal portion of the robotic arm using a spring-biased end effector coupling assembly comprising a spring member configured to provide an engagement compliance when conducting the grasp between the end effector and the targeted package. The spring member may be configured to have a prescribed spring constant selected to provide the engagement compliance. The spring-biased end effector coupling assembly may comprise an insertion axis constraining member

configured to facilitate spring-biased insertion of the spring-biased end effector coupling assembly along an axis prescribed by the axis constraining member. The axis constraining member may comprise a linear bearing assembly configured to facilitate movement along a single axis of motion.

BRIEF DESCRIPTION OF THE DRAWINGS:

[0083] Figure 1 illustrates a diagram of a robotic package handing system configuration;

[0084] Figure 2 illustrates an embodiment of a changeable end effectord configuration;

[0085] Figure 3 illustrates an embodiment of a head selector engaged with an end effector head;

[0086] Figure 4 illustrates an embodiment of a head selector engaged with an end effector head having lateral supports;

[0087] Figure 5 illustrates an embodiment of an end effector head having multiple selectable end effectors;

[0088] Figure 6 illustrates an embodiment of an end effector head having multiple selectable end effectors;

[0089] Figures 7A-7G illustrate various aspects of an embodiment of a robotic package handling configuration;

[0090] Figures 8A-8B illustrate various aspects of suction cup assembly end effectors;

[0091] Figures 9A-9B illustrate various aspects of suction cup assembly end effectors;

[0092] Figures 10A-10F illustrate various aspects of embodiments of place structure configurations;

[0093] Figures 11A-11C illustrate various aspects of embodiments of robotic package handling configurations featuring one or more intercoupled computing systems;

[0094] Figure 12 illustrates an embodiment of a computing architecture which may be utilized in implementing aspects of the subject configurations;

[0095] Figures 13-19 illustrate various embodiments of methods;

[0096] Figures 20A and 20B illustrate images of synthetic data;

[0097] Figures 21A and 21B illustrate parcel processing configurations featuring robotic sortation;

[0098] Figures 22A-22C illustrate aspects of parcel processing configurations featuring robotic sortation;

[0099] Figure 23 illustrates various aspects of induction configuration wherein packages or parcels may be transferred to a primary induction buffer;

[0100] Figures 24A-24B illustrate various aspects of primary induction processing and loading to a primary induction buffer;

[0101] Figure 25 illustrates aspects of a parcel processing configuration featuring a singulation, scanning, and sortation conveyor;

[0102] Figures 26A-26C illustrate aspects of parcel processing configurations featuring vision-based robotic singulation and sortation;

[0103] Figure 27 illustrates aspects of parcel processing configurations wherein sortation is followed by pack-out processing;

[0104] Figures 28A-28E illustrate aspects of a parcel processing configurations featuring robotic sortation;

[0105] Figures 29A-29H illustrate aspects of a parcel processing configurations featuring robotic sortation.

[0106] Figures 30-85 illustrate various aspects of systems and methods for controllable sortation.

DETAILED DESCRIPTION:

[0107] Referring to Figure 1, a system for planning and adapting to object manipulation can include: a robotic pick-and-place machine (2) with an actuation system (8) and a changeable end effector system (4); a sensing system and a grasp planning processing pipeline (6) used in control of the robotic pick-and-place machine. The system and method may additionally include

a workstation configuration module used in dynamically defining environmental configuration of the robotic system. The system is preferably used in situations where a set of objects in one region needs to be processed or manipulated in some way.

[0108] In many pick-and-place type applications, the system is used where a set of objects (e.g., products) are presented in some way within the environment. Objects may be stored and presented within bins, totes, bags, boxes, and/or other storage elements. Objects may also be presented through some item supply system such as a conveyor belt. The system may additionally need to manipulate objects to place objects in such storage elements such as by moving objects from a bin into a box specific to that object. Similarly, the system may be used to move objects into a bagger system or to another object manipulation system such as a conveyor belt.

[0109] The system may be implemented into an integrated workstation, wherein the workstation is a singular unit where the various elements are physically integrated. Some portions of the computing infrastructure and resources may however be remote and accessed over a communication network. In one example, the integrated workstation includes a robotic pick-and-place machine (2) with a physically coupled sensing system. In this way the integrated workstation can be moved and fixed into position and begin operating on objects in the environment. The system may alternatively be implemented as a collection of discrete components that operate cooperatively. For example, a sensing system in one implementation could be physically removed from the robotic pick-and-place machine. The workstation configuration module described below may be used in

customized configuration and setup of such a workstation.

[0110] The robotic pick-and-place machine functions as the automated system used to interact with an object. The robotic pick-and-place machine (2) preferably includes an actuation system (8) and an end effector (4) used to temporarily physically couple (e.g., grasp or attach) to an object and perform some manipulation of that object. The actuation system is used to move the end effector and, when coupled to one or more objects, move and orient an object in space. Preferably, the robotic pick-and-place machine is used to pick up an object, manipulate the object (move and/or reorient and object), and then place an object when done. Herein, the robotic pick-and-place machine is more generally referred to as the robotic system. A variety of robotic systems may be used. In one preferred implementation, the robotic system is an articulated arm using a pressure-based suction-cup end effector. The robotic system may include a variety of features or designs.

[0111] The actuation system (8) functions to translate the end effector through space. The actuation system will preferably move the end effector to various locations for interaction with various objects. The actuation system may additionally or alternatively be used in moving the end effector and grasped object(s) along a particular path, orienting the end effector and/or grasped object(s), and/or providing any suitable manipulation of the end effector. In general, the actuation system is used for gross movement of the end effector.

[0112] The actuation system (8) may be one of a variety of types of machines used to promote movement of the end effector. In one preferred variation, the

actuation system is a robotic articulated arm that includes multiple actuated degrees of freedom coupled through interconnected arm segments. One preferred variation of an actuated robotic arm is a 6-axis robotic arm that includes six degrees of freedom as shown in FIGURE 1. The actuation system may alternatively be a robotic arm with fewer degrees of freedom such as a 4-axis or 5-axis robotic arm or ones with additional articulated degrees of freedom such as a 7-axis robotic arm.

[0113] In other variations, the actuation system may be any variety of robotic systems such as a Cartesian robot, a cylindrical robot, a spherical robot, a SCARA robot, a parallel robot such as a delta robot, and/or any other variation of a robotic system for controlled actuation.

[0114] The actuation system (8) preferably includes an end arm segment. The end arm segment is preferably a rigid structure extending from the last actuated degree of freedom of the actuation system. In an articulated robot arm, the last arm segment couples to the end effector (4). As described below, the end of the end arm segment can include a head selector that is part of a changeable end effector system.

[0115] In one variation, the end arm segment may additionally include or connect to at least one compliant joint.

[0116] The compliant joint functions as at least one additional degree of freedom that is preferably positioned near the end effector. The compliant joint is preferably positioned at the distal end of the end arm segment of the actuation system, wherein the compliant joint can function as a "wrist" joint. The compliant joint preferably provides a supplementary amount of

dexterity near where the end effector interacts with an object, which can be useful during various situations when interacting with objects.

[0117] In a multi-tool changing variation of the system, the compliant joint preferably precedes the head selector component such that each attachable end effector head can be used with controllable compliance. Alternatively, one or more multiple end effectors may have a compliant joint.

[0118] In a multi-headed tool variation, a compliant joint may be integrated into a shared attachment point of the multi-headed end effector. In this way use of the connected end effectors can share a common degree of freedom at the compliant joint. Alternatively, one or more multiple end effectors of the multi-headed end effector may include a compliant joint. In this way, each individual end effector can have independent compliance.

[0119] The compliant joint is preferably a controllably compliant joint wherein the joint may be selectively made to move in an at least partially compliant manner. When moving in a compliant manner, the compliant joint can preferably actuate in response to external forces. Preferably, the compliant joint has a controllable rotational degree of freedom such that the compliant joint can rotate in response to external forces. The compliant joint can additionally preferably be selectively made to actuate in a controlled manner. In one preferred variation, the controllably compliant joint has one rotational degree of freedom that when engaged in a compliant mode rotates freely (at least within some angular range) and when engaged in a controlled mode can be actuated so as to rotate in a controlled manner. Compliant linear actuation may

additionally or alternatively be designed into a compliant joint. The compliant joint may additionally or alternatively be controlled for a variable or partially compliant form of actuation, wherein the compliant joint can be actuated but is compliant to forces above a particular threshold.

[0120] The end effector (4) functions to facilitate direct interaction with an object. Preferably, the system is used for grasping an object, wherein grasping describes physically coupling with an object for physical manipulation. Controllable grasping preferably enables the end effector to selectively connect/couple with an object ("grasp" or "pick") and to selectively disconnect/decouple from an object ("drop" or "place"). The end effector may controllably "grasp" an object through suction force, pinching the object, applying a magnetic field, and/or through any suit force. Herein, the system is primarily described for suction-based grasping of the object, but the variations described herein are not necessarily limited to suction-based end effectors.

[0121] In one preferred variation, the end effector (4) includes a suction end effector head (24, which may be more concisely referred to as a suction head) connected to a pressure system. A suction head preferably includes one or more suction cups (26, 28, 30, 32). The suction cups can come in variety of sizes, stiffnesses, shapes, and other configurations. Some examples of suction head configurations can include a single suction cup configuration, a four suction cup configuration, and/or other variations. The sizes, materials, geometry of the suction heads can also be changed to target different applications. The pressure

system will generally include at least one vacuum pump connected to a suction head through one or more hoses.

[0122] In one preferred variation, the end effector of the system includes a multi-headed end effector tool that includes multiple selectable end effector heads as shown in exemplary variations Figure 5 (34) and Figure 6 (24). Each end effector head can be connected to individually controlled pressure systems. The system can selectively activate one or multiple pressure systems to grasp using one or multiple end effectors of the multi-headed end effector tool. The end effector heads are preferably selected and used based on dynamic control input from the grasp planning model. The pressure system(s) may alternatively use controllable valves to redirect airflow. The different end effectors are preferably spaced apart. They may be angled in substantially the same direction, but the end effectors may alternatively be directed outwardly in non-parallel directions from the end arm segment.

[0123] As shown in the cross-sectional view of Figure 5, one exemplary variation of a multi-headed end effector tool can be a two-headed gripper (34). This variation may be specialized to reach within corners of deep bins or containers and pick up small objects (e.g., small items like a pencil) as well as larger objects (such as boxes). In one variation, each of the gripping head end effectors may be able to slide linearly on a spring mechanism. The end effector heads may be coupled to hoses that connect to the pressure system(s). The hoses can coil helically around the center shaft (to allow for movement) to connect the suction heads to the vacuum generators.

[0124] As shown in Figure 6, another exemplary variation of a multi-headed end effector tool (24) can

be a multi four-headed gripper. As shown in this variation, various sensors such as a camera or barcode reader can be integrated into the multi-headed end effector tool, shown here in the palm. Suction cup end effector heads can be selected to have a collectively broad application (e.g., one for small boxes, one for large boxes, one for loose polybags, one for stiffer polybags). The combination of multiple grippers can pick objects of different sizes. In some variations, this multi-headed end effector tool may be connected to the robot by a spring plunger to allow for error in positioning.

[0125] In another preferred variation of the system includes a changeable end effector system, which functions to enable the end effector to be changed. A changeable end effector system preferably includes a head selector (36), which is integrated into the distal end of the actuation system (e.g., the end arm segment), a set of end effector heads, and a head holding device (38), or tool holder for socalled "tool switching". The end effector heads are preferably selected and used based on dynamic control input from the grasp planning model. The head selector and an end effector head preferably attach together at an attachment site of the selector and the head. One or more end effector head can be stored in the head holding device (38) when not in and use. The head holding device can additionally orient the stored end effector heads during storage for easier selection. The head holding device may additionally partially restrict motion of an end effector head in at least one direction to facilitate attachment or detachment from the head selector.

[0126] The head selector system functions to selectively attach and detach to a plurality of end

effector heads. The end effector heads function as the physical site for engaging with an object. The end effectors can be specifically configured for different situations. In some variations, a head selector system may be used in combination with a multi-headed end effector tool. For example, one or multiple end effector heads may be detachable and changed through the head selector system.

[0127] The changeable end effector system may use a variety of designs in enabling the end effectors to be changed. In one variation, the changeable end effector is a passive variation wherein end effector heads are attached and detached to the robotic system without use of a controlled mechanism. In a passive variation, the actuation and/or air pressure control capabilities of the robotic system may be used to engage and disengage different end effector heads. Static magnets (44, 46), physical fixtures (48) (threads, indexing/alignment structures, friction-fit or snap-fit fixtures) and/or other static mechanism may also be used to temporarily attach an end effector head and a head selector.

[0128] In another variation, the changeable end effector is an active system that uses some activated mechanism (e.g., mechanical, electromechanical, electromagnetic, etc.) to engage and disengage with a selected end effector head. Herein, a passive variation is primarily used in the description, but the variations of the system and method may similarly be used with an active or alternative variation.

[0129] One preferred variation of the changeable end effector system is designed for use with a robotic system using a pressure system with suction head end effectors. The head selector can further function to channel the pressure to the end effector head. The head

selector can include a defined internal through-hole so that the pressure system is coupled to the end effector head. The end effector heads will generally be suction heads. A set of suction end effector heads can have a variety of designs as shown in Figure 2.

[0130] The head selector and/or the end effector heads may include a seal (40, 42) element circumscribing the defined through-hole. The seal can enable the pressure system to reinforce the attachment of the head selector and an end effector head. This force will be activated when the end effector is used to pick up an object and should help the end effector head stay attached when loaded with an outside object.

[0131] The seal (40, 42) is preferably integrated into the attachment face of the head selector, but a seal could additionally or alternatively be integrated into the end effector heads. The seal can be an O-ring, gasket, or other sealing element. Preferably, the seal is positioned along an outer edge of the attachment face. An outer edge is preferably a placement along the attachment face wherein there is more surface of the attachment face on an internal portion as compared to the outer portion. For example, in one implementation, a seal may be positioned so that over 75% of the surface area is in an internal portion. This can increase the surface area over-which the pressure system can exert a force.

[0132] Magnets (44, 46) may be used in the changeable end effector system to facilitate passive attachment. A magnet is preferably integrated into the head selector and/or the set of end effector heads. In a preferred variation, a magnet is integrated into both the head selector and the end effector heads. Alternatively, a magnet may be integrated into one of the head selectors

or the end effector head with the other having a ferromagnetic metal piece in place of a magnet.

[0133] In one implementation, the magnet has a single magnet pole aligned in the direction of attachment (e.g., north face of a magnet directed outward on the head selector and south face of a second magnet directed outward on each end effector head). Use of opposite poles in the head selector and the end effector heads may increase attractive force.

[0134] The magnet can be centered or aligned around the center of an attachment site. The magnet in one implementation can circumscribe the center and a defined cavity though which air can flow for a pressure-based end effector. In another variation, multiple magnets may be positioned around the center of the attachment point, which could be used in promoting some alignment between the head selector and an end effector head. In one variation, the magnet could be asymmetric about the center off-center and/or use altering magnetic pole alignment to further promote a desired alignment between the head selector and an end effector head.

[0135] In one implementation, a magnet can supply initial seating and holding of the end effector head when not engaged with an object (e.g., not under pressure) and the seal and/or the pressure system can provide the main attractive force when holding an object.

[0136] The changeable end effector system can include various structural elements that function in a variety of ways including providing reinforcement during loading, facilitating better physical coupling when attached, aligning the end effector heads when attached (and/or when in the head holding device), or providing other features to the system.

[0137] In one structural element variation, the head selector and the end effector heads can include complimentary registration structures as shown in Figure 3. A registration structure can be a protruding or recessed feature of the attachment face of the head selector and/or the end effector. In one variation, the registration structure is a groove or tooth. A registration structure may be used to restrict how a head selector and an end effector head attach. The head selector and the set of end effector heads may include one set of registration structures or a plurality of registration structure pairs. The registration structure may additionally or alternatively prevent rotation of the end effector head. In a similar manner, the registration structure can enable torque to be transferred through the coupling of the head selector and the end effector head.

[0138] In another structural element variation, the changeable end effector system can include lateral support structures (50) integrated into one or both of the head selector and the end effector heads. The lateral support structure functions to provide structural support and restrict rotation (e.g., rotation about an axis perpendicular to a defined central axis of the end arm segment). A lateral support structure preferably provides support when the end effector is positioned horizontally while holding an object. The lateral support structure can prevent or mitigate the situations where a torque applied when grasping an object causes the end effector head to be pulled off.

[0139] A lateral support structure (50) can be an extending structural piece that has a form that engages with the surface of the head selector and/or the end arm segment. A lateral support structure can be on one or

both head selector and end effector head (4). Preferably, complimentary lateral support structures are part of the body of the head selector and the end effector arms. In one variation, the complimentary lateral support structures of the end-effector and the head selector engage in a complimentary manner when connected as shown in Figure 4.

[0140] There can be a single lateral support structure. With a single lateral support structure, the robotic system may actively position the lateral support structure along the main axis benefiting from lateral support when moving an object. The robotic system in this variation can include position tracking and planning configuration to appropriately pick up an object and orient the end effector head so that the lateral support is appropriately positioned to provide the desired support. In some cases, this may be used for only select objects (e.g., large and/or heavy objects). In another variation, there may be a set of lateral support structures. The set of lateral support structures may be positioned around the perimeter so that a degree of lateral support is provided regardless of rotational orientation of the end effector head. For example, there may be three or four lateral support structures evenly distributed around the perimeter. In another variation, there may be a continuous support structure surrounding the edge of the end-effector piece.

[0141] A head holder or tool holder (38) device functions to hold the end effector heads when not in use. In one variation, the holder is a rack with a set of defined open slots that can hold a plurality of end effector heads. In one implementation, the holder includes a slot that is open so that an end effector

head can be slid into the slot. The holder slot can additionally engage around a neck of the end effector head so that the robotic system can pull perpendicular to disengage the head selector from the current end effector head. Conversely, when selecting a new end effector head, the actuation system can move the head selector into approximate position around the opening of the end effector head, slide the end effector head out of the holder slot, and the magnetic elements pull the end effector head onto the head selector.

[0142] The head holder device may include indexing structures that moves an end effector head into a desired position when engaged. This can be used if the features of the changeable end effector system need the orientation of the end effectors to be in a known position.

[0143] The sensing system function to collect data of the objects and the environment. The sensing system preferably includes an imaging system, which functions to collect image data. The imaging system preferably includes at least one imaging device (10) with a field of view in a first region. The first region can be where the object interactions are expected. The imaging system may additionally include multiple imaging devices (12, 14, 16, 18), such as digital camera sensors, used to collect image data from multiple perspectives of a distinct region, overlapping regions, and/or distinct non-overlapping regions. The set of imaging devices (e.g., one imaging device or a plurality of imaging devices) may include a visual imaging device (e.g., a camera). The set of imaging devices may additionally or alternatively include other types of imaging devices such as a depth camera. Other suitable types of imaging devices may additionally or alternatively be used.

[0144] The imaging system preferably captures an overhead or aerial view of where the objects will be initially positioned and moved to. More generally, the image data that is collected is from the general direction from which the robotic system would approach and grasp an object. In one variation, the collection of objects presented for processing is presented in a substantially unorganized collection. For example, a collection of various objects may be temporarily stored in a box or tote (in stacks and/or in disorganized bundles). In other variations, objects may be presented in a substantially organized or systematic manner. In one variation, objects may be placed on a conveyor built that is moved within range of the robotic system. In this variation, objects may be substantially separate from adjacent objects such that each object can be individually handled.

[0145] The system preferably includes a grasp planning processing pipeline (6) that is used to determine how to grab an object from a set of objects and optionally what tool to grab the object with. The processing pipeline can make of heuristic models, conditional checks, statistical models, machine learning or other data-based modeling, and/or other processes. In one preferred variation, the pipeline includes an image data segmenter, a grasp quality model is used to generate an initial set of candidate grasp plans, and then a grasp plan selection process or processes that use the set of candidate grasp plans.

[0146] The image data segmenter can segments image data to generate one or more image masks. The set of image masks could include object masks, object collection masks (e.g., segmenting multiple bins, totes, shelves, etc.), object feature masks (e.g., a barcode

mask), and/or other suitable types of masks. Image masks can be used in a grasp quality model and/or in a grasp plan selection process.

[0147] The grasp quality model functions to convert image data and optionally other input data into an output of a set of candidate grasp plans. The grasp quality model may include parameters of a deep neural network, support vector machine, random forest, and/or other machine learning models. In one variation, training a grasp quality model can include or be a convolutional neural network (CNN). The parameters of the grasp quality model will generally be optimized to substantially maximize (or otherwise enhance) performance on a training dataset, which can include a set of images, grasp plans for a set of points on images, and grasp results for those grasp plans (e.g., success or failure).

[0148] In one exemplary implementation, a grasp quality CNN is a model trained so that for an input of image data (e.g., visual or depth), the model can output a tensor/vector characterizing the unique tool, pose (position and/or orientation for centering a grasp), and probability of success. The grasp planning model and/or an additional processing model may additionally integrate modeling for object selection order, material-based tool selection, and/or other decision factors.

[0149] The training dataset may include real or synthetic images labeled manually or automatically. In one variation, simulation reality transfer learning can be used to train the grasp quality model. Synthetic images may be created by generating virtual scenes in simulation using a database of thousands of 3D object models with randomized textures and rendering virtual images of the scene using techniques from graphics.

[0150] A grasp plan selection process preferably assesses the set of candidate grasp plans from the grasp quality model and selects a grasp plan for execution. Preferably, a single grasp plan is selected though in some variations, such as if there are multiple robotic systems operating simultaneously, multiple grasp plans can be selected and executed in coordination to avoid interference. A grasp plan selection process can assess the probability of success of the top candidate grasp plans and evaluate time impact for changing a tool if some top candidate grasp plans are for a tool that is not the currently attached tool.

[0151] In some variations, the system may include a workstation configuration module. A workstation configuration module can be software implemented as machine interpretable instructions stored on a data storage medium that when performed by one or more computer processors cause the workstation configuration to output a user interface directing definition of environment conditions. A configuration tool may be attached as an end effector and used in marking and locating coordinates of key features of various environment objects.

[0152] The system may additionally include an API interface to various environment implemented systems. The system may include an API interface to an external system such as a warehouse management system (WMS), a warehouse control system (WCS), a warehouse execution system (WES), and/or any suitable system that may be used in receiving instructions and/or information on object locations and identity. In another variation, there may be an API interface into various order requests, which can be used in determining how to pack a collection of products into boxes for different orders.

[0153] Referring to Figures 7A-7F, various aspects of a robotic package handing configuration are illustrated. Referring to Figure 7A, a central frame (64) with multiple elements may be utilized to couple various components, such as a robotic arm (54), place structure (56), pick structure (62), and computing enclosure (60). As described in the aforementioned incorporated references, a movable component (58) of the place structure may be utilized to capture items from the place structure (56) and deliver them to various other locations within the system (52). Figure 7B illustrates a closer view of the system (52) embodiment, wherein the pick structure (62) illustrated comprises a bin defining a package containment volume bounded by a bottom and a plurality of walls, and may define an open access aperture to accommodate entry and egress of a portion of the robot arm, along with viewing by an imaging device (66). In other embodiments the pick structure may comprise a fixed surface such as a table, a movable surface such as a conveyor belt system, or tray. Referring to Figure 7C, the system may comprise a plurality of imaging devices configured to capture images of various aspects of the operation. Such imaging devices may comprise monochrome, grayscale, or color devices, and may comprise depth camera devices, such as those sold under the tradename RealSense(RTM) by Intel Corporation. A first imaging device (66) may be fixedly coupled to an element of the frame (64) and may be positioned and oriented to capture images with a field of view (80) oriented down into the pick structure (62), as shown in Figure 7C. A second imaging device (66) may be coupled to an element of the frame (64) and positioned and oriented to capture image information pertaining to end end effector (4) of the robotic arm

(54), as well as image information pertaining to a captured or grasped package which may be removably coupled to the end effector (4) after a successful grasp. Such image information may be utilized to estimate outer dimensional bounds of the grasped item or package, such as by fitting a 3-D rectangular prism around the targeted package and estimating length-width-height (L-W-H) of the rectangular prism. The 3-D rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector. The imaging devices may be automatically triggered by the intercoupled computing system (60). The computing system may be configured to estimate whether the targeted package is deformable by capturing a sequence of images of the targeted package during motion of the at targeted package and analyzing deformation of the targeted package within the sequence of images, such as by observing motion within regions of the images of the package during motion or acceleration of the package by the robotic arm (i.e., a rigid package would have regions that generally move together in unison; a compliant package may have regions with do not move in unison with accelerations and motions). As shown in Figures 7C and 7D, various additional imaging devices (74, 76, 78) may be positioned and oriented to provide fields of view (84, 86, 88) which may be useful in observing the activity of the robotic arm (54) and associated packages.

[0154] Referring to Figure 7E, a vacuum load source (90), such as a source of pressurized air or gas which may be controllably (such as by electromechanically controllable input valves operatively coupled to the computing system, with integrated pressure and/or velocity sensors for closed-loop control) circulated

through a venturi configuration and operatively coupled (such as via a conduit) to the end effector assembly to produce a controlled vacuum load for suction-cup assemblies and suction-based end effectors (4).

[0155] Figure 7F illustrates a closer view of a robotic arm (54) with end effector assembly (24) comprising two suction cup assemblies (26, 28) configured to assist in grasping a package, as described further in the aforementioned incorporated references. Referring to Figures 8A, 8B, and 7G, one embodiment of a suction cup assembly (26) is illustrated showing a vacuum coupling (104) coupled to an outer housing (92) which may comprise a bellows structure comprising a plurality of foldable wall portions coupled at bending margins; such a bellows structure may comprise a material selected from the group consisting of: polyethylene, polypropylene, rubber, and thermoplastic elastomer. An intercoupled inner internal structure (94) may comprise a wall member (114), such as a generally cynindrically shaped wall member as shown, as well as a proximal base member (112) which may define a plurality of inlet apertures (102) therethrough; it may further comprise a distal wall member (116) which defines an inner structural aperture ring portion, a plurality of transitional air channels (108), and an outer sealing lip member (96); it may further define an inner chamber (100). A gap (106) may be defined between potions of the outer housing member (92) and internal structure (94), such that vacuum from the vacuum source tends to pull air through the inner chamber (100), as well as associated inlet apertures (102) and transitional air channels using a prescribed path configured to assist in grasping while also preventing

certain package surface overprotrusions with generally non-compliant packages.

[0156] Referring to Figures 9A and 9B, as described in the aforementioned incorporated references, with a compliant package or portion thereof, the system may be configured to pull a compliant portion (122) up into the inner chamber (100) to ensure a relatively confident grasp with a compliant package, such as to an extent that the package portion (122) is at least partially encapsulating the package portion (122), as shown in Figure 9B.

[0157] Referring to Figures 10A-10F, as noted above, the place structure (56) may comprise a component (58) which may be rotatably and/or removably coupled to the remainder of the place structure (56) to assist in distribution of items from the place structure (56). As shown in Figure 10C, the place structure (56) may comprise a grill-like, or interrupted, surface configuration (128) with a retaining ramp (132) configured to accommodate rotatable and/or removable engagement of the complementary component (58), such as shown in Figure 10D, which may have a forked or interrupted configuration (126) to engage the other place structure component (56). Figure 10F schematically illustrates aspects of movable and rotatable engagement between the structures (56, 58), as described in the aforementioned incorporated references.

[0158] Referring to the system (52) configuration of Figure 11A, as noted above, a computing system, such as a VLSI computer, may be housed within a computing system housing structure (60). Figure 11B illustrates a view of the system of Figure 11A, but with the housing shown as transparent to illustrate the computing system (134) coupled inside. Referring to Figure 11C, in other

embodiments, additional computing resources may be operatively coupled (142, 144, 146) (such as by fixed network connectivity, or wireless connectivity such as configurations under the IEEE 802.11 standards); for example, the system may comprise an additional VLSI computer (136), and/or certain cloud-computing based computer resources (138), which may be located at one or more distant / non-local (148) locations.

[0159] Referring to Figure 12, an exemplary computer architecture diagram of one implementation of the system. In some implementations, the system is implemented in a plurality of devices in communication over a communication channel and/or network. In some implementations, the elements of the system are implemented in separate computing devices. In some implementations, two or more of the system elements are implemented in same devices. The system and portions of the system may be integrated into a computing device or system that can serve as or within the system.

[0160] The communication channel 1001 interfaces with the processors 1002A-1202N, the memory (e.g., a random-access memory (RAM)) 1003, a read only memory (ROM) 1004, a processor-readable storage medium 1005, a display device 1006, a user input device 1007, and a network device 1008. As shown, the computer infrastructure may be used in connecting a robotic system 1101, a sensor system 1102, a grasp planning pipeline 1103, and/or other suitable computing devices.

[0161] The processors 1002A-1002N may take many forms, such CPUs (Central Processing Units), GPUs (Graphical Processing Units), microprocessors, ML/DL (Machine Learning / Deep Learning) processing units such as a Tensor Processing Unit, FPGA (Field Programmable Gate

Arrays, custom processors, and/or any suitable type of processor.

[0162] The processors 1002A-1002N and the main memory 1003 (or some sub-combination) can form a processing unit 1010. In some embodiments, the processing unit includes one or more processors communicatively coupled to one or more of a RAM, ROM, and machine-readable storage medium; the one or more processors of the processing unit receive instructions stored by the one or more of a RAM, ROM, and machine-readable storage medium via a bus; and the one or more processors execute the received instructions. In some embodiments, the processing unit is an ASIC (Application-Specific Integrated Circuit). In some embodiments, the processing unit is a SoC (System-on-Chip). In some embodiments, the processing unit includes one or more of the elements of the system.

[0163] A network device 1008 may provide one or more wired or wireless interfaces for exchanging data and commands between the system and/or other devices, such as devices of external systems. Such wired and wireless interfaces include, for example, a universal serial bus (USB) interface, Bluetooth interface, Wi-Fi interface, Ethernet interface, near field communication (NFC) interface, and the like.

[0164] Computer and/or Machine-readable executable instructions comprising of configuration for software programs (such as an operating system, application programs, and device drivers) can be stored in the memory 1003 from the processor-readable storage medium 1005, the ROM 1004 or any other data storage system.

[0165] When executed by one or more computer processors, the respective machine-executable instructions may be accessed by at least one of

processors 1002A-1002N (of a processing unit 1010) via the communication channel 1001, and then executed by at least one of processors 1002A-1002N. Data, databases, data records or other stored forms data created or used by the software programs can also be stored in the memory 1003, and such data is accessed by at least one of processors 1002A-1002N during execution of the machine-executable instructions of the software programs.

[0166] The processor-readable storage medium 1005 is one of (or a combination of two or more of) a hard drive, a flash drive, a DVD, a CD, an optical disk, a floppy disk, a flash storage, a solid-state drive, a ROM, an EEPROM, an electronic circuit, a semiconductor memory device, and the like. The processor-readable storage medium 1005 can include an operating system, software programs, device drivers, and/or other suitable sub-systems or software.

[0167] As used herein, first, second, third, etc. are used to characterize and distinguish various elements, components, regions, layers and/or sections. These elements, components, regions, layers and/or sections should not be limited by these terms. Use of numerical terms may be used to distinguish one element, component, region, layer and/or section from another element, component, region, layer and/or section. Use of such numerical terms does not imply a sequence or order unless clearly indicated by the context. Such numerical references may be used interchangeable without departing from the teaching of the embodiments and variations herein.

[0168] As shown in Figure 13, a method for planning and adapting to object manipulation by a robotic system can include: collecting image data of an object

populated region S110; planning a grasp S200 comprised of evaluating image data through a grasp quality model to generate a set of candidate grasp plans S210 and processing candidate grasp plans and selecting a grasp plan S220; performing the selected grasp plan with a robotic system S310 and performing object interaction task S320. The grasp quality model preferably integrates grasp quality across a set of different robotic tools and therefore selection of a grasp plan can trigger changing of a tool. For a pick-and-place robot this can include changing the end effector head based on the selected grasp plan.

[0169] In a more detailed implementation shown in Figure 14, the method can included training a grasp quality model S120; configuring a robotic system workstation S130; receiving an object interaction task request S140 and triggering collecting image data of an object populated region S110; planning a grasp S200 which includes segmenting image data into region of interest masks S202, evaluating image data through the grasp quality model to generate a set of candidate grasp plans S210, and processing candidate grasp plans and selecting a grasp plan S220; performing the selected grasp plan with a robotic system S310 and performing object interaction task S320.

[0170] The method may be implemented by a system such as the system described herein, but the method may alternatively be implemented by any suitable system.

[0171] In one variation, the method can include training a grasp quality convolutional neural network S120, which functions to construct a data-driven model for scoring different grasp plans for a given set of image data.

[0172] The grasp quality model may include parameters of a deep neural network, support vector machine, random forest, and/or other machine learning models. In one variation, training a grasp quality model can include or is a convolutional neural network (CNN). The parameters of the grasp quality model will generally be optimized to substantially maximize (or otherwise enhance) performance on a training dataset, which can include a set of images, grasp plans for a set of points on images, and grasp results for those grasp plans (e.g., success or failure).

[0173] In one exemplary implementation, a grasp quality CNN is trained so that for an input of image data (e.g., visual or depth), the model can output a tensor/vector characterizing the unique tool, pose (position and/or orientation for centering a grasp), and probability of success.

[0174] The training dataset may include real or synthetic images labeled manually or automatically. In one variation, simulation reality transfer learning can be used to train the grasp quality model. Synthetic images may be created by generating virtual scenes in simulation using a database of thousands of 3D object models with randomized textures and rendering virtual images of the scene using techniques from graphics.

[0175] The grasp quality model may additionally integrate other features or grasp planning scoring into the model. In one variation, the grasp quality model integrates object selection order into the model. For example, a CNN can be trained using the metrics above, but also to prioritize selection of large objects so as to reveal smaller objects underneath and potentially revealing other higher probability grasp points. In other variations, various algorithmic heuristics or

processes can be integrated to account for object size, object material, object features like barcodes, or other features.

[0176] During execution of the method, the grasp quality model may additionally be updated and refined, as image data of objects is collected, grasp plans executed, and object interaction results determined. In some variations, a grasp quality model may be provided, wherein training and/or updating of the grasp quality model may not be performed by the entity executing the method.

[0177] In one variation, the method can include configuring a robotic system workstation S130, which functions to setup a robotic system workstation for operation. Configuring the robotic system workstation preferably involves configuring placement of features of the environment relative to the robotic system. For example, in a warehouse example, configuring the robotic system workstation involves setting coordinate positions of where a put-wall, a set of shelves, a box, an outbagger, a conveyor belt, or other regions where objects may be located or will be placed.

[0178] In one variation, configuring a robotic system can include the robotic system receiving manual manipulation of a configuration tool used as the end effector to define various geometries. A user interface can preferably guide the user through the process. For example, within the user interface, a set of standard environmental objects can be presented in a menu. After selection of the object, instructions can be presented guiding a user through a set of measurements to be made with the configuration end effector.

[0179] Configuration may also define properties of defined objects in the environment. This may provide

information useful in avoiding collisions, defining how to plan movements in different regions, and interact with objects based on the relevant environment objects. An environment object may be defined as being static to indicate the environment object does not move. An environment object may be defined as being mobile. For some mobile environment objects, a region in which the mobile environment object is expected may also be defined. For example, the robotic system workstation can be configured to understand the general region in which a box of objects may appear as well as the dimensions of the expected box. Various object specific features such as size and dimensions of moving parts (e.g., doors, box flaps) can also be configured. For example, the position of a conveyor along with the conveyor path can be configured. The robotic system may additionally be integrated with a suitable API to have data on conveyor state.

[0180] In one variation, the method can include receiving an object interaction task request S140, which functions to have some signal initiate object interactions by the robotic system. They request may specify where an object is located and more typically where a collection of objects is located. The request may additionally supply instructions or otherwise specify the action to take on the object. The object interaction task request may be received through an API. In one implementation an external system such as a warehouse management system (WMS), a warehouse control system (WCS), a warehouse execution system (WES), and/or any suitable system may be used in directing interactions such as specifying which tote should be used for object picking.

[0181] In one variation, the method may include receiving one or a more requests. The requests may be formed around the intended use case. In one example, the requests may be order requests specifying groupings of a set of objects. Objects specified in an order request will generally need to be bod, packaged or otherwise grouped together for further order processing. The selection of objects may be at least partially based on the set of requests, priority of the requests, and planned fulfillment of these orders. For example, an order with two objects that may be selected from one or more bins with high confidence may be selected for object picking and placing by the system prior to an object from an order request where the object is not identified or has lower confidence in picking capability at this time.

[0182] Block S110, which includes collecting image data of an object populated region, functions to observe and sense objects to be handled by a robotic system for processing. In some use-cases, the set of objects will include one or a plurality of types of products. Collecting image data preferably includes collecting visual image data using a camera system. In one variation, a single camera may be used. In another variation, multiple cameras may be used. Collecting image data may additionally or alternatively include collecting depth image data or other forms of 2D or 3D data from a particular region.

[0183] In one preferred implementation collecting image data includes capturing image data from an overhead or aerial perspective. More generally, the image data is collected from the general direction from which a robotic system would approach and grasp an object. The image data is preferably collected in

response to some signal such as an object interaction task request. The image data may alternatively be continuously or periodically processed to automatically detect when action should be taken.

[0184] Block S200, which includes planning a grasp, functions to determine which object to grab, how to grab the object and optionally which tool to use. Planning a grasp can make use of a grasp planning model in densely generating different grasps options and scoring them based on confidence and/or other metrics. In one variation, planning a grasp can include: segmenting image data into region of interest masks S202, evaluating image data through a neural network architecture to generate a set of candidate grasp plans S210, and processing candidate grasp plans and selecting a grasp plan S220. Preferably, the modeling used in planning a grasp, attempts to increase object interaction throughput. This can function to address the challenge of balancing probability of success using a current tool against the time cost of switching to a tool with higher probability of success.

[0185] Block S202, which includes segmenting image data into region of interest masks, functions to generate masks used in evaluating the image data in block S210. Preferably, one or more segmentation masks are generated from supplied image data input. Segmenting image data can include segmenting image data into object masks. Segmenting image data may additionally or alternatively include segmenting image data into object collections (e.g., segmenting on totes, bins, shelves, etc.). Segmenting image data may additionally or alternatively include segmenting image data into object feature masks. Object feature masks may be used in segmenting detected or predicted object features such as

barcodes or other object elements. There are some use cases where it is desirable to avoid grasping on particular features or to strive for grasping particular features.

[0186] Block S210, which includes evaluating image data through a grasp quality model to generate a set of candidate grasp plans, functions to output a set of grasp options from a set of input data. The image data is preferably one input into the grasp quality model. One or more segmentation masks from block S202 may additionally be supplied as input. Alternatively, the segmentation masks may be used to eliminate or select sections of the image data for where candidate grasps should be evaluated.

[0187] Preferably, evaluating image data through the grasp quality model includes evaluating the image data through a grasp quality CNN architecture. The grasp quality CNN can densely predict for multiple locations in the image data what are the grasp qualities for each tool and what is the probability of success if a grasp were to be performed. The output is preferably a map of tensor/vectors characterizing the tool, pose (position and/or orientation for centering a grasp), and probability of success.

[0188] As mentioned above, the grasp quality CNN may model object selection order, and so the output may also score grasp plans according to training data reflecting object order. In another variation, object material planning can be integrated into the grasp quality CNN or as an additional planning model used in determining grasps. Material planning process could classify image data as a map for handling a collection of objects of differing material. Processing of image data with a material planning process may be used in selection of

new tool. For example, if a material planning model indicates a large number of polybag wrapped objects, then a tool change may be triggered based on the classified material properties from a material model.

[0189] Block S220, which includes processing candidate grasp plans and selecting a grasp plan, functions to apply various heuristics and/or modeling in prioritizing the candidate grasp plans and/or selecting a candidate grasp plan. The output of the grasp quality model is preferably fed into subsequent processing stages that weigh different factors. A subset of the candidate grasp plans that have a high probability of success may be evaluated. Alternatively, all grasp plans may alternatively be processed in S220.

[0190] Part of selecting a candidate grasp plan is selecting a grasp plan based in part on the time cost of a tool change and the change in probability of a successful grasp. This can be considered for the current state of objects but also considered across the previous activity and potential future activity. In one preferred variation, the current tool state and grasp history (e.g., grasp success history for given tools) can be supplied as inputs. For example, if there were multiple failures with a given tool then that may inform the selection of a grasp plan with a different tool. When processing candidate grasp plans, there may be a bias towards keeping the same tool. Changing a tool takes time, and so the change in the probability of a successful grasp is weighed against the time cost for changing tools.

[0191] Some additional heuristics such as collision checking, feature avoidance, and other grasp heuristic conditions can additionally be assessed when planning a grasp. In a multi-headed end effector tool variation,

collision checking may additionally account for collisions and obstructions potentially accounted by the end effector heads not in use.

[0192] Block S310, which includes performing the selected grasp plan with a robotic system, functions to control the robotic system to grasp the object in the manner specified in the selected grasp plan.

[0193] Since the grasp plans are preferably associated with different tools, performing selected grasp plan using the indicated tool of the grasp plan may include selecting and/or changing the tool.

[0194] In a multi-headed end effector tool variation, the indicated tool (or tools) may be appropriately activated or used as a target point for aligning with the object. Since the end effector heads may be offset from the central axis of an end arm segment, motion planning of the actuation system preferably modifies actuation to appropriately align the correct head in a desired position.

[0195] In a changeable tool variation, if the current tool is different from the tool of the selected grasp plan, then the robotic system uses a tool change system to change tools and then executes the grasp plan. If the current tool is the same as the tool indicated in the selected grasp plan, then the robotic system moves to execute the grasp plan directly.

[0196] When performing the grasp plan an actuation system moves the tool (e.g., the end effector suction head) into position and executes a grasping action. In the case of a pressure-based pick-and-place machine, executing a grasping action includes activating the pressure system. During grasping, the tool (i.e., the end effector) of the robotic system will couple with the object. Then the object can be moved and manipulated for

subsequent interactions. Depending on the type of robotic system and end effector, grasping may be performed through a variety of grasping mechanisms and/or end effectors.

[0197] In the event that there are no suitable grasp plans identified in block S200, the method may include grasping and reorienting objects to present other grasp plan options. After reorientation, the scene of the objects can be re-evaluated to detect a suitable grasp plan. In some cases, multiple objects may be reoriented. Additionally or alternatively, the robotic system may be configured to disturb a collection of objects to perturb the position of multiple objects with the goal of revealing a suitable grasp point.

[0198] Once an object is grasped it is preferably extracted from the set of objects and then translated to another position and/or orientation, which functions to move and orient an object for the next stage.

[0199] If, after executing the grasp plan (e.g., when grasping an object or during performing object interaction task), the object is dropped or otherwise becomes disengaged from the robotic system, then the failure can be recorded. Data of this even can be used in updating the system and the method can include reevaluating the collection of objects for a new grasp plan. Similarly, data records for successful grasps can also be used in updating the system and the grasp quality modeling and other grasp planning processes.

[0200] Block S320, which includes performing object interaction task, functions to perform any object manipulation using the robotic system with a grasped object. The object interaction task may involve placing the object in a target destination (e.g., placing in another bin or box), changing orientation of object

prior to placing the object, moving the object for some object operation (e.g., such as barcode scanning), and/or performing any suitable action or set of actions. In one example, performing an object interaction task can involve scanning a barcode or other identifying marker on an object to detect an object identifier and then placing the object in a destination location based on the object identifier. When used in a facility used to fulfill shipment orders, a product ID obtained with the barcode information is used to look up a corresponding order and then determine which container maps to that order - the object can then be placed in that container. When performed repeatedly, multiple products for an order can be packed into the same container. In other applications, other suitable subsequent steps may be performed. Grasp failure during object interaction tasks can result in regrasping the object and/or returning to the collection of objects for planning and execution of a new object interaction. Regrasping an object may involve a modified grasp planning process that is focused on a single object at the site where the dropped object fell.

[0201] Referring to Figures 15-19, various method configurations are illustrated. Referring to Figure 15, one embodiment comprises providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, and a first

computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly defining a first inner capture chamber (402); and utilizing the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein conducting the grasp of the targeted package comprises pulling into and at least partially encapsulating a portion of the targeted package with the first inner capture chamber when the vacuum load is controllably activated adjacent the targeted package (404).

[0202] Referring to Figure 16, one embodiment comprises providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in

part upon the image information (408); and utilizing the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing device, the first suction cup assembly defining a first inner chamber, a first outer sealing lip, and a first vacuum-permeable distal wall member which are collectively configured such that upon conducting the grasp of the targeted package with the vacuum load controllably activated, the outer sealing lip may become removably coupled to at least one surface of the targeted package, while the vacuum-permeable distal wall member prevents over-protrusion of said surface of the targeted package into the inner chamber of the suction cup assembly.

[0203] Referring to Figure 17, one embodiment comprises providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in

part upon the image information (414); and utilizing the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package when the vacuum load is controllably activated adjacent the targeted package; and wherein before conducting the grasp, the computing device is configured to analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device, the neural network trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure (416).

[0204] Referring to Figure 18, one embodiment comprises providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, a first computing system operatively coupled to the robotic arm and the

first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information (420); utilizing the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package when the vacuum load is controllably activated adjacent the targeted package (422); providing a second imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector to estimate the outer dimensional bounds of the targeted package by fitting a 3-D rectangular prism around the targeted package and estimating L-W-H of said rectangular prism, and to utilize the fitted 3-D rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector (424); and utilizing the first computing system to operate the robotic arm and end effector to place the targeted package upon the place structure in a specific position and orientation relative to the place structure (426).

[0205] Referring to Figure 19, one embodiment comprises collecting image data pertaining to a populated region (430); planning a grasp which is comprised of evaluating image data through a grasp

quality model to generate a set of candidate grasp plans, processing candidate grasp plans and selecting a grasp plan (432); performing the selected grasp plan with a robotic system (434); and performing an object interaction task (436).

[0206] Referring to Figure 20A and 20B, two synthetic training images (152, 154) are shown, each featuring a synthetic pick structure bin (156, 158) containing a plurality of synthetic packages (160, 162). Synthetic volumes may be created and utilized to create large numbers of synthetic image data, such as is shown in Figures 20A and 20B, to rapidly train a neural network to facilitate automatic operation of the robotic arm in picking targeted packaged from the pick structure and placing them on the place structure. Views may be created from a plurality of viewing vectors and positions, and the synthetic volumes may be varied as well. For example, the neural network may be trained using views developed from synthetic data comprising rendered color images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure; it also may be trained using views developed from synthetic data comprising rendered depth images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure; it also may be trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more randomized synthetic packages as contained by a synthetic pick structure; it also may be trained using synthetic data wherein the synthetic packages are randomized by color texture; further, it may also be trained using synthetic data wherein the synthetic packages are randomized by a physically-based rendering mapping selected from the

group consisting of: reflection, diffusion, translucency, transparency, metallicity, and microsurface scattering; further the neural network may be trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages in random positions and orientations as contained by a synthetic pick structure.

[0207] The first computing system may be configured such that conducting the grasp comprises analyzing a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure. Analyzing a plurality of candidate grasps may comprise examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package. Analyzing a plurality of candidate grasps may comprise examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach orientations. Analyzing a plurality of candidate grasps comprises examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach positions. A first suction cup assembly may comprise a first outer sealing lip, wherein a sealing engagement with a surface comprises a substantially complete engagement of the first outer sealing lip with the surface. Examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a

surface of the targeted package may be conducted in a purely geometric fashion. A first computing system may be configured to select the execution grasp based upon a candidate grasps factor selected from the group consisting of: estimated time required; estimated computation required; and estimated success of grasp.

[0208] The system may be configured such that a single neural network is able to predict grasps for multiple types of end effector or tool configurations (i.e., various combinations of numbers of suction cup assemblies; also various vectors of approach). The system may be specifically configured to not analyze torques and loads, such as at the robotic arm or in other members, relative to targeted packages in the interest of system processing speed (i.e., in various embodiments, with packages for mailing, it may be desirable to prioritize speed over torque or load based analysis).

[0209] As noted above, in various embodiments, to randomize the visual appearance of items in the synthetic/simulated training data, the system may be configured to randomize a number of properties that are used to construct the visual representation (including but not limited to: color texture, which may comprise base red-green-blue values that may be applied to the three dimensional model; also physically-based rendering maps, which may be applied to the surfaces, may be utilized, including but not limited to reflection, diffusion, translucency, transparency, metallicity, and/or microsurface scattering).

[0210] Referring to Figure 21A, from a general perspective, many distribution and/or logistics centers may be characterized as having parcels and packages incoming through a loading dock (170), such as one

configured to accommodate trucks, a certain level of sorting, and parcels and packages going out through a loading dock (178) after sortation, such as a different outgoing loading dock relative to an incoming loading dock. In a conventional paradigm, much of the sortation would be conducted manually by human employees. As shown in Figure 21A, after after unloading into the facility (170), primary processing may be conducted to prepare the items for robotic sortation (174) by one or more robotic systems, such as those described above (52) in reference to Figure 7A. The outputs of sortation may be directed to what may be called "pack-out" processing (176), wherein packages or parcels may be labelled, grouped, and/or placed in additional packaging (such as bags or boxes) to be ready for transfer and/or loading into outgoing vehicles, such as through the outgoing truck loading dock (178).

[0211] Referring to Figure 21B, the most basic elements of a configuration such as that of Figure 21A include unloading parcels from inbound vehicles (180), sorting the parcels, such as via robotic sortation using machine vision robot (182), and transferring or loading outgoing parcels to be dispatched to a next destination, such as via a truck or other vehicle (184).

[0212] Referring to Figure 22A, a configuration similar to that of Figure 21B is illustrated, with additional intermediate steps of: primary induction of parcels to a generally large platform, table, or conveyor, which may be termed a "primary induction buffer" and generally configured to be an initial recipient of incoming packages for further processing (186); "singulation", or physical separation of packages from one another, to facilitate further sorting (188); and after sorting of the parcels, such as by

precision machine vision robot as described above (182), assembly of outgoing parcels in appropriate configurations for transfer (which may be called "pack-out") (190).

[0213] Figure 22B illustrates a parcel handing embodiment wherein a distribution center generally may be configured to receive parcels, precision sort them, and output them in sorted manner for further processing and/or delivery (224). Trucks containing incoming parcels may be parked at unloading dock (226). Parcels may be unloaded from containers or housings (which may be in the form of large containers referred to as "gaylord boxes" or "gaylords", pallets, or other forms) from trucks (such as by the use of telescoping conveyor systems, hydraulic liftgates, and/or pallet jacks) (228). Smaller parcels may be removed from large containers / gaylords / pallets, such as by a hydraulic tilt/dump system (230), such as that available under the tradename, "Vestil HBD-2-48 Hydraulic Box Dumper". Parcels may be positioned upon one or more large tables, platforms, or conveyors (which may be called "primary induction buffers") for primary induction processing (232). Primary induction processing may be conducted (such as mass leveling, bulk spreading, distribution into mobile bins; such as by utilizing a configuration such as that illustrated in Figure 24B) in preparation for subsequent singulation and sorting (234). Singulation, scanning, and at least partial sorting of parcels may be conducted (such as by mechanical and/or electromechanical systems, such as diverters or conveyors, and scan and/or image capture devices), and sorted parcels directed toward transfer to pack-out processing (236). Non-sorted parcels may be transferred or diverted (such as via manual or electromechanically-

enhanced chutes, conveyors, and/or bins) to a robotic sorting system such as is illustrated in Figure 7A (a conveyor style input is illustrated in Figure 28A) (238). Robotic sorting (240) may be conducted, as described above, with sorted parcels placed into an output containment system, such as those shown in the configurations of Figures 7A and Figures 29A-29H, for example. Robotically-sorted parcels may be transferred from the sorted output containment configuration to a pack-out processing station (such as via manual or electromechanically-enhanced propulsion of sorted output containment system) (242). Pack-out processing of discrete sorted parcels or groups thereof may be conducted (such as assembly into boxes or bags and/or larger containers or pallets, with labelling) (244). Assembled pack-out results may be transported into trucks at an outbound loading dock (246), to storage, or positioned for further transfer alternative. Loaded outgoing trucks may depart (248) to conduct delivery and/or transfer.

[0214] Figure 22C illustrates another variation featuring further automation configuration. Referring to Figure 22C, a distribution center may be configured to receive parcels, precision sort them, and output them in sorted manner for further processing and/or delivery (252). Trucks containing incoming parcels may be parked at unloading dock, such as via autonomous local vehicle navigation (254). Parcels may be unloaded (which may be in the form of large containers referred to as gaylord boxes or gaylords, pallets, or other forms) from trucks (such as by the use of telescoping conveyor systems, hydraulic liftgates, and/or pallet jacks which may be autonomously or semi-autonomously controlled) (256). Smaller parcels may be removed from larger containers /

gaylords / pallets (such as by autonomous or semi-autonomous electromechanical transport and/or hydraulic tilt/dump systems) (258). Parcels may be assembled, such as via one or more electromechanical systems (such as via autonomous or semi-autonomous convenance subsystem) of parcels upon one or more large tables, platforms, or conveyors (which may be called "primary induction buffers") for primary induction processing (260). Electromechanical primary induction processing of parcels may be conducted (such as mass leveling, bulk spreading, distribution into mobile bins; such as described, for example, in reference to Figure 24B) in preparation for subsequent singulation and sorting (262). Singulation, scanning, and at least partial sorting of parcels may be conducted (such as by mechanical and/or electromechanical systems, such as diverters or conveyors, and scan and/or image capture devices); sorted parcels directed toward transfer to pack-out processing (264). Non-sorted parcels may be transferred or diverted (such as via manual or electromechanically-enhanced chutes, conveyors, and/or bins) to robotic sorting system, such as that described above in reference to Figure 7A (266), and such robotic sorting system may be utilized to sort parcels into a sorted output containment system (268), such as those shown in the configurations of Figures 7A and Figures 29A-29H, for example. Transfer of robotically-sorted parcels may be conducted from sorted output containment system to pack-out processing station (such as via autonomous or semi-autonomous electromechanically-enhanced propulsion of sorted output containment system) (270). Pack-out processing of sorted discrete parcels or groups thereof may be conducted (such as electromechanical autonomous or semi-autonomous assembly

into boxes or bags and/or larger containers or pallets, with labelling) (272). Transportation of assembled pack-out results into trucks at outbound loading dock, or in a configuration for alternative transfer or storage, may be conducted (such as via autonomous or semi-autonomous electromechanical transport and/or truck loading systems) (274). Loaded outgoing trucks may depart (276) to conduct delivery and/or transfer.

[0215] Referring to Figures 23-29H, various aspects of configurations such as those described in reference to Figures 22A-22C are illustrated. Referring to Figure 23, a truck (282) may be unloaded using a telescoping electromechanical conveyor (302) which may be centrally or locally controlled to move boxes of various sizes, such as relatively large gaylords (284) from the truck (282) and into the distribution or logistics center (280). The gaylords may contain one or more smaller individual parcels (290), and may be coupled (286) to a pallet (288) or other structure. An electromechanical or robotic de-palletizing system (304) may be utilized to remove stacks or assemblies (300) of individual parcels from a pallet (288) structure. After local transport of unloaded items, such as by a pallet jack (292), scissor lift (294), manually-navigated electromechanical driven lift (296), or an autonomous or semi-autonomous box, container, and/or pallet moving device (298) such as a TUG (RTM) robot, lifting and/or dumping system (306) may be utilized to position individual parcels upon a large table or conveyor which may serve as a primary induction buffer (312); alternatively manual (308) intervention may be utilized for moving and/or lifting.

[0216] Referring to Figure 24A, a primary induction buffer (312) is illustrated with piles of parcels (290)

in overlapping formations of various types following efficiently-paced assembly onto the buffer (312). Referring to Figure 24B, to reduce the piling of parcels upon each other, and to generally start singulation, mechanical intervention (such as by substantially horizontal movement (322) of a bulkhead member (324) relative to the induction buffer (312); the bulkhead member (324) may be coupled to one or more weighted elongate members (326), such as chains, to further assist in mechanically spreading the parcels out) may be used to spread parcels and generally reduce vertical stacking.

[0217] Referring back to Figure 24A, as parcels are migrated through processing, such as via elevation drop and/or electromechanical assistance such as via one or more conveyors, they may be migrated to a singulation conveyor (316), and the transition (314) may involve one or more chutes or channels (318) configured to direct the parcels, and in some instances, provide further initial singulation through channeling and directing. Vibration or other mild loading may be utilized to further provide initial singulation and parcel spreading at or after the primary induction buffer.

[0218] Referring to Figure 25, a singulation, scanning, and sorting conveyor configuration (316) is illustrated to receive the parcels (328) passed on from primary induction and to maintain a relatively high rate of processing (i.e., a relatively high forward conveyor velocity) while continuing to singulate parcels, and where possible while retaining a high throughput, provide some sortation. Incoming parcels (328) pass through the fields of view of one or more scanning devices (340, 342; additional may be positioned underneath a transparent viewing window 344; such

devices may comprise computer vision cameras and/or barcode scanners, for example, as described above in reference to the package identification and analysis configurations pertaining to robotic sortation systems such as that illustrated in Figure 7A; generally they are configured to identify packages as they are moving quickly by, and provide an intercoupled computing system with the ability to not only log the presence and instantaneous position of the package, but to also activate a multi-axis conveyor system, such as one featuring a conveyance zone (334) featuring second-axis of conveyance movement which may be utilized to eject or transfer (332) and thereby provide a limited sortation or routing capability during singulation). As shown in Figure 25, the multi-axis conveyor system, as facilitated by the scanning and identification capability, facilitates some early sorting/routing (332), at least some of which may be directly into containers (284) which may be transported (292, 294, 296, 298, etc) directly to pack-out processing. The intercoupled computing system may be configured to operate the various degrees of freedom of the conveyor to divert or exit various packages based upon known positioning of such identified packages on the conveyor, such as via the timing of the scanning (340, 342, 344) and/or the timing or positioning of the conveyor belt or belts, such as from joint monitoring encoders intercoupled into the conveyor drive configuration. Packages or parcels that are not diverted or sorted (330) may be moved ahead along the conveyor system (316) to further processing, such as is illustrated in the configurations of Figures 26A-26C.

[0219] Referring to Figure 26A, in a next sequence of illustrative system configurations wherein processing

throughput and velocity is maintained as a maximum as long as possible into the processing, incoming packages (330) may be passed through a scanning configuration (340, 342, 344) as shown, to provide a singulation robot subsystem (360), such as that illustrated in Figure 26B, opportunity to operate a robotic arm (54) and end effector (4) such as those illustrated in Figure 7A, with benefit of the scanning / image capture provided by the scanning configuration (340, 342, 344), to capture, lift, and reposition various parcels or packages (290) for improved singulation on the associated conveyor (346) or other structure. In other words, where a package position needs to be adjusted, the robot (54, 4) can move it into better singulation position, and alternatively given time, provide for a sortation on the spot with delivery straight to a nearby container for transfer to pack-out. A plurality of such singulation robots (360) is shown, in Figure 26A in series (but may be in parallel from either side of a conveyor 348, or both series and parallel depending upon throughput objectives). A third scanning configuration is shown after the singulation robots (360) to provide the system with a final viewing of singulation status and a sorting opportunity, such as through multi-degree-of-freedom conveyor: directly (350) to containers (284) for transfer to pack-out, directly (352) to a vision-based robotic sortation system (174) such as is described in reference to Figure 7A, and/or directly (354) to electromechanical sorting by gantry, further multi-degree-of-freedom conveyor, palletizing robot, or other integrated subsystem (358).

[0220] Referring to Figure 26C, a configuration similar to that of Figure 26A is illustrated, with an additional multi-degree-of-freedom conveyor (334) for

additional diversion (332) alternative, such as for re-routing of non-singulated items (336) or transferring (362) for return (338) to prior processing stage for further singulation. Packages which are not directed to sorting or re-routing (332) may be passed into a remainder capture (356) container, chute, conveyor, or other capture device for re-routing to prior processing stages.

[0221] Referring to Figure 27, in various configurations, a panoply of subsystems may be employed and coordinated to move packages quickly. As shown in Figure 27, incoming parcels from sortation or singulation may be sorted to container (350), from robotic sortation (174), from other electromechanical systems (358), or from singulation processes (364) and may be transferred and mobilized to pack-out processing (376) by various subsystems as described above (292, 294, 296, 298, 302, and chute/conveyor systems/networks 366). Pack-out processing(376) may use electromechanical band-application systems (368) and box-formation systems (370), robotic pallet loaders (372), palletizing robots (374), as well as manual labor (308). The results of pack-out may be directed to the loading dock, storage, or further transfer (378), for example, by various subsystems as described above (292, 294, 296, 298, 302, and chute/conveyor systems/networks 366).

[0222] Referring to Figure 28A, a robotic sortation system (52) such as that described in reference to Figure 7A is shown with a conveyor (380) input routing feed (352). Referring to Figure 28B, a group of sortation containers or bins (382) may be served by a sorting robot (54, 4) as described above, which may be fed by a sloped / gravity-feed input container (388) for

input packages to be sorted by the robot (54, 4) and placed into one of two electromechanically controllably tiltable distribution containers (386) which may be controllably and electromechanically movable along two linear rail (384) subsystems for delivery into the bins (382). Referring to Figure 28C, a linear rail (384) may also be operatively and controllably coupled to a robot arm (54) for further sorting and distribution alternative configuration, speed, and constraint. Referring to Figure 28D, a robotic sorting configuration (54, 4) may be utilized to pick from an sloped input feed container (388) and distribute to one of a stack of three electromechanically controllably tiltable distribution containers (394) which may be controllably and electromechanically movable along three associated linear rail (396) subsystems for delivery into a group of bins (392). Figure 28E illustrates a robotic singulation and/or sortation configuration (54, 4) capturing packages (290) from a sloped / gravity-feed input container (388) and moving them to a singulation and/or sortation position/orientation.

[0223] Referring to Figures 29A and 29B, configurations such as that illustrated in Figure 7A are shown, highlighting the plurality of output containment structures or bins (386) that become the targets for parcels sorted by robot (54, 4) output. Figure 29C illustrates that elongate carts coupling three bins (in the illustrated embodiment; number may be varied in accordance with application) may be pulled out (400) and transported to pack-out, such as via wheels (442) which may be fitted to the bottoms of the elongate carts (398) for ease of motion on a floor (440), as shown in Figure 29D. Referring to Figure 29E, in another embodiment, an entire bank of bins (398) may be coupled together and

removed together in unitary fashion, such as via coupling structure (446) with larger wheels (444). Referring to Figures 29F-29H, in various embodiments, the robotic sortation system may be configured to sort to a top layer of bins or containment features (448), after which a controllably openable door (450) may be switched to an open condition (451 - as in Figure 29G) such that parcels or items previously located in the top layer of bins or containment features (448) fall down and are transferred to a lower layer (449) of bins or containment features (448). The doors (450) may be closed again, as shown in Figure 29H, such that sorting may continue into the upper layer (448), and also such that transfer of the sorted goods out of the lower layer (449) may progress, such as via conveyor or via swapping out the entire lower layer (449) for transfer away from the sorting robot and swapping in of a new/empty lower layer.

[0224] As noted above, the subject systems and methods pertain to various permutations and combinations of components and modules. For example, various input systems and modules are described, such as wheeled bins, mobile robots, gaylord dumpers, and conveyors (which may be, for example, configured to only provide forward/backward controllable motion, or multi-axis motion, such as in two orthogonal directions, or omnidirectionally, such as with a multi-belted a ball-matrix based conveyance system or module). The various components generally are subject to control by a centralized computing system which is operatively coupled to each component (such as via wired or wireless connectivity, such as via IEEE 802.11, Bluetooth, nearfield, or similar) such that each component may be operated and controlled by the central computing system

(which, as noted above, may comprise one or more integrated computing systems, including mobile computing systems such as mobile phones, tablets, laptops, and the like). These subsystems may be monitored and observed using a variety of sensors, such as optical encoders for joint rotation axes, load sensing cells (such as, for example, those based upon piezoelectric materials, strain gauges, and the members of known spring constant or bulk modulus wherein deflection may be measured and correlated with loading; also inverse kinematic techniques may be utilized to determine estimates for loads in elongate assemblies such as robot arms), image capture devices of various types (such as color, infrared, monochrome, stereo, LIDAR, and barcode scanners, and multimodal configuration, such as those which may capture both image and barcode information together by virtue of optical character recognition and/or barcode analysis based upon image capture; further multimodal sensing configurations may integrate LIDAR point cloud data with at least partially correlated image data, to provide, for example, so-called "image fusion" capabilities wherein uncorrelated errors from a plurality of different subsystems may be utilized to benefit the synergy of having both. Further, so-called "SLAM" or simultaneous localization and mapping techniques may be utilized wherein location data is known or determinable from kinematics, fiducials, position sensors (such as GPS, electromagnetic flux based, or signal-triangulation based) or other use of Jacobian transforms and/or local coordinate systems. From a high-level perspective, Figure 30 illustrates the general flow of several embodiments of such systems, wherein a robotic sorting

system may be utilized to assist in processing various packages or parcels.

[0225] Referring to Figure 31, incoming parcels from receiving or other systems may be inbound (502) for processing. Primary induction and singulation (such as loading parcels onto an initial conveyance system, physically spreading and leveling parcels) may be conducted (504), and packages may be transported to an input container or buffer that is operatively coupled with a robotic sorting system (such as via large so-called "gaylord" container, or passive or electromechanically-active conveyance system) (506). In each opportunity wherein an image capture device is available and/or utilized, the system may be configured to operate a runtime version of a neural network trained to assist in identifying packages, structures, potential jams, and other related issues. The neural network may be trained, at least in part, using synthetic data created for specific scaleable training purposes, as noted above. Precision robotic sorting of packages or parcels may be conducted (such as from a gaylord or other input container or conveyance, past one or more imaging devices and/or barcode scanners, onto a place structure where it may be picked up by a complementary movable component and distributed to an output container) (508), followed by transportation from sorting output to pack-out (such as by sorting output container manually-movable or automatically-movable assembly, or by transfer from sorting output container to pack-out transfer system, such as by vertical release to intercoupled pack-out transport system) (510). Input management to pack-out may be conducted, such as via pack-out input buffer configuration (such as via gaylor container, conveyance system, and/or intercoupled pack-

out transport system) (512), followed generally by pack-out processing; output from pack-out for transfer to outgoing trucks or other systems (514). Figures 32A-32G illustrate again how a package (209) may be robotically (54) sorted. The incoming parcel (290) may be grasped from an pick structure (such as an input bin) by the robot (54) as described above, passed across the field of view of a scanner and/or imaging device to preferably capture package identifying information, and placed upon the place structure (56) where it may be specifically positioned and/or oriented at placement, such as by use of an extrinsic structure which may be controllable to have one or more stable or movable ramps or other features to assist in manipulating a package. The package (209) may be moved from the place structure using a movable component (58), such as one configured to closely engage the other place structure component (56; which may have a ramp or other extrinsic feature as shown), such as via a forked configuration. The movable complementary component (58) may be moved along a gantry system comprising, for example, one or more rails, or a horizontal structure (520) movably coupled to one or more rails (522) as shown, and may be tilted/dumped into a particular location in a matrix of bins, bags, or other containers (516), as shown in Figures 32A-32G. Such containers (516) may be removable through side exit features (524) for further processing. Referring to Figures 33A-34F, a movable container (532) may receive packages (290) from the robot (54) which may automatically pull them from a large input bin pick structure (534) using the aforementioned vision-based grasp analysis and execution, and the container (532) may controllably transport packages (290) using one or more linear or nonlinear rails (526, 528) so that the

packages (290) may be dropped, such as via electromechanical tilt/dump at the container (532) in a selected bins of the bin assembly (530). Referring to Figures 34A-34E, such a bin assembly may be vertical and comprise a plurality of rails (532) coupled by a vertical rail structure (540) as shown, so that packages (290) may be processed from input (534) to sortation in a specific portion of the output bin assembly (538). Figure 34E illustrates that a movable vertical rail assembly (542) may provide vertical degrees of freedom, as well as controlled movement along another axis, such as along (544) an axis parallel to the plane of the floor. Controlled motion may be via intercoupled electric motors, wheels, belts, and/or movable members such as leadscrews. Figure 34F illustrates a configuration wherein a plurality of robot sorting stations (54) serves a plurality of rails to reach many output bins.

[0226] Referring to Figures 35A-35C, a package (209) may be positioned and/or oriented on a place structure component (56), which may feature an extrinsic manipulation feature such as a ramp (548), or may be relatively simple without such extrinsics other than a substantially planar surface. As shown in Figures 35D-39D, a controllably closeable package containment module (554) with one or more controllably movable doors or closure features (such as the forked assembly 552, a slide away bottom door 558, and/or rotate-away bottom doors 562; each of which preferably is electromechanically operated and controlled by the central computing system) may be utilized to transiently couple to, contain, or hold, a package (290), and then controllably release it.

[0227] Referring to Figures 40A-40C, one or more carts or wheeled bins (564) may be utilized to transport sorted packages away from the sorting system (52), but a relatively large area (such as 568, or larger 570) may be needed to maneuver these modules. Figure 41C illustrates a configuration wherein multiple vertical assemblies (572) of output containers may be made accessible to a single robot (54) with a configuration as shown wherein an input buffer (534) can feed one robot (54) to the pluralities of containers (572). Referring to Figures 41A-44M, vertical bin assemblies (530) may be addressed with pluralities of movable container (532) fed by a sorting robot (54) and one or more input containers (534), conveyances, or other input module. Referring to Figure 41D, with a gap (574) between stacks of output containers (530), it may be useful to have a central gantry system featuring a movable base (582), vertical support (580), and distal movable member (578), each of which may be preferably electromechanically controllably movable to reach the various bins (530) using motors, belts, lead screws, articulated arms, and the like, as shown. Figure 41G illustrates that the main vertical member (580) may have a roll degree of freedom (586), as well as a top rotatable member (588) which may be operatively coupled to a rotation drive motor (590). Controllable containers (554) and also graspers (600) which may feature teeth or other features configured to engage features of a container, as shown in Figure 44G, may be utilized to pull over a desired bin (530) for distribution; further, referring to Figure 44H, a controllably deployable hook member (636) may be utilized to removably and securely couple to a targeted bin (530); further, referring to Figure 44K, for

example, a geometrically expandable cam assembly (640) may be utilized to be inserted into a feature such as a small enclosure (642), and to lock thereto upon tension before release with a releasing member as desired. Referring to Figures 42A-43A, various exit conduits and configurations may be utilized to guide away sorted packages, such as tilted bin orientations (592), exit conduits or ramps (594), or one or more vertically-oriented layers of controllably releasable doors (598) as shown in Figure 43A.

[0228] Referring to Figure 43B, incoming parcels from receiving or other systems may be incoming (602), and they may be addressed as shown (604, 606, 608, 610, 612, 614, 616) in Figure 43B. Referring to Figures 43C-43D, one or more mobile robots (620) may be utilized to move packages away from sorting.

[0229] Referring to Figure 45, similar processing steps may integrate pack-out processing (652, 654, 656, 658, 660, 662, and 664). Figures 46A-46E illustrate that controllable package or container grasping or capturing configurations such as those described above may be utilized to process packages from input conveyance (678) to sorting robot (54) to centralized distribution conveyor (676), wherein they may be transferred to the matrix of bins and then later, when full or at a commanded time, pulled up and out of their bin matrix position to be transferred, such as via a linear rail or gantry, to an exit container (670) or cupboard, which may be configured to temporarily hold the contents until commanded to exit the contents, such as into a bin (674) for transport to packout. Figure 46E illustrates that these systems and subsystems may be combined to greater throughput in a warehouse environment, for example. Figures 47-57 illustrate

various flowcharts of suitable sortation embodiments and configurations (702, 704, 706, 708, 710, 712, 714, 716, 718, 720, 722; carousel (728) system 724); 730, 732, 734, 736; 738, 740, 742, 744, 746, 748, 750, 752; 754, 756, 758, 760, 762, 764; 768, 770, 772, 774, 776; 778, 780, 782, 784, 786, 788, 790; 792, 794, 796, 798, 800, 802, 804, 806; 808, 810, 812, 814, 816; 818, 820, 822, 824, 826; 828, 830, 832, 834). Figure 58 illustrates (836) various time domain aspects of one embodiment of suction-based grasp. Figures 59 and 60 illustrate additional grasp execution and processing configuration steps (838, 840, 842, 844, 846; 852, 854, 856, 858, 860). Figures 61, 62, and 63 illustrate various report interview views and control interface reporting displays and/or outputs (866, 868, 870) which may be utilized to connect various user (862, 864). Figures 64-69 illustrate various configurations wherein a pruning or input processing assembly (874), such as one comprising vibratory stimulators, ramps, chutes, waterfalls, and turns, may be utilized to singulate packages so that they may be conveyed (876) either toward a rejection container (878) for further subsequent processing, such as when the computing system deems, in view of pertinent image information, that a grasp is not possible or is suboptimal; a multi-directional conveyance (876) may be utilized to forward packages ready for further processing to a sortation module (882), which may comprise a plurality of sorting robots or multiaxial devices such as conveyors or diverters, which may sort packages into particular output containers. Systems may scale these configurations as shown in Figure 69 (890). Figures 70-77 illustrate further views of such configurations. Figure 78 illustrates an end effector support assembly (902) which may be configured to route

vacuum lines (not shown; from vacuum ports 912 through wrist aperture 914) while also providing constrained motion (such as via a linear bearing 904) which may be suspected, such as via controlled/selected tension and/or compression using a contained compression member (906) (such as a spring). The lower face (908) may be coupled to one or more suction cups (not shown). Figure 79 illustrate a simplified view of a sort configuration (916). Figure 80 illustrates a sort configuration (918) wherein an input conveyance (922; may be multiaxial; may be configured to work with one or more sorting robots 54 not shown at one of the plurality of sorting stations 920) may be utilized to feed a sorting assembly (882), with rejected packages going to a reject or "jackpot" bin (886) or one of the reject or ejection bins which may be placed adjacent the sorting stations (920). Figure 81 illustrates that an output conveyance (928) may be utilized to load a truck or other shipping or output container (924) through an opening or access portal such as a door (926). An image capture device and/or LIDAR sensor (934) may be configured to conduct SLAM analysis of the enclosure of the container (924) so that controllably extensible support members (930, 932; such as lead screws, tension members, cantilevered members, or the like; preferably electromechanically deployable under load control to prevent damage) may stabilize the conveyance within the enclosure for loading of the packages into the enclosure using the results of the SLAM analysis.

[0230] Figures 82, 84, and 85 illustrate various configurations wherein one robot (54) may be scaled to serve more outputs, such as pallets, using rotatable base, movable rail, mobile robot, or similar technologies to geometrically scale access. Figure 84

illustrates (938) various configurations wherein extrinsic structures may be utilized to assist in manipulation of a package.

[0231] Various exemplary embodiments of the invention are described herein. Reference is made to these examples in a non-limiting sense. They are provided to illustrate more broadly applicable aspects of the invention. Various changes may be made to the invention described and equivalents may be substituted without departing from the true spirit and scope of the invention. In addition, many modifications may be made to adapt a particular situation, material, composition of matter, process, process act(s) or step(s) to the objective(s), spirit or scope of the present invention. Further, as will be appreciated by those with skill in the art that each of the individual variations described and illustrated herein has discrete components and features which may be readily separated from or combined with the features of any of the other several embodiments without departing from the scope or spirit of the present inventions. All such modifications are intended to be within the scope of claims associated with this disclosure.

[0232] The invention includes methods that may be performed using the subject devices. The methods may comprise the act of providing such a suitable device. Such provision may be performed by the end user. In other words, the "providing" act merely requires the end user obtain, access, approach, position, set-up, activate, power-up or otherwise act to provide the requisite device in the subject method. Methods recited herein may be carried out in any order of the recited events which is logically possible, as well as in the recited order of events.

[0233] Exemplary aspects of the invention, together with details regarding material selection and manufacture have been set forth above. As for other details of the present invention, these may be appreciated in connection with the above-referenced patents and publications as well as generally known or appreciated by those with skill in the art. The same may hold true with respect to method-based aspects of the invention in terms of additional acts as commonly or logically employed.

[0234] In addition, though the invention has been described in reference to several examples optionally incorporating various features, the invention is not to be limited to that which is described or indicated as contemplated with respect to each variation of the invention. Various changes may be made to the invention described and equivalents (whether recited herein or not included for the sake of some brevity) may be substituted without departing from the true spirit and scope of the invention. In addition, where a range of values is provided, it is understood that every intervening value, between the upper and lower limit of that range and any other stated or intervening value in that stated range, is encompassed within the invention.

[0235] Also, it is contemplated that any optional feature of the inventive variations described may be set forth and claimed independently, or in combination with any one or more of the features described herein. Reference to a singular item, includes the possibility that there are plural of the same items present. More specifically, as used herein and in claims associated hereto, the singular forms "a," "an," "said," and "the" include plural referents unless the specifically stated

otherwise. In other words, use of the articles allow for "at least one" of the subject item in the description above as well as claims associated with this disclosure. It is further noted that such claims may be drafted to exclude any optional element. As such, this statement is intended to serve as antecedent basis for use of such exclusive terminology as "solely," "only" and the like in connection with the recitation of claim elements, or use of a "negative" limitation.

[0236] Without the use of such exclusive terminology, the term "comprising" in claims associated with this disclosure shall allow for the inclusion of any additional element--irrespective of whether a given number of elements are enumerated in such claims, or the addition of a feature could be regarded as transforming the nature of an element set forth in such claims. Except as specifically defined herein, all technical and scientific terms used herein are to be given as broad a commonly understood meaning as possible while maintaining claim validity.

[0237] The breadth of the present invention is not to be limited to the examples provided and/or the subject specification, but rather only by the scope of claim language associated with this disclosure.

CLAIMS

1. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp

comprises engaging the targeted package and controllably activating the vacuum load;

wherein before conducting the grasp, the first computing system is configured to analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device, the neural network trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure.

2. The system of claim 1, wherein the first computing system is further configured to analyze the plurality of candidate grasps based a continuous learning configuration of the neural network wherein data from a set of known and actual experiences is utilized to further train the neural network.

3. The system of claim 2, wherein the set of known and actual experiences is based upon prior operation of the particular robotic arm of the system.

4. The system of claim 2, wherein the set of known and actual experiences is based upon prior operation of a different robotic arm similar to the particular robotic arm of the system.

5. The system of claim 4, wherein the different robotic arm similar to the particular robotic arm of the system is substantially identical to the particular robotic arm of the system.

6. The system of claim 1, wherein the first computing system is configured to analyze the plurality of candidate grasps based upon a kinematic reach of the robotic arm and end effector.

7. The system of claim 1, wherein the first computing system is configured to analyze the plurality of candidate grasps based upon a location of labeling information of the targeted package based upon the image information from the first imaging device.

8. The system of claim 7, wherein the first computing system is configured to analyze the plurality of candidate grasps based upon a location of barcode labeling information of the targeted package based upon the image information from the first imaging device.

9. The system of claim 8, wherein the first computing system is configured to analyze the plurality of candidate grasps based upon a location of labeling information of the targeted package based upon the image information from the first imaging device, and to select an execution grasp that does not have the end effector covering the barcode labeling information.

10. The system of claim 1, further comprising a frame structure configured to fixedly couple the robotic arm to the place structure.

11. The system of claim 10, wherein the pick structure is removably coupled to the frame structure.

12. The system of claim 1, wherein the place structure comprises a placement tray.

13. The system of claim 12, wherein the placement tray comprises first and second rotatably coupled members, the first and second rotatably coupled members being configured to form a substantially flat tray base surface when in a first rotated configuration relative to each other, and to form a lifting fork configuration when in a second rotated configuration relative to each other.

14. The system of claim 12, wherein the placement tray is operatively coupled to one or more actuators configured to controllably change an orientation of at least a portion of the placement tray, the one or more actuators being operatively coupled to the first computing system.

15. The system of claim 1, wherein the pick structure comprises an element selected from the group consisting of: a bin, a tray, a fixed surface, and a movable surface.

16. The system of claim 15, wherein the pick structure comprises a bin configured to define a package containment volume bounded by a bottom and a plurality of walls, as well as an open access aperture configured to accommodate entry and egress of at least the distal portion of the robotic arm.

17. The system of claim 16, wherein the first imaging device is configured to capture the image information pertaining to the pick structure and one or more packages through the open access aperture.

18. The system of claim 16, wherein the first imaging device comprises a depth camera.

19. The system of claim 1, wherein the first imaging device is configured to capture color image data.

20. The system of claim 10, wherein the first computing system comprises a VLSI computer operatively coupled to the frame structure.

21. The system of claim 1, wherein the first computing system comprises a network of intercoupled computing devices, at least one of which is remotely located relative to the robotic arm.

22. The system of claim 1, further comprising a second computing system operatively coupled to the first computing system.

23. The system of claim 22, wherein the second computing system is remotely located relative to the first computing system, and the first and second computing systems are operatively coupled via a computer network.

24. The system of claim 1, wherein the first computing system is configured such that conducting the grasp comprises analyzing a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure.

25. The system of claim 24, wherein analyzing a plurality of candidate grasps comprises examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package.

26. The system of claim 25, wherein analyzing a plurality of candidate grasps comprises examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach orientations.

27. The system of claim 25, wherein analyzing a plurality of candidate grasps comprises examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach positions.

28. The system of claim 25, wherein the first suction cup assembly comprises a first outer sealing lip, and wherein a sealing engagement with a surface comprises a substantially complete engagement of the first outer sealing lip with the surface.

29. The system of claim 25, wherein examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package is conducted in a purely geometric fashion.

30. The system of claim 24, wherein the first computing system is configured to select the execution grasp based upon a candidate grasps factor selected from the group consisting of: estimated time required; estimated computation required; and estimated success of grasp.

31. The system of claim 1, wherein the first suction cup assembly comprises a bellows structure.

32. The system of claim 31, wherein the bellows structure comprises a plurality of wall portions adjacently coupled with bending margins.

33. The system of claim 32, wherein the bellows structure comprises a material selected from the group consisting of: polyethylene, polypropylene, rubber, and thermoplastic elastomer.

34. The system of claim 1, wherein the first suction cup assembly comprises an outer housing and an internal structure coupled thereto.

35. The system of claim 34, wherein the internal structure of the first suction cup assembly comprises a wall member coupled to a proximal base member.

36. The system of claim 35, wherein the wall member comprises a substantially cylindrical shape having proximal and distal ends, and wherein the proximal base member forms a substantially circular interface with the proximal end of the wall member.

37. The system of claim 35, wherein the proximal base member defines one or more inlet apertures therethrough, the one or more inlet apertures being configured to allow air flow therethrough in accordance with activation of the controllably activated vacuum load.

38. The system of claim 37, wherein the internal structure further comprises a distal wall member comprising a structural aperture ring portion configured to define access to the inner capture chamber, as well as one or more transitional air channels configured to allow air flow therethrough in accordance with activation of the controllably activated vacuum load.

39. The system of claim 38, wherein the one or more inlet apertures and the one or more transitional air channels function to allow a prescribed flow of air through the capture chamber to facilitate releasable coupling of the first suction cup assembly with the targeted package.

40. The system of claim 1, wherein the one or more packages are selected from the group consisting of: a bag, a "poly bag", a "poly", a fiber-based bag, a fiber-based envelope, a bubble-wrap bag, a bubble-wrap envelope, a "jiffy" bag, a "jiffy" envelope, and a substantially rigid cuboid structure.

41. The system of claim 40, wherein the one or more packages comprise a fiber-based bag comprising a paper composite or polymer composite.

42. The system of claim 40, wherein the one or more packages comprise a fiber-based envelope comprising a paper composite or polymer composite.

43. The system of claim 40, wherein the one or more packages comprise a substantially rigid cuboid structure comprising a box.

44. The system of claim 1, wherein the end effector comprises a second suction cup assembly coupled to the controllably activated vacuum load.

45. The system of claim 44, wherein the second suction cup assembly defines a second inner capture chamber configured to pull into and at least partially encapsulate a portion of the targeted package when the vacuum load is controllably activated adjacent the targeted package.

46. The system of claim 1, further comprising a second imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector.

47. The system of claim 46, wherein the first computing system and second imaging device are configured to capture the one or more images such that outer dimensional bounds of the targeted package may be estimated.

48. The system of claim 47, wherein the first computing system is configured to utilize the one or more images to determine dimensional bounds of the targeted package by fitting a 3-D rectangular prism around the targeted package and estimating the L-W-H of said rectangular prism.

49. The system of claim 48, wherein the first computing system is configured to utilize the fitted 3-D rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector.

50. The system of claim 46, further comprising a third imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector.

51. The system of claim 46, wherein the second imaging device and first computing system are further configured to estimate

whether the targeted package is deformable by capturing a sequence of images of the targeted package during motion of the targeted package and analyzing deformation of the targeted package within the sequence of images.

52. The system of claim 46, wherein the first computing system and second imaging device are configured to capture and utilize the one or more images after the grasp has been conducted using the end effector to estimate whether a plurality of packages, or zero packages, have been yielded with the conducted grasp.

53. The system of claim 52, wherein the first computing system is configured to abort a grasp upon determination that a plurality of packages, or zero packages, have been yielded by the conducted grasp.

54. The system of claim 1, wherein the end effector comprises a tool switching head portion configured to controllably couple to and uncouple from the first suction cup assembly using a tool holder mounted within geometric proximity of the distal portion of the robotic arm.

55. The system of claim 54, wherein the tool holder is configured to hold and be removably coupled to one or more additional suction cup assemblies or one or more other package interfacing tools, such that the first computing device may be configured to conduct tool switching using the tool switching head portion.

56. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the place structure comprises at least one substantially planar surface and one or more extrinsic

dexterity geometric features extending away from the at least one substantially planar surface, the one or more extrinsic dexterity geometric features configured to provide counter-loading relative to movements of the targeted package via the robotic arm and end effector, to assist the robotic arm and end effector in manipulating the targeted package before the targeted package is released at the place structure.

57. The system of claim 56, wherein the one or more extrinsic dexterity geometric features are selected from the group consisting of: a protruding wall; a protruding ramp; a protruding ramp/wall; a compound ramp; a compound wall; and a compound ramp/wall.

58. The system of claim 56, wherein the one or more extrinsic dexterity geometric features comprise one or more controllably movable degrees of freedom to change shape operatively coupled to the first computing system.

59. The system of claim 56, wherein the first imaging device is configured to provide image information pertaining to the place structure, and wherein based at least in part upon the image information, the first computing system is configured to utilize a neural network to operate the robotic arm and end effector while conducting the grasp and contacting one or more aspects of the extrinsic dexterity geometric features to obtain a desired orientation of the targeted package upon release of the targeted package to the place structure.

60. The system of claim 59, wherein the neural network is trained based at least in part upon synthetic imagery

pertaining to synthetic packages and synthetic extrinsic dexterity geometric features.

61. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture stereo image information pertaining to the pick structure and one or more packages comprising pairs of images pertaining to the substantially same capture field but with different perspectives;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load

operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein before conducting the grasp, the first computing system is configured to geometrically map a three-dimensional volume around the targeted package based at least in part upon the stereo image information from the first imaging device, and analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device and informed by the stereo image information, the neural network trained at least in part using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure.

62. The system of claim 61, wherein the first imaging device is configured to provide pairs of images with different perspectives selected to provide relative depth discernment, and is based, at least in part, upon the selected distance between the first imaging device and the targeted package.

63. The system of claim 61, wherein the neural network is trained using views developed from synthetic data wherein noise has been modelled into the rendered images.

64. The system of claim 61, wherein the neural network is trained using views from real data selected to match a high-resolution imaging device sensor.

65. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

a centralized storage system configured to store event information pertaining to operations of the robotic arm, end effector, and first imaging device;

a user computing system operatively coupled to the centralized storage system;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the centralized storage system is configured to allow a user operating the user computing system to view event information pertaining to the image information from the first imaging device as well as data and meta-data pertaining to the event information through a user interface configurable by the user to facilitate sequential event viewing pertaining to operation of the robotic arm and end effector.

66. The system of claim 65, wherein the centralized storage system is configured to allow a user operating the user computing system to receive a user interface flag pertaining to an operational error, and to view an operational visual sequence pertaining to the event information associated with the operational error.

67. The system of claim 65, wherein the centralized storage system is configured to allow a user operating the user computing system to receive one or more written reports pertaining to operation of the package handling system.

68. The system of claim 67, wherein the one or more written reports may comprise elements selected from the group consisting of: operating analytics data; event logging data; sort frequency data; and integrated facility data.

69. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector;

an output distribution gantry configured to transport packages from the place structure to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the place structure, move the targeted package away from the place structure to a position adjacent

to the output container, and cause the targeted package to be dropped into the output container;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry.

70. The system of claim 69, further comprising an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated degrees of freedom.

71. The system of claim 70, wherein each of the output containers of the array is organized in a substantially co-planar configuration.

72. The system of claim 69, wherein the output distribution gantry comprises an electromechanical coupler configured to controllably couple or decouple from a selected output container.

73. The system of claim 72, wherein the electromechanical coupler comprises an output container grasper.

74. The system of claim 72, wherein the electromechanical coupler comprises an electromechanically operated hook configured to be removably coupled to a selected output container.

75. The system of claim 69, wherein the place structure is configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially orthogonal vertical configuration relative to the substantially gravity-level orientation of the place structure.

76. The system of claim 69, wherein the place structure is configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially parallel vertical configuration relative to the substantially gravity-level orientation of the place structure.

77. The system of claim 69, further comprising a barcode scanner operatively coupled to the first computing system and configured to scan one or more labels which may be present upon a targeted package.

78. The system of claim 69, wherein the place structure comprises a conveyor configured to move a targeted package toward the output distribution gantry once released by the end effector.

79. The system of claim 69, wherein the output distribution gantry is configured to controllably exit one or more contained packages utilizing a controllably-releasable door configuration.

80. The system of claim 69, wherein the output distribution gantry comprises a rail system.

81. The system of claim 69, wherein the output distribution gantry comprises a conveyor.

82. The system of claim 69, wherein the output distribution gantry is configured to controllably grasp a plurality of targeted packages at once.

83. The system of claim 69, further comprising a second output distribution gantry operatively coupled to the first output distribution gantry and configured to receive packages transferred from the first output distribution gantry.

84. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

a first scanning device operatively coupled to the first computing system and configured to scan identifiable information which may be passed within a field of view of the first scanning device;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp

comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to operate the first scanning device to capture identifying information pertaining to the targeted package by positioning and/or orienting the targeted package relative to the first scanning device such that the first scanning device field of view has geometric access to the identifiable information of the targeted package.

85. The system of claim 84, wherein the identifiable information comprises a package label.

86. The system of claim 85, wherein the package label comprises a barcode readable by the first scanning device.

87. The system of claim 84, wherein the first computing system is configured to operate the robotic arm and end effector to pass the identifiable information of the targeted package into the field of view of the first scanning device.

88. The system of claim 84, wherein the first computing system is configured to identify a location of the identifiable information on the targeted package utilizing the image information from the first imaging device.

89. The system of claim 88, wherein the first computing system is configured to reorient and examine an aspect of the targeted package that is not viewable with the first imaging device when the first computing system has failed to find the

identifiable information on the targeted package in an initial orientation relative to the first imaging device.

90. The system of claim 85, wherein the first computing system is configured to read one or more aspects of the package label using optical character recognition.

91. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the pack-out module comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically couple packages for further separate processing.

92. The system of claim 91, wherein the pack-out module comprises an element selected from the group consisting of: a ramp; a chute; a diverter; an external wrapping system; a palletizing system; a wheeled cart; and a mobile robot.

93. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to release the grasp by controllably de-activating the vacuum load with the end effector in a release position and orientation from the end effector relative to the place structure as influenced by the position and orientation of the end effector at the time of de-activating the vacuum load;

wherein the first computing system is configured to select a release position and orientation to accommodate a subsequent repositioning or reorientation of the targeted package away from the place structure.

94. The system of claim 93, wherein the subsequent repositioning or reorientation is selected from the group consisting of: a push into a container; a drag into a container; a tip-reorientation to cause a rotational fall into a container; a coupling with move to another location; and a coupling with a reorientation to another location.

95. The system of claim 93, wherein the first computing system is configured to select a release position and orientation of the targeted package based at least in part upon an additional factor of the targeted package selected from the group consisting of: a material property of the targeted package; a moment of inertia of the targeted package; dimensions of the targeted package; and location of labeling information of the targeted package.

96. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to construct and execute a motion plan for repositioning and reorienting the targeted package when coupled to the end effector in a manner that minimizes disruption of the targeted package.

97. The system of claim 96, wherein the motion plan is selected to minimize loading of the targeted package.

98. The system of claim 97, wherein the motion plan is selected to minimize angular acceleration of the targeted package.

99. The system of claim 97, wherein the motion plan is selected to minimize linear acceleration of the targeted package.

100. The system of claim 97, wherein the motion plan is selected to minimize impact loading as a result of one or more collisions with other objects.

101. The system of claim 96, wherein the motion plan is selected to minimize vibratory loading of the targeted package.

102. The system of claim 96, wherein the first computing system is configured to utilize the image information from the first imaging device to identify labeling information present on the targeted package.

103. The system of claim 102, wherein the labeling information is selected from the group consisting of: barcode information, address information, and shipping label information.

104. The system of claim 102, wherein the first computing system is configured to construct and execute the motion plan to position and orient the targeted package such that the labeling information is exposed for capture.

105. The system of claim 104, further comprising a barcode scanner, wherein the first computing system is configured to construct and execute the motion plan to position and orient the targeted package such that the labeling information is exposed for capture by the barcode scanner.

106. The system of claim 104, wherein the first computing system is configured to utilize optical character recognition to gather information from the labeling information.

107. The system of claim 96, wherein the first computing system is configured to select a release position and orientation to accommodate a subsequent repositioning or reorientation of the targeted package away from the place structure.

108. The system of claim 107, wherein the subsequent repositioning or reorientation is selected from the group consisting of: a push into a container; a tip-reorientation to cause a rotational fall into a container; a coupling with move to another location; and a coupling with a reorientation to another location.

109. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to receive loading information from the robotic arm, and to utilize the loading information and image information from the first imaging device to characterize one or more material properties of the targeted package.

110. The system of claim 109, wherein the loading information from the robotic arm comprises kinematic data pertaining to operation of the robotic arm when the end effector has been utilized to conduct a grasp of the targeted package.

111. The system of claim 109, further comprising one or more load cells operatively coupled to the robotic arm and configured to determine loads associated with operation of the robotic arm.

112. The system of claim 109, wherein the one or more material properties of the targeted package are selected from the group consisting of: moment of inertia; stability under acceleration; apparent stiffness of exterior structure; structural modulus of the targeted package.

113. The system of claim 109, wherein the first computing system is configured to subject the targeted package to a characterizing loading treatment to assist in characterizing the one or more material properties of the targeted package.

114. The system of claim 113, wherein the characterizing loading treatment comprises a relatively high-impulse load application.

115. The system of claim 113, wherein the characterizing loading treatment comprises an acceleration.

116. The system of claim 115, wherein the acceleration is rotational.

117. The system of claim 113, wherein the characterizing loading treatment comprises exposing at least a portion of the targeted package to a high-velocity stream of gas.

118. The system of claim 117, wherein the stream of gas comprises high-velocity air from an aperture.

119. The system of claim 113, wherein the first imaging device is configured to capture information pertaining to the behavior of the targeted package during the characterizing loading treatment.

120. The system of claim 113, wherein the characterizing loading treatment comprises causing the targeted package to be moved relative to another surface.

121. The system of claim 113, wherein the characterizing loading treatment comprises causing the targeted package to be re-oriented relative to another surface.

122. The system of claim 109, wherein while conducting the grasp with the robotic arm and end effector, the first computing system is configured to pass the targeted package within a field of view of the first imaging device, and wherein image information pertaining to the targeted package as it is passed within the field of view of the first imaging device is utilized by the first computing system to fit a three-dimensional rectangular prism around the targeted package and estimate three side dimensions of the three-dimensional rectangular prism.

123. The system of claim 122, wherein the first computing system is further configured to utilize the fitted three-dimensional rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector.

124. The system of claim 122, wherein first computing system is further configured to estimate the tightest possible three-dimensional rectangular prism around the targeted package.

125. The system of claim 122, wherein first computing system is further configured to construct a three-dimensional model of the targeted package.

126. The system of claim 109, wherein the first computing system is configured to utilize the image information from the first imaging device to capture barcode information from a targeted package.

127. The system of claim 126, wherein the barcode information comprises an estimate of quality of the captured barcode information from the targeted package.

128. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

a package input module operatively coupled to the first computing system and configured to provide a supply of packages to be transferred to the pick structure;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a number of the one or more packages transiently coupled to the pick structure.

129. The system of claim 128, wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon image information from the first imaging device.

130. The system of claim 128, wherein the package input module is configured to be able to automatically eject a targeted package based at least in part upon analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable.

131. The system of claim 130, wherein analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable is based upon a neural network.

132. The system of claim 131, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

133. The system of claim 130, wherein the package input module comprises a mechanical ejection element configured to controllably eject a targeted package into a separate routing to be subsequently re-processed.

134. The system of claim 133, wherein the mechanical ejection element is selected from the group consisting of: a pusher, a diverter, an arm, and a multidirectional conveyor.

135. The system of claim 133, wherein the mechanical ejection element is configured to be operated pneumatically or electromechanically.

136. The system of claim 128, wherein the first computing system is configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector.

137. The system of claim 136, wherein the first computing system is configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector based upon a neural network.

138. The system of claim 137, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

139. The system of claim 128, further comprising a second imaging device positioned and oriented to capture image information pertaining to the package input module and one or more packages.

140. The system of claim 128, wherein the first computing system is configured to utilize the image information from the first imaging device to determine whether a package jam has occurred.

141. The system of claim 140, wherein analysis by the first computing system of the image information from the first

imaging device whether a package jam has occurred is based upon a neural network.

142. The system of claim 141, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

143. The system of claim 140, wherein the first computing system is configured to send a notification to one or more users upon determination that a package jam has occurred.

144. The system of claim 140, wherein the first computing system is configured to automatically take one or more steps to resolve a package jam upon determination that a package jam has occurred.

145. The system of claim 144, wherein the one or more steps to resolve a package jam are selected from the group consisting of: applying mechanical vibration, applying a load to move one or more targeted packages, and reversing movement of one or more targeted packages.

146. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container comprised to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to estimate when the output container is at a desired level of fullness based at least in part upon an aggregated package volume determined at least in part based upon image information from

the first imaging device acquired before the plurality of the one or more packages has entered the output container.

147. The system of claim 146, wherein the computing system is configured to estimate when the output container is at a desired level of fullness based upon an additional input selected from the group consisting of: an image of the output container; a weight of the output container; a shape of the output container.

148. The system of claim 146, wherein the first imaging device is configured to capture image information pertaining to the output container.

149. The system of claim 146, wherein the computing system is configured to utilize the image information from the first imaging device in determining whether a jam has occurred.

150. The system of claim 149, wherein the computing system is configured to utilize a neural network to determine whether a jam has occurred, the neural network trained based upon imagery of one or more packages.

151. The system of claim 150, wherein the imagery of one or more packages is based at least in part upon synthetic imagery.

152. The system of claim 146, further comprising a second imaging device operatively coupled to the first computing

system and configured to capture image information pertaining to the output container.

153. The system of claim 152, wherein the computing system is configured to utilize the image information from the second imaging device in determining whether a jam has occurred.

154. The system of claim 153, wherein the computing system is configured to utilize a neural network to determine whether a jam has occurred, the neural network trained based upon imagery of one or more packages.

155. The system of claim 152, wherein the imagery of one or more packages is based at least in part upon synthetic imagery.

156. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the pack-out module comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically place packages into a transport container in a manner selected to facilitate manual unloading at a plurality of destinations.

157. The system of claim 156, wherein the pack-out module comprises an element selected from the group consisting of: a

ramp; a chute; a diverter; an external wrapping system; a palletizing system; a robotic arm; and a mobile robot.

158. The system of claim 156, wherein the transport container is a delivery truck comprising a package enclosure, and wherein the pack-out module comprises a first conveyance module configured to controllably place packages into the package enclosure to facilitate a predetermined order of manual unloading at the plurality of destinations.

159. The system of claim 156, wherein the transport container is a shipping container, and wherein the pack-out module comprises a first conveyance module configured to controllably place packages into the shipping container to facilitate a predetermined order of manual unloading at the plurality of destinations.

160. The system of claim 156, wherein the pack-out module comprises a distal portion configured to be cantilevered into an entry door of the transport container.

161. The system of claim 160, wherein the pack-out module distal portion comprises at least one local stability loading member configured to be controllably extended away from the pack-out module distal portion to be removably coupled to a portion of the transport container to stabilize the pack-out module distal portion relative to the transport container.

162. The system of claim 161, wherein the stability loading member is configured to be primarily loaded in tension.

163. The system of claim 161, wherein the stability loading member is configured to be primarily loaded in compression.

164. The system of claim 161, wherein the stability loading member is configured to be primarily loaded in bending.

165. The system of claim 156, further comprising a second imaging device configured to capture image information regarding the transport container.

166. The system of claim 165, wherein the first computing system is configured to conduct simultaneous localization and mapping pertaining to geometric features of the transport container.

167. The system of claim 165, wherein the second imaging device is coupled to the pack-out module.

168. The system of claim 156, wherein the pack-out module comprises a robotic arm configured to automatically place packages into the transport container.

169. The system of claim 168, wherein the robotic arm is coupled to a movable base to facilitate movement relative to the transport container.

170. The system of claim 169, wherein the movable base comprises an element selected from the group consisting of: an electromechanically-movable base; a manually-movable base; and a rail-constrained movable base.

171. The system of claim 156, further comprising an output buffer structure coupled between the end effector and the pack-out module, the output buffer structure configured to contain packages output from the robotic arm and associated end effector before the pack-out module is able to automatically place the packages into the transport container.

172. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the pack-out module comprises a palletizing system having one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically place packages upon a pallet base.

173. The system of claim 172, wherein the pack-out module further comprises an element selected from the group consisting of: a ramp; a chute; a diverter; a robotic arm; and a mobile robot.

174. The system of claim 172, wherein the pack out module further comprises a coupling module configured to

automatically couple packages placed upon the pallet base using an applied circumferential containment member.

175. The system of claim 172, wherein the pack-out module comprises a robotic arm configured to automatically place packages upon the pallet base.

176. The system of claim 175, wherein the robotic arm is coupled to a movable base to facilitate movement relative to the pallet base.

177. The system of claim 176, wherein the movable base comprises an element selected from the group consisting of: an electromechanically-movable base; a manually-movable base; and a rail-constrained movable base.

178. The system of claim 172, further comprising an output buffer structure coupled between the end effector and the pack-out module, the output buffer structure configured to contain packages output from the robotic arm and associated end effector before the pack-out module is able to automatically place the packages upon the pallet base.

179. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein while conducting the grasp with the robotic arm and end effector, the first computing system is configured to pass the targeted package within a field of view of the first imaging device, and wherein image information pertaining to the targeted package as it is passed within the field of view of the first imaging device is utilized by the first computing system to fit a three-dimensional rectangular prism around the

targeted package and estimate three side dimensions of the three-dimensional rectangular prism.

180. The system of claim 179, wherein the first computing system is further configured to utilize the fitted three-dimensional rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector.

181. The system of claim 179, wherein first computing system is further configured to estimate the tightest possible three-dimensional rectangular prism around the targeted package.

182. The system of claim 179, wherein first computing system is further configured to construct a three-dimensional model of the targeted package.

183. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a movable place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

an output container configured to receive packages which may be moved away from the movable place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector;

an output distribution gantry coupled to the movable place structure and configured to transport packages from the movable place structure to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the movable place structure, move the targeted package away from the end effector to a position adjacent to the output container, and cause the targeted package to be dropped into the output container;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the movable place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first

suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the output distribution gantry comprises two or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry.

184. The system of claim 183, further comprising an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the two or more controllably actuated degrees of freedom.

185. The system of claim 184, wherein each of the output containers of the array is organized in a substantially co-planar configuration.

186. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

a package input module operatively coupled to the first computing system and configured to be operated by the first computing system based at least in part upon the image information to mechanically process a plurality of incoming packages from a substantially disordered mechanical organization to provide a supply of packages to be transferred to the pick structure that is substantially singulated, and to prune away certain packages which do not become substantially singulated as a result of the mechanical process;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load.

187. The system of claim 186, wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a number of the

one or more packages transiently coupled to the pick structure.

188. 1The system of claim 186, wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon the image information pertaining to the pick structure.

189. The system of claim 186, wherein the package input module comprises one or more mechanical singulation elements configured to mechanically process and direct the substantially singulated supply of packages toward the pick structure.

190. The system of claim 189, wherein the one or more mechanical singulation elements are selected from the group consisting of: a ramp sequence; a vibratory actuator; a belt; a coordinated plurality of belts; a ball sorter conveyor; a step sequence; a chute with one or more 90-degree turns; a mechanical diverter; a vertical mechanical filter; and a horizontal mechanical filter.

191. The system of claim 186, wherein the package input module is configured to be operated by the first computing system to prune away certain packages which do not become substantially singulated as a result of the mechanical process using a diversion element configured to selectably divert one or more targeted packages.

192. The system of claim 191, wherein the diversion element is a mechanical diverter.

193. The system of claim 191, wherein the diversion element is a diversion conveyor.

194. The system of claim 186, wherein the package input module is operatively coupled to the first computing system and configured to be operated by the first computing system based at least in part upon the image information to mechanically process a plurality of incoming packages from a substantially disordered mechanical organization to provide a supply of packages to be transferred to the pick structure that is substantially singulated, to prune away certain packages which do not become substantially singulated as a result of the mechanical process, and to move toward singulation certain packages based upon the image information.

195. The system of claim 194, wherein the first computing system may be configured to move the certain packages toward singulation using one or more mechanical singulation elements configured to mechanically process these certain packages.

196. The system of claim 195, wherein the one or more mechanical singulation elements are selected from the group consisting of: a ramp sequence; a vibratory actuator; a belt; a coordinated plurality of belts; a ball sorter conveyor; a step sequence; a chute with one or more 90-degree turns; a mechanical diverter; a vertical mechanical filter; and a horizontal mechanical filter.

197. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

a package input module operatively coupled to the first computing system and configured to provide a supply of packages to be transferred to the pick structure;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp

comprises engaging the targeted package and controllably activating the vacuum load;

wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a rate at which the robotic arm and end effector are able to conduct a grasp from the pick structure and release a targeted package at the place structure.

198. The system of claim 197, wherein the first computing system is configured to substantially match the rate at which the robotic arm and end effector are able to conduct a grasp from the pick structure and release a targeted package at the place structure with a supply rate provided to the pick structure by the package input module.

199. The system of claim 197, wherein the package input module is configured to be able to automatically eject a targeted package based at least in part upon analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable.

200. The system of claim 199, wherein analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable is based upon a neural network.

201. The system of claim 200, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

202. The system of claim 199, wherein the package input module comprises a mechanical ejection element configured to controllably eject a targeted package into a separate routing to be subsequently re-processed.

203. The system of claim 202, wherein the mechanical ejection element is selected from the group consisting of: a pusher, a diverter, an arm, and a multidirectional conveyor.

204. The system of claim 202, wherein the mechanical ejection element is configured to be operated pneumatically or electromechanically.

205. The system of claim 197, wherein the first computing system is configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector.

206. The system of claim 205, wherein the first computing system is configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector based upon a neural network.

207. The system of claim 206, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

208. The system of claim 197, further comprising a second imaging device positioned and oriented to capture image information pertaining to the package input module and one or more packages.

209. The system of claim 197, wherein the first computing system is configured to utilize the image information from the first imaging device to determine whether a package jam has occurred.

210. The system of claim 209, wherein analysis by the first computing system of the image information from the first imaging device whether a package jam has occurred is based upon a neural network.

211. The system of claim 210, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

212. The system of claim 209, wherein the first computing system is configured to send a notification to one or more users upon determination that a package jam has occurred.

213. The system of claim 209, wherein the first computing system is configured to automatically take one or more steps to resolve a package jam upon determination that a package jam has occurred.

214. The system of claim 213, wherein the one or more steps to resolve a package jam are selected from the group consisting of: applying mechanical vibration, applying a load to move one or more targeted packages, and reversing movement of one or more targeted packages.

215. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

a second imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the one or more packages from a second perspective that differs from a first perspective of the first imaging device;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to utilize image information from the first imaging device and second imaging device in a sensor fusion configuration to estimate external dimensions of the targeted package.

216. The system of claim 215, wherein the first and second perspectives are substantially orthogonal.

217. The system of claim 215, wherein the first and second perspectives are substantially opposite.

218. The system of claim 215, wherein the first imaging device has a measurement error pertaining to the targeted package that is substantially uncorrelated relative to a measurement error that the second imaging device has pertaining to the targeted package.

219. The system of claim 215, further comprising a third imaging device operatively coupled to the first computing

system and configured to capture image information pertaining to the one or more packages from a third perspective that differs from the first perspective of the first imaging device or the second perspective of the second imaging device.

220. The system of claim 215, wherein the first computing system is configured to utilize the image information from the first imaging device and second imaging device to construct a three-dimensional model of the one or more packages.

221. The system of claim 215, wherein the first computing system is configured to utilize the image information from the first imaging device and second imaging device to estimate one or more material properties of a targeted package.

222. The system of claim 215, wherein the one or more material properties of a targeted package are selected from the group consisting of: package stiffness, package bulk modulus, package rigidity, package exterior compliance, and estimated looseness of exterior package material.

223. The system of claim 222, wherein the first computing system is configured to utilize a neural network to estimate the one or more material properties, the neural network trained utilizing imagery pertaining to a package exterior training dataset.

224. The system of claim 223, wherein the imagery is based at least in part upon synthetic imagery.

225. The system of claim 215, wherein the first computing system is configured to utilize the image information from the first imaging device and second imaging device to estimate a quality control variable pertaining to one or more targeted packages selected from the group consisting of: existence of package damage, existence of multiple packages bound together, and whether the end effector has successfully conducted a grasp.

226. The system of claim 225, wherein the first computing system is configured to utilize a neural network to estimate the quality control variable, the neural network trained utilizing imagery pertaining to a package exterior training dataset.

227. The system of claim 226, wherein the imagery is based at least in part upon synthetic imagery.

228. A robotic package handling system, comprising:

a package input module configured to move a plurality of incoming packages in a primary advancement direction along a conveyance platform while also being configured to selectably move one or more targeted packages from the plurality away from the conveyance platform;

a first imaging device positioned and oriented to capture image information pertaining to the conveyance platform and plurality of incoming packages;

a first computing system operatively coupled to the package input module and the first imaging device, and configured to receive the image information from the first imaging device

and command movements of package input module based at least in part upon the image information;

an output container configured to receive packages which may be moved away from the conveyance platform, the output container configured to at least temporarily contain a plurality of the one or more packages from the conveyance platform as they are moved by operation of the first computing system and package input module;

an output distribution gantry configured to transport packages from the conveyance platform to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been moved from the conveyance platform to a position adjacent to the output container, and cause the targeted package to be dropped into the output container;

wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the package input module and output distribution gantry.

229. The system of claim 228, further comprising an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated degrees of freedom.

230. The system of claim 229, wherein each of the output containers of the array is organized in a substantially co-planar configuration.

231. The system of claim 228, wherein the package input module comprises a bi-directional conveyor.

232. The system of claim 228, wherein the package input module comprises an omnidirectional ball sorter conveyor.

233. The system of claim 228, wherein the package input module comprises a mechanical diverter configured to selectably move one or more targeted packages from the plurality away from the conveyance platform.

234. The system of claim 228, further comprising a guiding structure operatively coupled between the package input module and output distribution gantry, the guiding structure configured to mechanically guide the one or more targeted packages from the plurality away from the conveyance platform and to the output distribution gantry.

235. The system of claim 234, wherein the guiding structure comprises an element selected from the group consisting of: a chute, a ramp, a funnel, and a conveyor.

236. The system of claim 228, wherein the output distribution gantry is configured to be able to controllably removably

couple to a selected output container and to remove the selected output container from the output distribution gantry.

237. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector;

an output distribution gantry configured to transport packages from the place structure to the output container, the output distribution gantry configured to transiently couple to a

targeted package which has been released by the robotic arm and end effector upon the place structure, move the targeted package away from the place structure to a position adjacent to the output container, and cause the targeted package to be dropped into the output container;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry; and

wherein the output distribution gantry is configured to be able to controllably removably couple to a selected output container and to remove the selected output container from the output distribution gantry.

238. The system of claim 237, further comprising an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of

the output containers of the array through utilization of the one or more controllably actuated degrees of freedom.

239. The system of claim 238, wherein each of the output containers of the array is organized in a substantially co-planar configuration.

240. The system of claim 237, wherein the output distribution gantry comprises an electromechanical coupler configured to controllably couple or decouple from a selected output container.

241. The system of claim 240, wherein the electromechanical coupler comprises an output container grasper.

242. The system of claim 240, wherein the electromechanical coupler comprises an electromechanically operated hook configured to be removably coupled to a selected output container.

243. The system of claim 237, wherein the place structure is configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially orthogonal vertical configuration relative to the substantially gravity-level orientation of the place structure.

244. The system of claim 237, wherein the place structure is configured to have at least one surface having a substantially

gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially parallel vertical configuration relative to the substantially gravity-level orientation of the place structure.

245. The system of claim 237, further comprising a barcode scanner operatively coupled to the first computing system and configured to scan one or more labels which may be present upon a targeted package.

246. The system of claim 237, wherein the place structure comprises a conveyor configured to move a targeted package toward the output distribution gantry once released by the end effector.

247. The system of claim 237, wherein the output distribution gantry is configured to controllably exit one or more contained packages utilizing a controllably-releasable door configuration.

248. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first suction cup assembly defines a first inner capture chamber configured such that conducting the grasp of the targeted package comprises pulling into and at least partially encapsulating a portion of the targeted package with the first inner capture chamber when the vacuum load is controllably activated adjacent the targeted package.

249. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first suction cup assembly defines a first inner chamber, a first outer sealing lip, and a first vacuum-permeable distal wall member which are collectively configured

such that upon conducting the grasp of the targeted package with the vacuum load controllably actuated, the outer sealing lip may become removably coupled to at least one surface of the targeted package, while the vacuum-permeable distal wall member prevents over-protrusion of said surface o the targeted package into the inner chamber of the suction cup assembly.

250. A system, comprising:

a robotic pick-and-place machine comprising an actuation system and a changeable end effector system configured to facilitate selection and switching between a plurality of end effector heads;

a sensing system; and

a grasp planning processing pipeline used in control of the robotic pick-and-place machine.

251. The system of claim 250, wherein the changeable end effector system comprises a head selector integrated into a distal end of the actuation system, a set of end effector heads, and a head holding device, wherein the head selector attaches with one of the sets of end effector heads at a respective attachment face.

252. The system of claim 250, wherein the changeable end effector system further comprises at least one magnet circumscribing a center of one of the head selector or end effector head to supply initial seating and holding of the end effector head.

253. The system of claim 252, wherein at least one of the head selector or each of the set of end effector heads comprise a seal positioned along an outer edge of a respective attachment face.

254. The system of claim 251, wherein the head selector and the set of end effector heads comprise complimentary registration structures.

255. The system of claim 251, wherein the head selector and the set of end effector heads comprise a lateral support structure geometry selected to assist with grasping a compliant package.

256. The system of claim 251, wherein the set of end effector heads comprise a set of suction end effectors.

257. The system of claim 251, wherein the actuation system comprises an articulated arm.

258. A robotic package handling system, comprising:

a robotic arm comprising a distal portion and a proximal base portion;

an end effector coupled to the distal portion of the robotic arm;

a place structure in geometric proximity to the distal portion of the robotic arm;

a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm;

a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages;

a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the end effector is coupled to the distal portion of the robotic arm using a spring-biased end effector coupling assembly comprising a spring member configured to provide an engagement compliance when conducting the grasp between the end effector and the targeted package.

259. The system of claim 258, wherein the spring member is configured to have a prescribed spring constant selected to provide the engagement compliance.

260. The system of claim 258, wherein the spring-biased end effector coupling assembly comprises an insertion axis constraining member configured to facilitate spring-biased insertion of the spring-biased end effector coupling assembly along an axis prescribed by the axis constraining member.

261. The system of claim 260, wherein the axis constraining member comprises a linear bearing assembly configured to facilitate movement along a single axis of motion.

262. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure in geometric proximity to the distal portion of the robotic arm, a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein before conducting the grasp, the first computing system is configured to analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device, the neural network trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure.

263. The method of claim 262, wherein the first computing system is further configured to analyze the plurality of candidate grasps based a continuous learning configuration of the neural network wherein data from a set of known and actual experiences is utilized to further train the neural network.

264. The method of claim 263, wherein the set of known and actual experiences is based upon prior operation of the particular robotic arm of the system.

265. The method of claim 263, wherein the set of known and actual experiences is based upon prior operation of a different robotic arm similar to the particular robotic arm of the system.

266. The method of claim 265, wherein the different robotic arm similar to the particular robotic arm of the system is substantially identical to the particular robotic arm of the system.

267. The method of claim 262, wherein the first computing system is configured to analyze the plurality of candidate grasps based upon a kinematic reach of the robotic arm and end effector.

268. The method of claim 262, wherein the first computing system is configured to analyze the plurality of candidate grasps based upon a location of labeling information of the targeted package based upon the image information from the first imaging device.

269. The method of claim 268, wherein the first computing system is configured to analyze the plurality of candidate grasps based upon a location of barcode labeling information of the targeted package based upon the image information from the first imaging device.

270. The method of claim 269, wherein the first computing system is configured to analyze the plurality of candidate grasps based upon a location of labeling information of the targeted package based upon the image information from the first imaging device, and to select an execution grasp that does not have the end effector covering the barcode labeling information.

271. The method of claim 262, further comprising a frame structure configured to fixedly couple the robotic arm to the place structure.

272. The method of claim 271, wherein the pick structure is removably coupled to the frame structure.

273. The method of claim 262, wherein the place structure comprises a placement tray.

274. The method of claim 273, wherein the placement tray comprises first and second rotatably coupled members, the first and second rotatably coupled members being configured to form a substantially flat tray base surface when in a first rotated configuration relative to each other, and to form a lifting fork configuration when in a second rotated configuration relative to each other.

275. The method of claim 273, wherein the placement tray is operatively coupled to one or more actuators configured to controllably change an orientation of at least a portion of the placement tray, the one or more actuators being operatively coupled to the first computing system.

276. The method of claim 262, wherein the pick structure comprises an element selected from the group consisting of: a bin, a tray, a fixed surface, and a movable surface.

277. The method of claim 276, wherein the pick structure comprises a bin configured to define a package containment volume bounded by a bottom and a plurality of walls, as well as an open access aperture configured to accommodate entry and egress of at least the distal portion of the robotic arm.

278. The method of claim 277, wherein the first imaging device is configured to capture the image information pertaining to the pick structure and one or more packages through the open access aperture.

279. The method of claim 277, wherein the first imaging device comprises a depth camera.

280. The method of claim 262, wherein the first imaging device is configured to capture color image data.

281. The method of claim 271, wherein the first computing system comprises a VLSI computer operatively coupled to the frame structure.

282. The method of claim 262, wherein the first computing system comprises a network of intercoupled computing devices, at least one of which is remotely located relative to the robotic arm.

283. The method of claim 262, further comprising a second computing system operatively coupled to the first computing system.

284. The method of claim 283, wherein the second computing system is remotely located relative to the first computing system, and the first and second computing systems are operatively coupled via a computer network.

285. The method of claim 262, wherein the first computing system is configured such that conducting the grasp comprises analyzing a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure.

286. The method of claim 285, wherein analyzing a plurality of candidate grasps comprises examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package.

287. The method of claim 286, wherein analyzing a plurality of candidate grasps comprises examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach orientations.

288. The method of claim 286, wherein analyzing a plurality of candidate grasps comprises examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package from a plurality of different end effector approach positions.

289. The method of claim 286, wherein the first suction cup assembly comprises a first outer sealing lip, and wherein a sealing engagement with a surface comprises a substantially complete engagement of the first outer sealing lip with the surface.

290. The method of claim 286, wherein examining locations on the targeted package where the first suction cup assembly is predicted to be able to form a sealing engagement with a surface of the targeted package is conducted in a purely geometric fashion.

291. The method of claim 285, wherein the first computing system is configured to select the execution grasp based upon a candidate grasps factor selected from the group consisting of: estimated time required; estimated computation required; and estimated success of grasp.

292. The method of claim 262, wherein the first suction cup assembly comprises a bellows structure.

293. The method of claim 292, wherein the bellows structure comprises a plurality of wall portions adjacently coupled with bending margins.

294. The method of claim 293, wherein the bellows structure comprises a material selected from the group consisting of: polyethylene, polypropylene, rubber, and thermoplastic elastomer.

295. The method of claim 262, wherein the first suction cup assembly comprises an outer housing and an internal structure coupled thereto.

296. The method of claim 295, wherein the internal structure of the first suction cup assembly comprises a wall member coupled to a proximal base member.

297. The method of claim 296, wherein the wall member comprises a substantially cylindrical shape having proximal and distal ends, and wherein the proximal base member forms a substantially circular interface with the proximal end of the wall member.

298. The method of claim 296, wherein the proximal base member defines one or more inlet apertures therethrough, the one or more inlet apertures being configured to allow air flow therethrough in accordance with activation of the controllably activated vacuum load.

299. The method of claim 298, wherein the internal structure further comprises a distal wall member comprising a structural aperture ring portion configured to define access to the inner capture chamber, as well as one or more transitional air channels configured to allow air flow therethrough in accordance with activation of the controllably activated vacuum load.

300. The method of claim 299, wherein the one or more inlet apertures and the one or more transitional air channels function to allow a prescribed flow of air through the capture chamber to facilitate releasable coupling of the first suction cup assembly with the targeted package.

301. The method of claim 262, wherein the one or more packages are selected from the group consisting of: a bag, a "poly bag", a "poly", a fiber-based bag, a fiber-based envelope, a bubble-wrap bag, a bubble-wrap envelope, a "jiffy" bag, a "jiffy" envelope, and a substantially rigid cuboid structure.

302. The method of claim 301, wherein the one or more packages comprise a fiber-based bag comprising a paper composite or polymer composite.

303. The method of claim 301, wherein the one or more packages comprise a fiber-based envelope comprising a paper composite or polymer composite.

304. The method of claim 301, wherein the one or more packages comprise a substantially rigid cuboid structure comprising a box.

305. The method of claim 262, wherein the end effector comprises a second suction cup assembly coupled to the controllably activated vacuum load.

306. The method of claim 305, wherein the second suction cup assembly defines a second inner capture chamber configured to pull into and at least partially encapsulate a portion of the targeted package when the vacuum load is controllably activated adjacent the targeted package.

307. The method of claim 262, further comprising a second imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector.

308. The method of claim 307, wherein the first computing system and second imaging device are configured to capture the one or more images such that outer dimensional bounds of the targeted package may be estimated.

309. The method of claim 308, wherein the first computing system is configured to utilize the one or more images to determine dimensional bounds of the targeted package by fitting a 3-D rectangular prism around the targeted package and estimating the L-W-H of said rectangular prism.

310. The method of claim 309, wherein the first computing system is configured to utilize the fitted 3-D rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector.

311. The method of claim 307, further comprising a third imaging device operatively coupled to the first computing

system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector.

312. The method of claim 307, wherein the second imaging device and first computing system are further configured to estimate whether the targeted package is deformable by capturing a sequence of images of the targeted package during motion of the targeted package and analyzing deformation of the targeted package within the sequence of images.

313. The method of claim 307, wherein the first computing system and second imaging device are configured to capture and utilize the one or more images after the grasp has been conducted using the end effector to estimate whether a plurality of packages, or zero packages, have been yielded with the conducted grasp.

314. The method of claim 313, wherein the first computing system is configured to abort a grasp upon determination that a plurality of packages, or zero packages, have been yielded by the conducted grasp.

315. The method of claim 262, wherein the end effector comprises a tool switching head portion configured to controllably couple to and uncouple from the first suction cup assembly using a tool holder mounted within geometric proximity of the distal portion of the robotic arm.

316. The method of claim 315, wherein the tool holder is configured to hold and be removably coupled to one or more additional suction cup assemblies or one or more other package interfacing tools, such that the first computing device may be configured to conduct tool switching using the tool switching head portion.

317. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the place structure comprises at least one substantially planar surface and one or more extrinsic dexterity geometric features extending away from the at least one substantially planar surface, the one or more extrinsic dexterity geometric features configured to provide counter-loading relative to movements of the targeted package via the robotic arm and end effector, to assist the robotic arm and end effector in manipulating the targeted package before the targeted package is released at the place structure.

318. The method of claim 317, wherein the one or more extrinsic dexterity geometric features are selected from the group consisting of: a protruding wall; a protruding ramp; a protruding ramp/wall; a compound ramp; a compound wall; and a compound ramp/wall.

319. The method of claim 317, wherein the one or more extrinsic dexterity geometric features comprise one or more controllably movable degrees of freedom to change shape operatively coupled to the first computing system.

320. The method of claim 317, wherein the first imaging device is configured to provide image information pertaining to the place structure, and wherein based at least in part upon the image information, the first computing system is configured to utilize a neural network to operate the robotic arm and end effector while conducting the grasp and contacting one or more aspects of the extrinsic dexterity geometric features to obtain a desired orientation of the targeted package upon release of the targeted package to the place structure.

321. The method of claim 320, wherein the neural network is trained based at least in part upon synthetic imagery pertaining to synthetic packages and synthetic extrinsic dexterity geometric features.

322. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture stereo image information pertaining to the pick structure and one or more packages comprising pairs of images pertaining to the substantially same capture field but with different perspectives; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein before conducting the grasp, the first computing system is configured to geometrically map a three-dimensional volume around the targeted package based at least in part upon the stereo image information from the first imaging device, and analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device and informed by the stereo image information, the neural network trained at least in part using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure.

323. The method of claim 322, wherein the first imaging device is configured to provide pairs of images with different perspectives selected to provide relative depth discernment, and is based, at least in part, upon the selected distance between the first imaging device and the targeted package.

324. The method of claim 322, wherein the neural network is trained using views developed from synthetic data wherein noise has been modelled into the rendered images.

325. The method of claim 322, wherein the neural network is trained using views from real data selected to match a high-resolution imaging device sensor.

326. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal

portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; a centralized storage system configured to store event information pertaining to operations of the robotic arm, end effector, and first imaging device; and a user computing system operatively coupled to the centralized storage system;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the centralized storage system is configured to allow a user operating the user computing system to view event information pertaining to the image information from the first imaging device as well as data and meta-data pertaining to the event information through a user interface configurable by the user to facilitate sequential event viewing pertaining to operation of the robotic arm and end effector.

327. The method of claim 326, wherein the centralized storage system is configured to allow a user operating the user computing system to receive a user interface flag pertaining to an operational error, and to view an operational visual sequence pertaining to the event information associated with the operational error.

328. The method of claim 326, wherein the centralized storage system is configured to allow a user operating the user computing system to receive one or more written reports pertaining to operation of the package handling system.

329. The method of claim 328, wherein the one or more written reports may comprise elements selected from the group consisting of: operating analytics data; event logging data; sort frequency data; and integrated facility data.

330. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based

at least in part upon the image information; an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; and an output distribution gantry configured to transport packages from the place structure to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the place structure, move the targeted package away from the place structure to a position adjacent to the output container, and cause the targeted package to be dropped into the output container;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry.

331. The method of claim 330, further comprising an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated degrees of freedom.

332. The method of claim 331, wherein each of the output containers of the array is organized in a substantially co-planar configuration.

333. The method of claim 330, wherein the output distribution gantry comprises an electromechanical coupler configured to controllably couple or decouple from a selected output container.

334. The method of claim 333, wherein the electromechanical coupler comprises an output container grasper.

335. The method of claim 333, wherein the electromechanical coupler comprises an electromechanically operated hook configured to be removably coupled to a selected output container.

336. The method of claim 330, wherein the place structure is configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially orthogonal vertical configuration relative to the substantially gravity-level orientation of the place structure.

337. The method of claim 330, wherein the place structure is configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially parallel vertical configuration relative to the substantially gravity-level orientation of the place structure.

338. The method of claim 330, further comprising a barcode scanner operatively coupled to the first computing system and configured to scan one or more labels which may be present upon a targeted package.

339. The method of claim 330, wherein the place structure comprises a conveyor configured to move a targeted package toward the output distribution gantry once released by the end effector.

340. The method of claim 330, wherein the output distribution gantry is configured to controllably exit one or more contained packages utilizing a controllably-releasable door configuration.

341. The method of claim 330, wherein the output distribution gantry comprises a rail system.

342. The method of claim 330, wherein the output distribution gantry comprises a conveyor.

343. The method of claim 330, wherein the output distribution gantry is configured to controllably grasp a plurality of targeted packages at once.

344. The method of claim 330, further comprising a second output distribution gantry operatively coupled to the first output distribution gantry and configured to receive packages transferred from the first output distribution gantry.

345. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a first scanning device operatively coupled to the first computing system and configured to scan identifiable information which may be passed within a field of view of the first scanning device;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to operate the first scanning device to capture identifying information pertaining to the targeted package by positioning and/or orienting the targeted package relative to the first scanning device such that the first scanning device field of view has geometric access to the identifiable information of the targeted package.

346. The method of claim 345, wherein the identifiable information comprises a package label.

347. The method of claim 346, wherein the package label comprises a barcode readable by the first scanning device.

348. The method of claim 345, wherein the first computing system is configured to operate the robotic arm and end effector to pass the identifiable information of the targeted package into the field of view of the first scanning device.

349. The method of claim 345, wherein the first computing system is configured to identify a location of the identifiable information on the targeted package utilizing the image information from the first imaging device.

350. The method of claim 349, wherein the first computing system is configured to reorient and examine an aspect of the targeted package that is not viewable with the first imaging device when the first computing system has failed to find the identifiable information on the targeted package in an initial orientation relative to the first imaging device.

351. The method of claim 346, wherein the first computing system is configured to read one or more aspects of the package label using optical character recognition.

352. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a

targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the pack-out module comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically couple packages for further separate processing.

353. The method of claim 352, wherein the pack-out module comprises an element selected from the group consisting of: a ramp; a chute; a diverter; an external wrapping system; a palletizing system; a wheeled cart; and a mobile robot.

354. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing

system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to release the grasp by controllably de-activating the vacuum load with the end effector in a release position and orientation from the end effector relative to the place structure as influenced by the position and orientation of the end effector at the time of de-activating the vacuum load;

wherein the first computing system is configured to select a release position and orientation to accommodate a subsequent repositioning or reorientation of the targeted package away from the place structure.

355. The method of claim 354, wherein the subsequent repositioning or reorientation is selected from the group consisting of: a push into a container; a drag into a container; a tip-reorientation to cause a rotational fall

into a container; a coupling with move to another location; and a coupling with a reorientation to another location.

356. The method of claim 354, wherein the first computing system is configured to select a release position and orientation of the targeted package based at least in part upon an additional factor of the targeted package selected from the group consisting of: a material property of the targeted package; a moment of inertia of the targeted package; dimensions of the targeted package; and location of labeling information of the targeted package.

357. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to construct and execute a motion plan for repositioning and reorienting the targeted package when coupled to the end effector in a manner that minimizes disruption of the targeted package.

358. The method of claim 357, wherein the motion plan is selected to minimize loading of the targeted package.

359. The method of claim 358, wherein the motion plan is selected to minimize angular acceleration of the targeted package.

360. The method of claim 358, wherein the motion plan is selected to minimize linear acceleration of the targeted package.

361. The method of claim 358, wherein the motion plan is selected to minimize impact loading as a result of one or more collisions with other objects.

362. The method of claim 357, wherein the motion plan is selected to minimize vibratory loading of the targeted package.

363. The method of claim 357, wherein the first computing system is configured to utilize the image information from the first imaging device to identify labeling information present on the targeted package.

364. The method of claim 363, wherein the labeling information is selected from the group consisting of: barcode information, address information, and shipping label information.

365. The method of claim 363, wherein the first computing system is configured to construct and execute the motion plan to position and orient the targeted package such that the labeling information is exposed for capture.

366. The method of claim 365, further comprising a barcode scanner, wherein the first computing system is configured to construct and execute the motion plan to position and orient the targeted package such that the labeling information is exposed for capture by the barcode scanner.

367. The method of claim 365, wherein the first computing system is configured to utilize optical character recognition to gather information from the labeling information.

368. The method of claim 357, wherein the first computing system is configured to select a release position and orientation to accommodate a subsequent repositioning or

reorientation of the targeted package away from the place structure.

369. The method of claim 368, wherein the subsequent repositioning or reorientation is selected from the group consisting of: a push into a container; a tip-reorientation to cause a rotational fall into a container; a coupling with move to another location; and a coupling with a reorientation to another location.

370. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load

operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to receive loading information from the robotic arm, and to utilize the loading information and image information from the first imaging device to characterize one or more material properties of the targeted package.

371. The method of claim 370, wherein the loading information from the robotic arm comprises kinematic data pertaining to operation of the robotic arm when the end effector has been utilized to conduct a grasp of the targeted package.

372. The method of claim 370, further comprising one or more load cells operatively coupled to the robotic arm and configured to determine loads associated with operation of the robotic arm.

373. The method of claim 370, wherein the one or more material properties of the targeted package are selected from the group consisting of: moment of inertia; stability under acceleration; apparent stiffness of exterior structure; structural modulus of the targeted package.

374. The method of claim 373, wherein the first computing system is configured to subject the targeted package to a characterizing loading treatment to assist in characterizing the one or more material properties of the targeted package.

375. The method of claim 374, wherein the characterizing loading treatment comprises a relatively high-impulse load application.

376. The method of claim 374, wherein the characterizing loading treatment comprises an acceleration.

377. The method of claim 376, wherein the acceleration is rotational.

378. The method of claim 374, wherein the characterizing loading treatment comprises exposing at least a portion of the targeted package to a high-velocity stream of gas.

379. The method of claim 378, wherein the stream of gas comprises high-velocity air from an aperture.

380. The method of claim 374, wherein the first imaging device is configured to capture information pertaining to the behavior of the targeted package during the characterizing loading treatment.

381. The method of claim 374, wherein the characterizing loading treatment comprises causing the targeted package to be moved relative to another surface.

382. The method of claim 374, wherein the characterizing loading treatment comprises causing the targeted package to be re-oriented relative to another surface.

383. The method of claim 370, wherein while conducting the grasp with the robotic arm and end effector, the first computing system is configured to pass the targeted package within a field of view of the first imaging device, and wherein image information pertaining to the targeted package as it is passed within the field of view of the first imaging device is utilized by the first computing system to fit a three-dimensional rectangular prism around the targeted package and estimate three side dimensions of the three-dimensional rectangular prism.

384. The method of claim 383, wherein the first computing system is further configured to utilize the fitted three-dimensional rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector.

385. The method of claim 383, wherein first computing system is further configured to estimate the tightest possible three-dimensional rectangular prism around the targeted package.

386. The method of claim 383, wherein first computing system is further configured to construct a three-dimensional model of the targeted package.

387. The method of claim 370, wherein the first computing system is configured to utilize the image information from the first imaging device to capture barcode information from a targeted package.

388. The method of claim 387, wherein the barcode information comprises an estimate of quality of the captured barcode information from the targeted package.

389. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a package input module operatively coupled to the first computing system and configured to provide a supply of packages to be transferred to the pick structure;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a number of the one or more packages transiently coupled to the pick structure.

390. The method of claim 389, wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon image information from the first imaging device.

391. The method of claim 389, wherein the package input module is configured to be able to automatically eject a targeted package based at least in part upon analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable.

392. The method of claim 391, wherein analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable is based upon a neural network.

393. The method of claim 392, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

394. The method of claim 391, wherein the package input module comprises a mechanical ejection element configured to controllably eject a targeted package into a separate routing to be subsequently re-processed.

395. The method of claim 394, wherein the mechanical ejection element is selected from the group consisting of: a pusher, a diverter, an arm, and a multidirectional conveyor.

396. The method of claim 394, wherein the mechanical ejection element is configured to be operated pneumatically or electromechanically.

397. The method of claim 389, wherein the first computing system is configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector.

398. The method of claim 397, wherein the first computing system is configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector based upon a neural network.

399. The method of claim 398, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

400. The method of claim 389, further comprising a second imaging device positioned and oriented to capture image information pertaining to the package input module and one or more packages.

401. The method of claim 389, wherein the first computing system is configured to utilize the image information from the first imaging device to determine whether a package jam has occurred.

402. The method of claim 401, wherein analysis by the first computing system of the image information from the first imaging device whether a package jam has occurred is based upon a neural network.

403. The method of claim 402, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

404. The method of claim 401, wherein the first computing system is configured to send a notification to one or more users upon determination that a package jam has occurred.

405. The method of claim 401, wherein the first computing system is configured to automatically take one or more steps to resolve a package jam upon determination that a package jam has occurred.

406. The method of claim 405, wherein the one or more steps to resolve a package jam are selected from the group consisting of: applying mechanical vibration, applying a load to move one or more targeted packages, and reversing movement of one or more targeted packages.

407. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container comprised to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to estimate when the output container is at a desired level of fullness based at least in part upon an aggregated package volume determined at least in part based upon image information from the first imaging device acquired before the plurality of the one or more packages has entered the output container.

408. The method of claim 407, wherein the computing system is configured to estimate when the output container is at a desired level of fullness based upon an additional input selected from the group consisting of: an image of the output container; a weight of the output container; a shape of the output container.

409. The method of claim 407, wherein the first imaging device is configured to capture image information pertaining to the output container.

410. The method of claim 407, wherein the computing system is configured to utilize the image information from the first imaging device in determining whether a jam has occurred.

411. The method of claim 410, wherein the computing system is configured to utilize a neural network to determine whether a

jam has occurred, the neural network trained based upon imagery of one or more packages.

412. The method of claim 411, wherein the imagery of one or more packages is based at least in part upon synthetic imagery.

413. The method of claim 407, further comprising a second imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the output container.

414. The method of claim 413, wherein the computing system is configured to utilize the image information from the second imaging device in determining whether a jam has occurred.

415. The method of claim 414, wherein the computing system is configured to utilize a neural network to determine whether a jam has occurred, the neural network trained based upon imagery of one or more packages.

416. The method of claim 413, wherein the imagery of one or more packages is based at least in part upon synthetic imagery.

417. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric

proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a pack-out module configured to receive packages which may be moved away from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the pack-out module comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically place packages into a transport container in a manner selected to facilitate manual unloading at a plurality of destinations.

418. The method of claim 417, wherein the pack-out module comprises an element selected from the group consisting of: a ramp; a chute; a diverter; an external wrapping system; a palletizing system; a robotic arm; and a mobile robot.

419. The method of claim 417, wherein the transport container is a delivery truck comprising a package enclosure, and wherein the pack-out module comprises a first conveyance module configured to controllably place packages into the package enclosure to facilitate a predetermined order of manual unloading at the plurality of destinations.

420. The method of claim 417, wherein the transport container is a shipping container, and wherein the pack-out module comprises a first conveyance module configured to controllably place packages into the shipping container to facilitate a predetermined order of manual unloading at the plurality of destinations.

421. The method of claim 417, wherein the pack-out module comprises a distal portion configured to be cantilevered into an entry door of the transport container.

422. The method of claim 421, wherein the pack-out module distal portion comprises at least one local stability loading member configured to be controllably extended away from the pack-out module distal portion to be removably coupled to a portion of the transport container to stabilize the pack-out module distal portion relative to the transport container.

423. The method of claim 422, wherein the stability loading member is configured to be primarily loaded in tension.

424. The method of claim 422, wherein the stability loading member is configured to be primarily loaded in compression.

425. The method of claim 422, wherein the stability loading member is configured to be primarily loaded in bending.

426. The method of claim 417, further comprising a second imaging device configured to capture image information regarding the transport container.

427. The method of claim 426, wherein the first computing system is configured to conduct simultaneous localization and mapping pertaining to geometric features of the transport container.

428. The method of claim 426, wherein the second imaging device is coupled to the pack-out module.

429. The method of claim 417, wherein the pack-out module comprises a robotic arm configured to automatically place packages into the transport container.

430. The method of claim 429, wherein the robotic arm is coupled to a movable base to facilitate movement relative to the transport container.

431. The method of claim 430, wherein the movable base comprises an element selected from the group consisting of: an electromechanically-movable base; a manually-movable base; and a rail-constrained movable base.

432. The method of claim 417, further comprising an output buffer structure coupled between the end effector and the pack-out module, the output buffer structure configured to contain packages output from the robotic arm and associated end effector before the pack-out module is able to automatically place the packages into the transport container.

433. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a pack-out module configured to receive packages which may be moved away

from the place structure after release from the end effector, automatically transport them away from proximity of the robotic arm, and automatically prepare them for further separate processing;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the pack-out module comprises a palletizing system having one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and pack-out module to automatically place packages upon a pallet base.

434. The method of claim 433, wherein the pack-out module further comprises an element selected from the group consisting of: a ramp; a chute; a diverter; a robotic arm; and a mobile robot.

435. The method of claim 433, wherein the pack out module further comprises a coupling module configured to automatically couple packages placed upon the pallet base using an applied circumferential containment member.

436. The method of claim 433, wherein the pack-out module comprises a robotic arm configured to automatically place packages upon the pallet base.

437. The method of claim 436, wherein the robotic arm is coupled to a movable base to facilitate movement relative to the pallet base.

438. The method of claim 437, wherein the movable base comprises an element selected from the group consisting of: an electromechanically-movable base; a manually-movable base; and a rail-constrained movable base.

439. The method of claim 433, further comprising an output buffer structure coupled between the end effector and the pack-out module, the output buffer structure configured to contain packages output from the robotic arm and associated end effector before the pack-out module is able to automatically place the packages upon the pallet base.

440. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure

and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein while conducting the grasp with the robotic arm and end effector, the first computing system is configured to pass the targeted package within a field of view of the first imaging device, and wherein image information pertaining to the targeted package as it is passed within the field of view of the first imaging device is utilized by the first computing system to fit a three-dimensional rectangular prism around the targeted package and estimate three side dimensions of the three-dimensional rectangular prism.

441. The method of claim 440, wherein the first computing system is further configured to utilize the fitted three-dimensional rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector.

442. The method of claim 440, wherein first computing system is further configured to estimate the tightest possible three-dimensional rectangular prism around the targeted package.

443. The method of claim 440, wherein first computing system is further configured to construct a three-dimensional model of the targeted package.

444. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a movable place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the movable place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; and an output distribution gantry coupled to the movable place structure and configured to transport packages from the movable place structure to the output container, the output distribution gantry configured to transiently couple to a

targeted package which has been released by the robotic arm and end effector upon the movable place structure, move the targeted package away from the end effector to a position adjacent to the output container, and cause the targeted package to be dropped into the output container;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the movable place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the output distribution gantry comprises two or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the robotic arm, end effector, and output distribution gantry.

445. The method of claim 444, further comprising an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the two or more controllably actuated degrees of freedom.

446. The method of claim 445, wherein each of the output containers of the array is organized in a substantially co-planar configuration.

447. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a package input module operatively coupled to the first computing system and configured to be operated by the first computing system based at least in part upon the image information to mechanically process a plurality of incoming packages from a substantially disordered mechanical organization to provide a supply of packages to be transferred to the pick structure that is substantially singulated, and to prune away certain packages which do not become substantially singulated as a result of the mechanical process;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load.

448. The method of claim 447, wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a number of the one or more packages transiently coupled to the pick structure.

449. The method of claim 447, wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon the image information pertaining to the pick structure.

450. The method of claim 447, wherein the package input module comprises one or more mechanical singulation elements configured to mechanically process and direct the substantially singulated supply of packages toward the pick structure.

451. The method of claim 450, wherein the one or more mechanical singulation elements are selected from the group consisting of: a ramp sequence; a vibratory actuator; a belt; a coordinated plurality of belts; a ball sorter conveyor; a step sequence; a chute with one or more 90-degree turns; a mechanical diverter; a vertical mechanical filter; and a horizontal mechanical filter.

452. The method of claim 447, wherein the package input module is configured to be operated by the first computing system to prune away certain packages which do not become substantially singulated as a result of the mechanical process using a diversion element configured to selectably divert one or more targeted packages.

453. The method of claim 452, wherein the diversion element is a mechanical diverter.

454. The method of claim 452, wherein the diversion element is a diversion conveyor.

455. The method of claim 447, wherein the package input module is operatively coupled to the first computing system and configured to be operated by the first computing system based at least in part upon the image information to mechanically process a plurality of incoming packages from a substantially disordered mechanical organization to provide a supply of packages to be transferred to the pick structure that is substantially singulated, to prune away certain packages which do not become substantially singulated as a result of the mechanical process, and to move toward singulation certain packages based upon the image information.

456. The method of claim 455, wherein the first computing system may be configured to move the certain packages toward singulation using one or more mechanical singulation elements configured to mechanically process these certain packages.

457. The method of claim 456, wherein the one or more mechanical singulation elements are selected from the group consisting of: a ramp sequence; a vibratory actuator; a belt; a coordinated plurality of belts; a ball sorter conveyor; a step sequence; a chute with one or more 90-degree turns; a mechanical diverter; a vertical mechanical filter; and a horizontal mechanical filter.

458. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a package input module operatively coupled to the first computing system and configured to provide a supply of packages to be transferred to the pick structure;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the package input module is configured to be operated by the first computing system to control the supply based at least in part upon a rate at which the robotic arm and end effector are able to conduct a grasp from the pick structure and release a targeted package at the place structure.

459. The method of claim 458, wherein the first computing system is configured to substantially match the rate at which the robotic arm and end effector are able to conduct a grasp from the pick structure and release a targeted package at the place structure with a supply rate provided to the pick structure by the package input module.

460. The method of claim 458, wherein the package input module is configured to be able to automatically eject a targeted package based at least in part upon analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable.

461. The method of claim 460, wherein analysis by the first computing system of the image information from the first imaging device that the targeted package may be unpickable is based upon a neural network.

462. The method of claim 461, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

463. The method of claim 460, wherein the package input module comprises a mechanical ejection element configured to controllably eject a targeted package into a separate routing to be subsequently re-processed.

464. The method of claim 463, wherein the mechanical ejection element is selected from the group consisting of: a pusher, a diverter, an arm, and a multidirectional conveyor.

465. The method of claim 463, wherein the mechanical ejection element is configured to be operated pneumatically or electromechanically.

466. The method of claim 458, wherein the first computing system is configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector.

467. The method of claim 466, wherein the first computing system is configured to utilize the image information from the first imaging device to estimate a likely success rate for conducting a grasp of a particular targeted package before the particular targeted package reaches the end effector based upon a neural network.

468. The method of claim 467, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

469. The method of claim 458, further comprising a second imaging device positioned and oriented to capture image information pertaining to the package input module and one or more packages.

470. The method of claim 458, wherein the first computing system is configured to utilize the image information from the first imaging device to determine whether a package jam has occurred.

471. The method of claim 470, wherein analysis by the first computing system of the image information from the first imaging device whether a package jam has occurred is based upon a neural network.

472. The method of claim 471, wherein the neural network is trained, at least in part, based upon synthetic package imagery.

473. The method of claim 470, wherein the first computing system is configured to send a notification to one or more users upon determination that a package jam has occurred.

474. The method of claim 470, wherein the first computing system is configured to automatically take one or more steps

to resolve a package jam upon determination that a package jam has occurred.

475. The method of claim 474, wherein the one or more steps to resolve a package jam are selected from the group consisting of: applying mechanical vibration, applying a load to move one or more targeted packages, and reversing movement of one or more targeted packages.

476. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; and a second imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the one or more packages from a second perspective that differs from a first perspective of the first imaging device;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first computing system is configured to utilize image information from the first imaging device and second imaging device in a sensor fusion configuration to estimate external dimensions of the targeted package.

477. The method of claim 476, wherein the first and second perspectives are substantially orthogonal.

478. The method of claim 476, wherein the first and second perspectives are substantially opposite.

479. The method of claim 476, wherein the first imaging device has a measurement error pertaining to the targeted package that is substantially uncorrelated relative to a measurement error that the second imaging device has pertaining to the targeted package.

480. The method of claim 476, further comprising a third imaging device operatively coupled to the first computing system and configured to capture image information pertaining to the one or more packages from a third perspective that differs from the first perspective of the first imaging device or the second perspective of the second imaging device.

481. The method of claim 476, wherein the first computing system is configured to utilize the image information from the first imaging device and second imaging device to construct a three-dimensional model of the one or more packages.

482. The method of claim 476, wherein the first computing system is configured to utilize the image information from the first imaging device and second imaging device to estimate one or more material properties of a targeted package.

483. The method of claim 476, wherein the one or more material properties of a targeted package are selected from the group consisting of: package stiffness, package bulk modulus, package rigidity, package exterior compliance, and estimated looseness of exterior package material.

484. The method of claim 483, wherein the first computing system is configured to utilize a neural network to estimate the one or more material properties, the neural network trained utilizing imagery pertaining to a package exterior training dataset.

485. The method of claim 484, wherein the imagery is based at least in part upon synthetic imagery.

486. The method of claim 476, wherein the first computing system is configured to utilize the image information from the first imaging device and second imaging device to estimate a quality control variable pertaining to one or more targeted packages selected from the group consisting of: existence of

package damage, existence of multiple packages bound together, and whether the end effector has successfully conducted a grasp.

487. The method of claim 486, wherein the first computing system is configured to utilize a neural network to estimate the quality control variable, the neural network trained utilizing imagery pertaining to a package exterior training dataset.

488. The method of claim 487, wherein the imagery is based at least in part upon synthetic imagery.

489. A robotic package handling method, comprising:

providing a package input module configured to move a plurality of incoming packages in a primary advancement direction along a conveyance platform while also being configured to selectably move one or more targeted packages from the plurality away from the conveyance platform; a first imaging device positioned and oriented to capture image information pertaining to the conveyance platform and plurality of incoming packages; a first computing system operatively coupled to the package input module and the first imaging device, and configured to receive the image information from the first imaging device and command movements of package input module based at least in part upon the image information; an output container configured to receive packages which may be moved away from the conveyance platform, the output container configured to at least temporarily contain a plurality of the one or more packages from the conveyance platform as they are moved by operation of

the first computing system and package input module; and an output distribution gantry configured to transport packages from the conveyance platform to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been moved from the conveyance platform to a position adjacent to the output container, and cause the targeted package to be dropped into the output container;

wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the package input module and output distribution gantry.

490. The method of claim 489, further comprising an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated degrees of freedom.

491. The method of claim 490, wherein each of the output containers of the array is organized in a substantially co-planar configuration.

492. The method of claim 489, wherein the package input module comprises a bi-directional conveyor.

493. The method of claim 489, wherein the package input module comprises an omnidirectional ball sorter conveyor.

494. The method of claim 489, wherein the package input module comprises a mechanical diverter configured to selectably move one or more targeted packages from the plurality away from the conveyance platform.

495. The method of claim 489, further comprising a guiding structure operatively coupled between the package input module and output distribution gantry, the guiding structure configured to mechanically guide the one or more targeted packages from the plurality away from the conveyance platform and to the output distribution gantry.

496. The method of claim 495, wherein the guiding structure comprises an element selected from the group consisting of: a chute, a ramp, a funnel, and a conveyor.

497. The method of claim 489, wherein the output distribution gantry is configured to be able to controllably removably couple to a selected output container and to remove the selected output container from the output distribution gantry.

498. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; a first computing system operatively

coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; an output container configured to receive packages which may be moved away from the place structure after release from the end effector, the output container configured to at least temporarily contain a plurality of the one or more packages from the pick structure as they are placed by operation of the first computing system, robotic arm, and end effector; and an output distribution gantry configured to transport packages from the place structure to the output container, the output distribution gantry configured to transiently couple to a targeted package which has been released by the robotic arm and end effector upon the place structure, move the targeted package away from the place structure to a position adjacent to the output container, and cause the targeted package to be dropped into the output container;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the output distribution gantry comprises one or more controllably actuated degrees of freedom operatively coupled to the first computing system, such that the first computing system may be configured to coordinate operations between the

robotic arm, end effector, and output distribution gantry; and

wherein the output distribution gantry is configured to be able to controllably removably couple to a selected output container and to remove the selected output container from the output distribution gantry.

499. The method of claim 498, further comprising an array of output containers organized in proximity to the place structure, wherein the output distribution gantry is configured to be able to place the targeted package in each of the output containers of the array through utilization of the one or more controllably actuated degrees of freedom.

500. The method of claim 499, wherein each of the output containers of the array is organized in a substantially co-planar configuration.

501. The method of claim 498, wherein the output distribution gantry comprises an electromechanical coupler configured to controllably couple or decouple from a selected output container.

502. The method of claim 501, wherein the electromechanical coupler comprises an output container grasper.

503. The method of claim 501, wherein the electromechanical coupler comprises an electromechanically operated hook configured to be removably coupled to a selected output container.

504. The method of claim 498, wherein the place structure is configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially orthogonal vertical configuration relative to the substantially gravity-level orientation of the place structure.

505. The method of claim 498, wherein the place structure is configured to have at least one surface having a substantially gravity-level orientation, and wherein the output distribution gantry is oriented in a substantially parallel vertical configuration relative to the substantially gravity-level orientation of the place structure.

506. The method of claim 498, further comprising a barcode scanner operatively coupled to the first computing system and configured to scan one or more labels which may be present upon a targeted package.

507. The method of claim 498, wherein the place structure comprises a conveyor configured to move a targeted package toward the output distribution gantry once released by the end effector.

508. The method of claim 498, wherein the output distribution gantry is configured to controllably exit one or more contained packages utilizing a controllably-releasable door configuration.

509. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first suction cup assembly defines a first inner capture chamber configured such that conducting the grasp of the targeted package comprises pulling into and at least partially encapsulating a portion of the targeted package with the first inner capture chamber when the vacuum load is controllably activated adjacent the targeted package.

510. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the first suction cup assembly defines a first inner chamber, a first outer sealing lip, and a first vacuum-permeable distal wall member which are collectively configured such that upon conducting the grasp of the targeted package with the vacuum load controllably actuated, the outer sealing lip may become removably coupled to at least one surface of the targeted package, while the vacuum-permeable distal wall

member prevents over-protrusion of said surface to the targeted package into the inner chamber of the suction cup assembly.

511. A method, comprising:

providing a robotic pick-and-place machine comprising an actuation system and a changeable end effector system configured to facilitate selection and switching between a plurality of end effector heads; providing a sensing system; and configuring a grasp planning processing pipeline to control the robotic pick-and-place machine.

512. The method of claim 511, wherein the changeable end effector system comprises a head selector integrated into a distal end of the actuation system, a set of end effector heads, and a head holding device, wherein the head selector attaches with one of the sets of end effector heads at a respective attachment face.

513. The method of claim 512, wherein the changeable end effector system further comprises at least one magnet circumscribing a center of one of the head selector or end effector head to supply initial seating and holding of the end effector head.

514. The method of claim 513, wherein at least one of the head selector or each of the set of end effector heads comprise a seal positioned along an outer edge of a respective attachment face.

515. The method of claim 512, wherein the head selector and the set of end effector heads comprise complimentary registration structures.

516. The method of claim 512, wherein the head selector and the set of end effector heads comprise a lateral support structure geometry selected to assist with grasping a compliant package.

517. The method of claim 512, wherein the set of end effector heads comprise a set of suction end effectors.

518. The method of claim 512, wherein the actuation system comprises an articulated arm.

519. A robotic package handling method, comprising:

providing a robotic arm comprising a distal portion and a proximal base portion; an end effector coupled to the distal portion of the robotic arm; a place structure in geometric proximity to the distal portion of the robotic arm; a pick structure transiently coupled to one or more packages and positioned in geometric proximity to the distal portion of the robotic arm; a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages; and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information;

wherein the first computing system is configured to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to be at least transiently coupled with the place structure;

wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package and controllably activating the vacuum load;

wherein the end effector is coupled to the distal portion of the robotic arm using a spring-biased end effector coupling assembly comprising a spring member configured to provide an engagement compliance when conducting the grasp between the end effector and the targeted package.

520. The method of claim 519, wherein the spring member is configured to have a prescribed spring constant selected to provide the engagement compliance.

521. The method of claim 519, wherein the spring-biased end effector coupling assembly comprises an insertion axis constraining member configured to facilitate spring-biased insertion of the spring-biased end effector coupling assembly along an axis prescribed by the axis constraining member.

522. The method of claim 521, wherein the axis constraining member comprises a linear bearing assembly configured to facilitate movement along a single axis of motion.

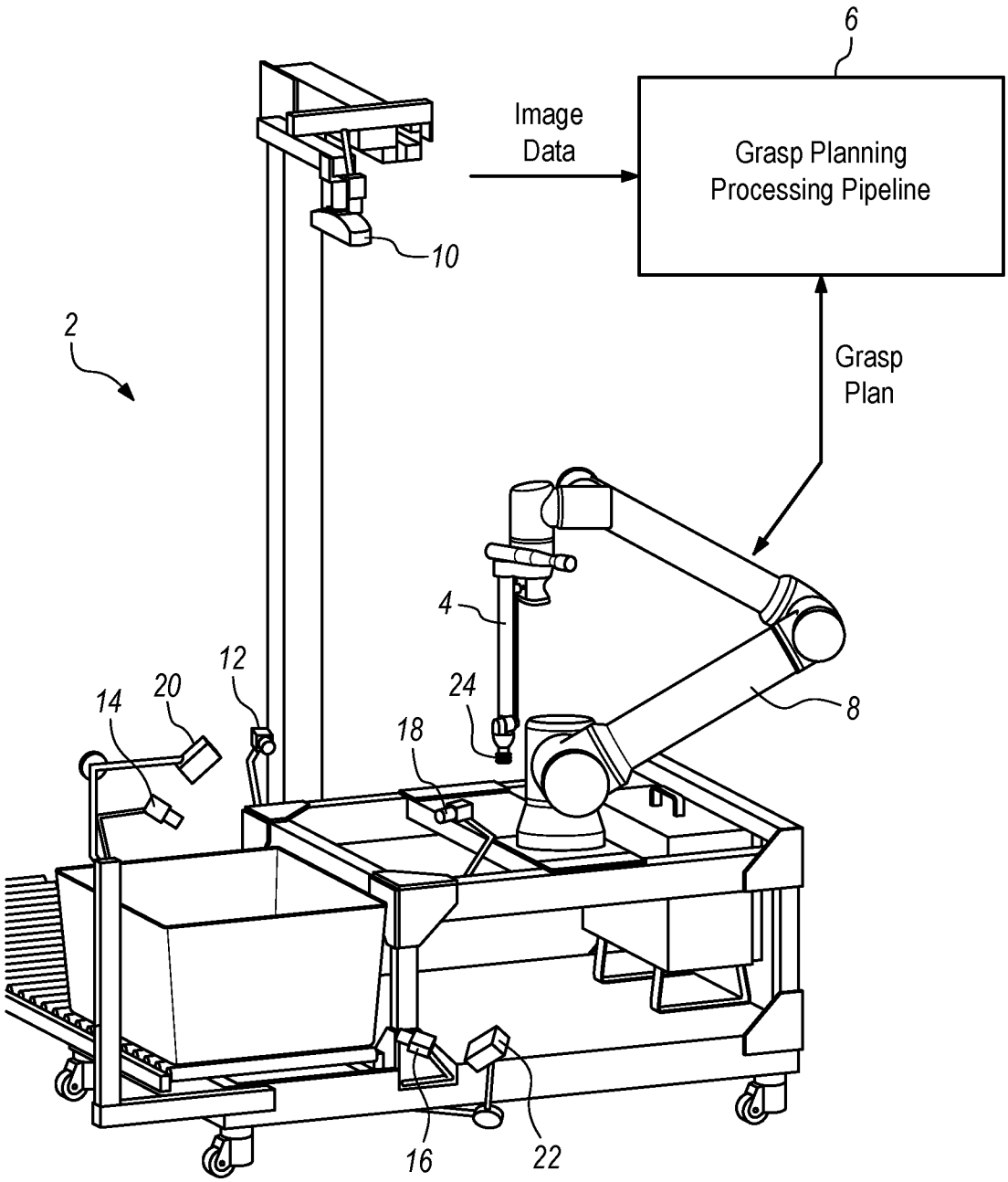

6
Image Data
Grasp Planning Processing Pipeline
10
2
Grasp Plan
4
12
20
14
24
8
18
16
22

FIG. 1

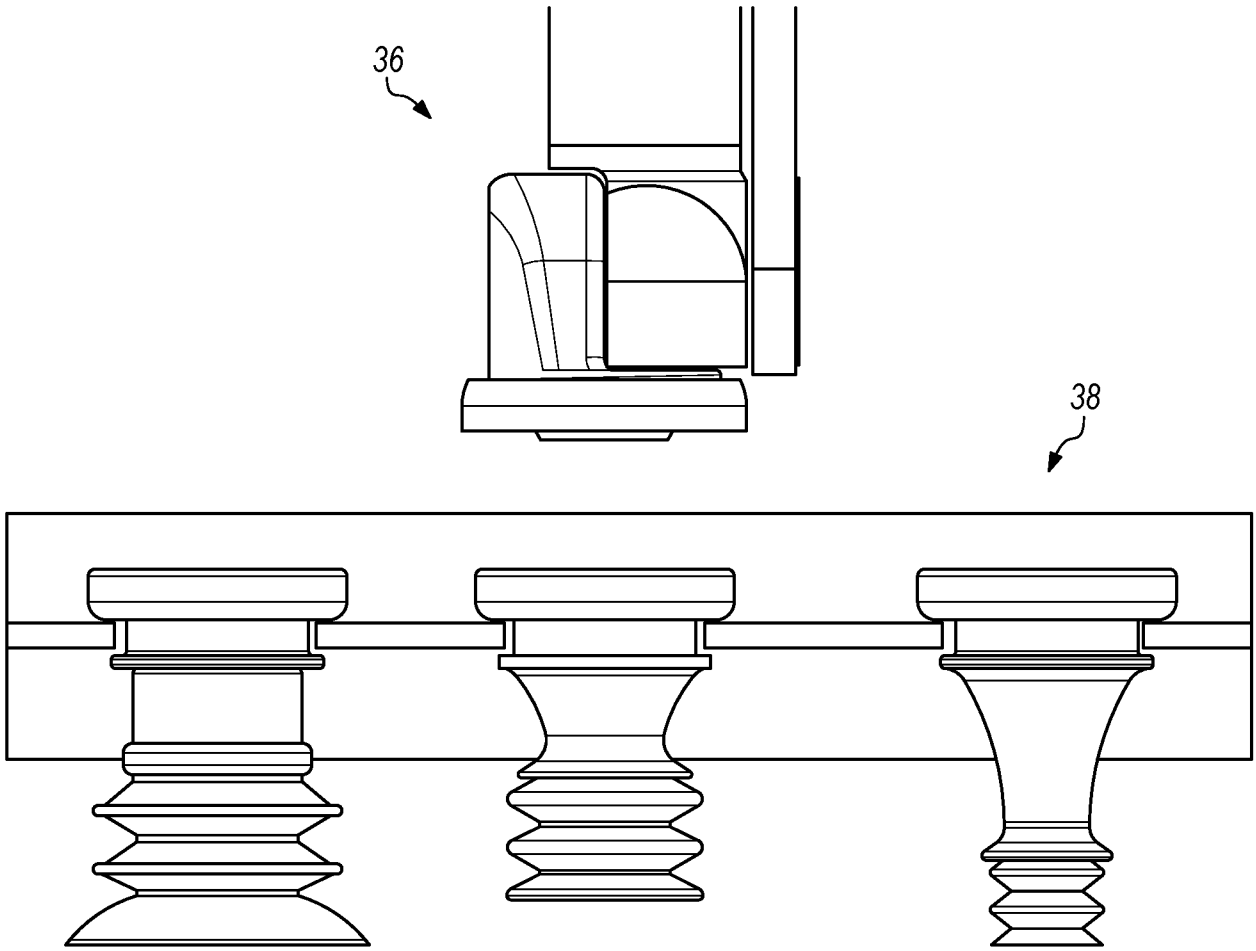


FIG. 2

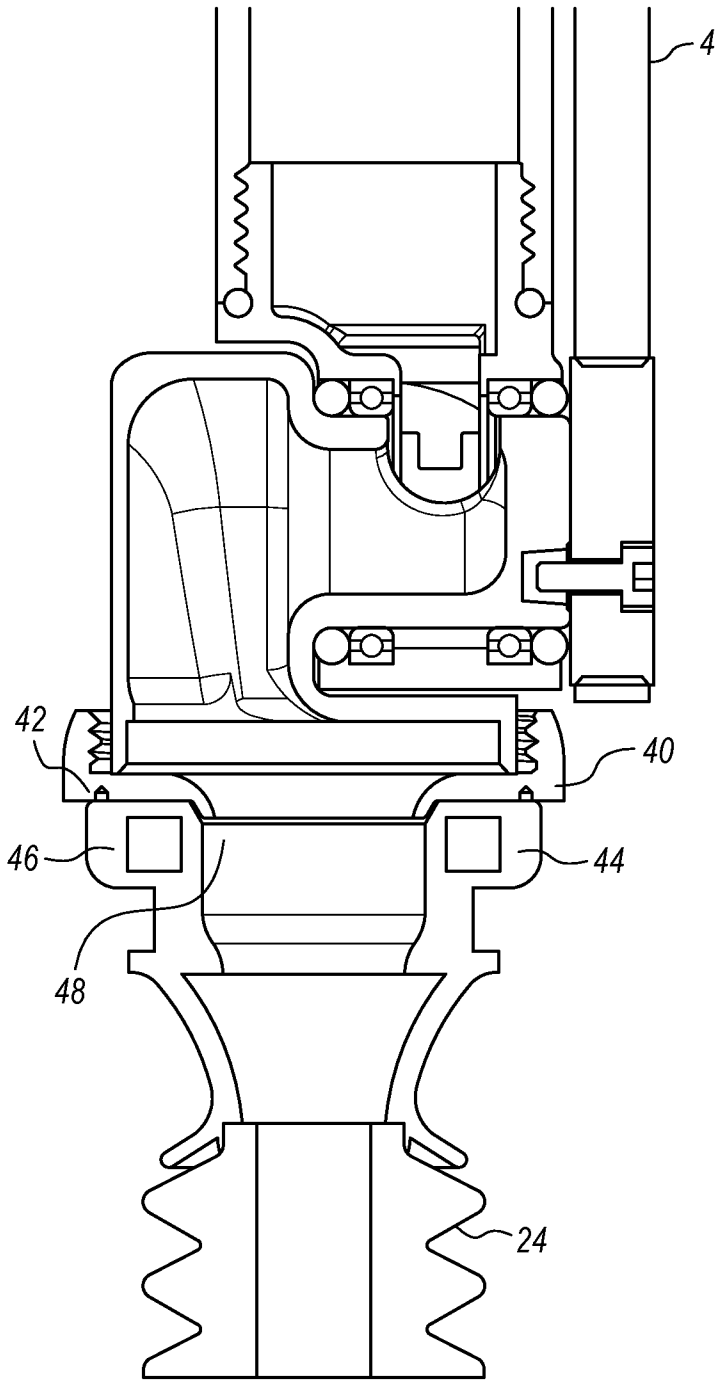


FIG. 3

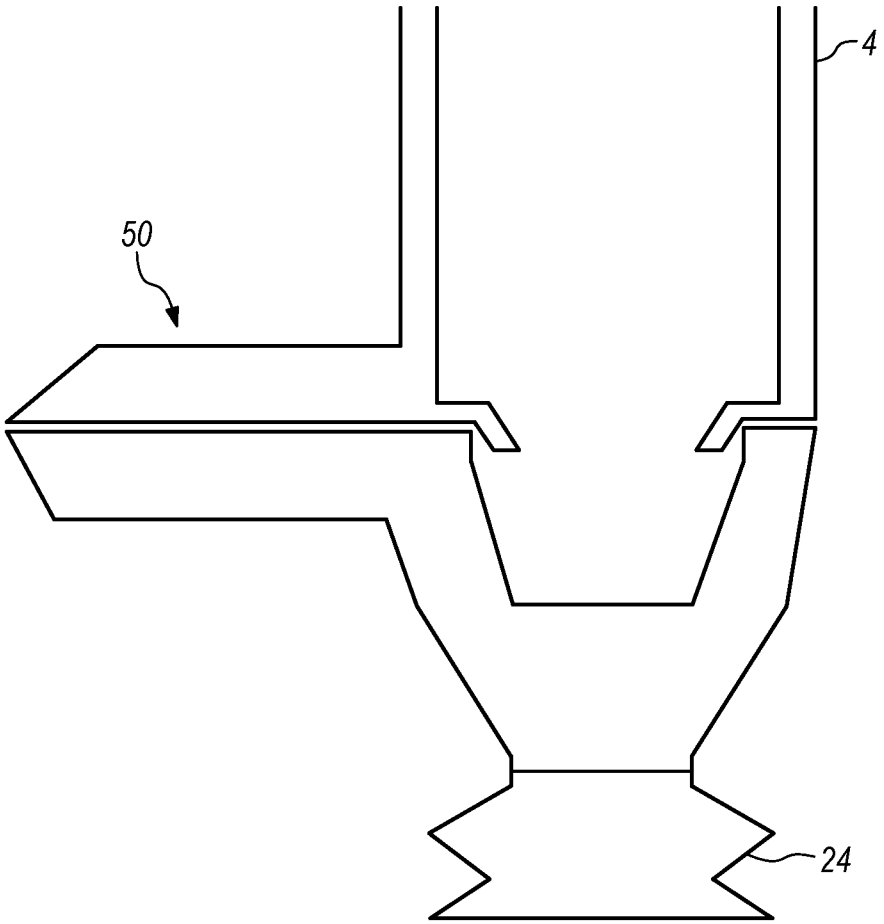


FIG. 4

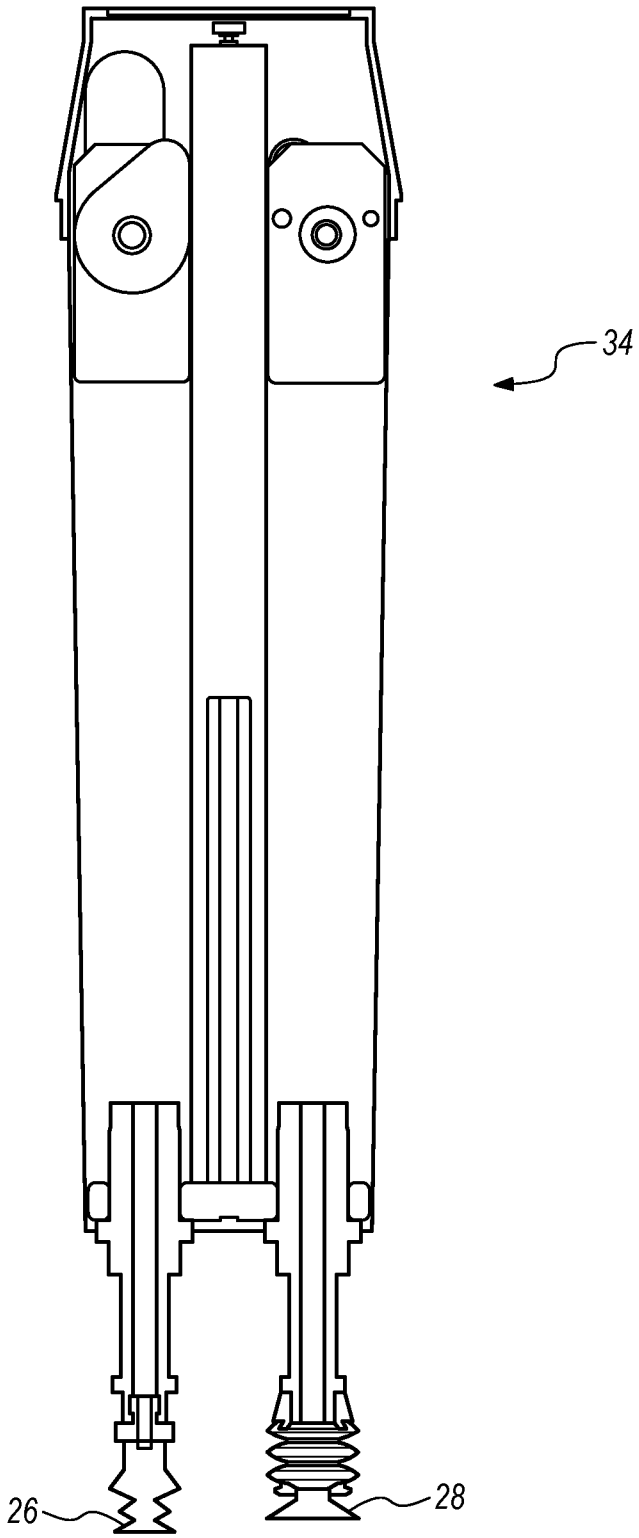


FIG. 5

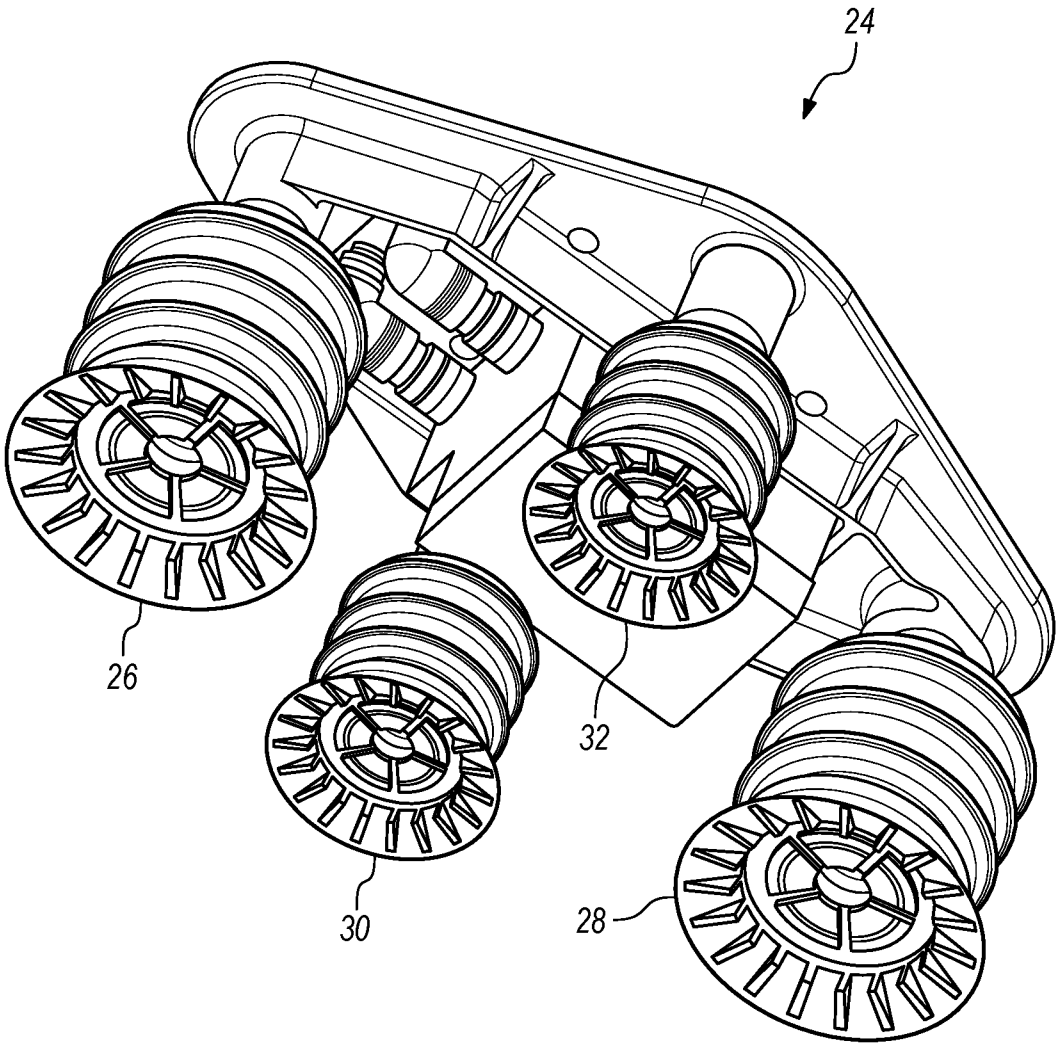


FIG. 6

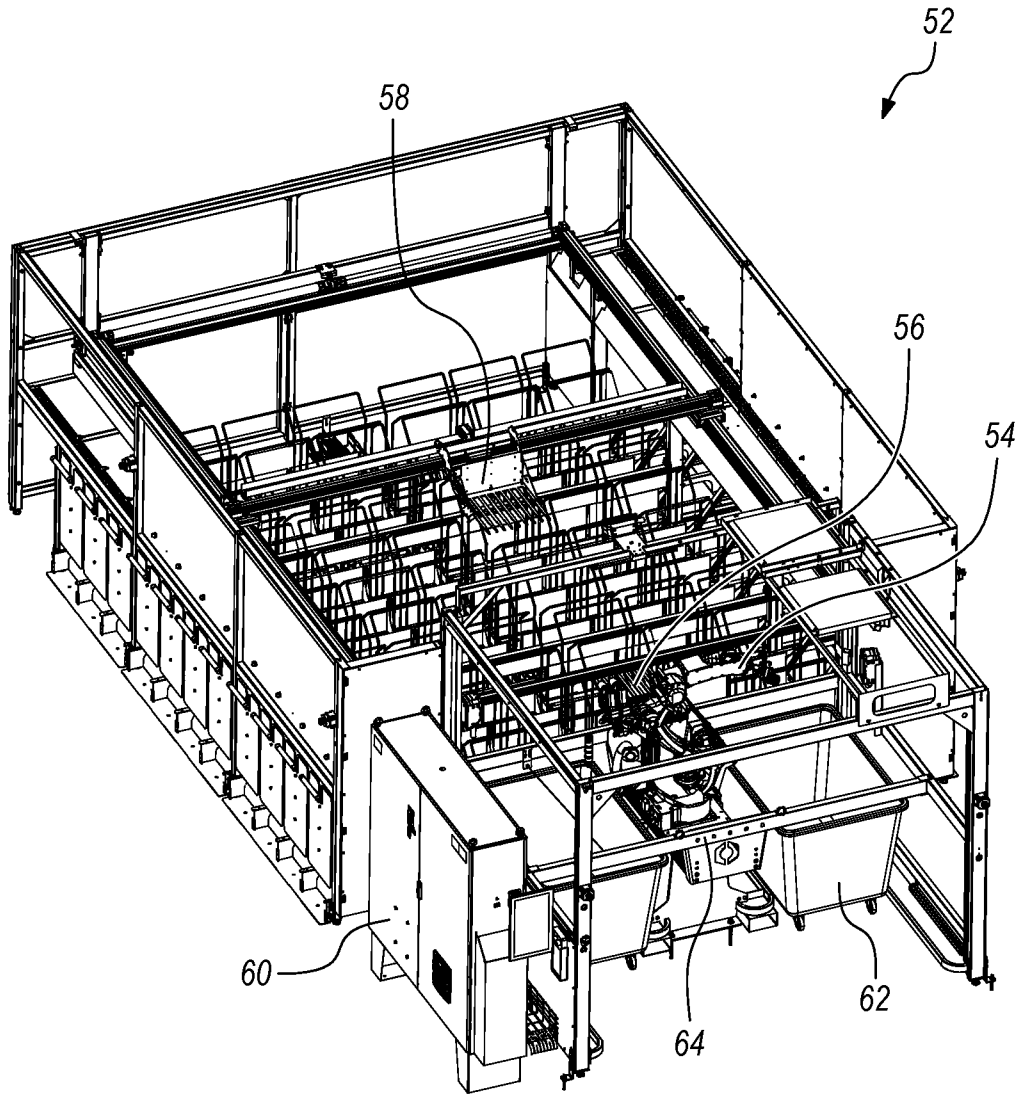


FIG. 7A

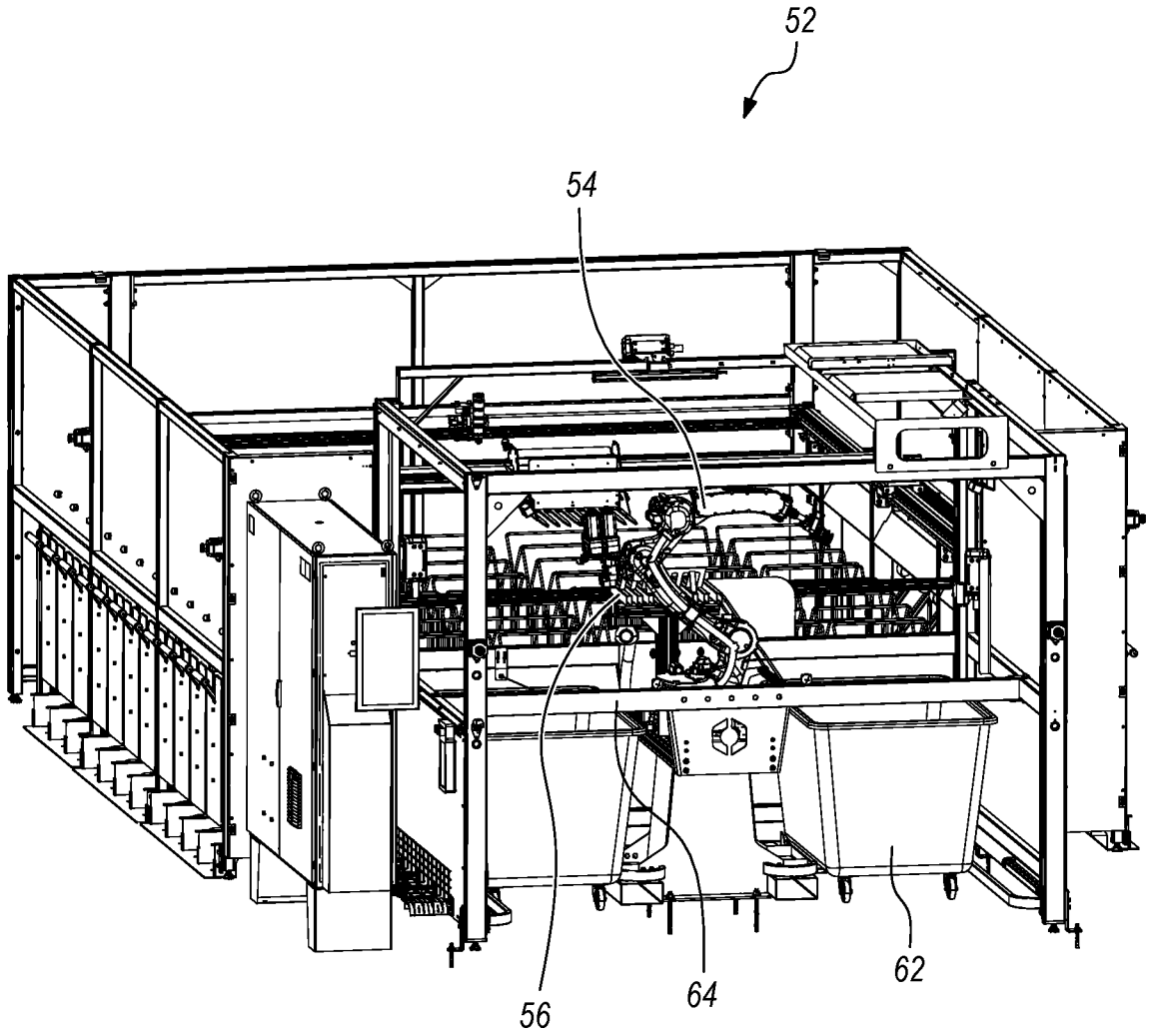


FIG. 7B

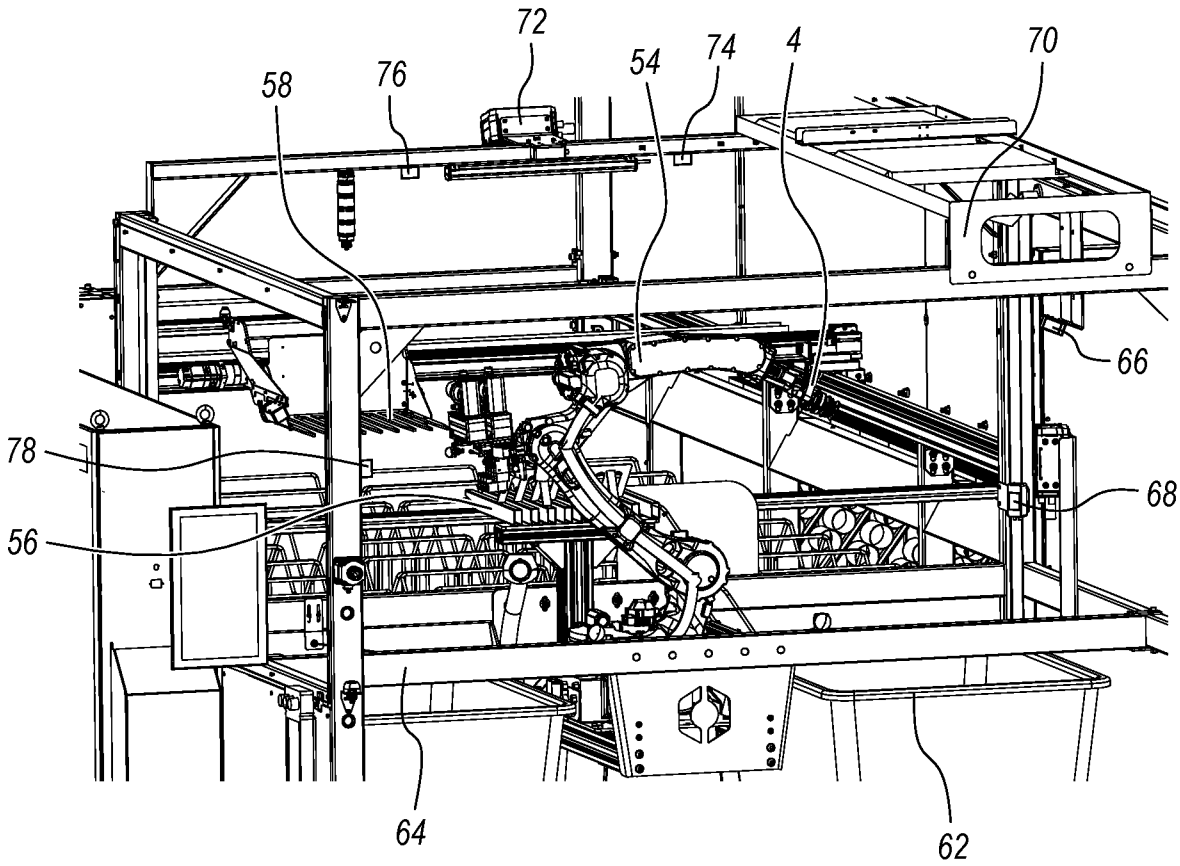


FIG. 7C

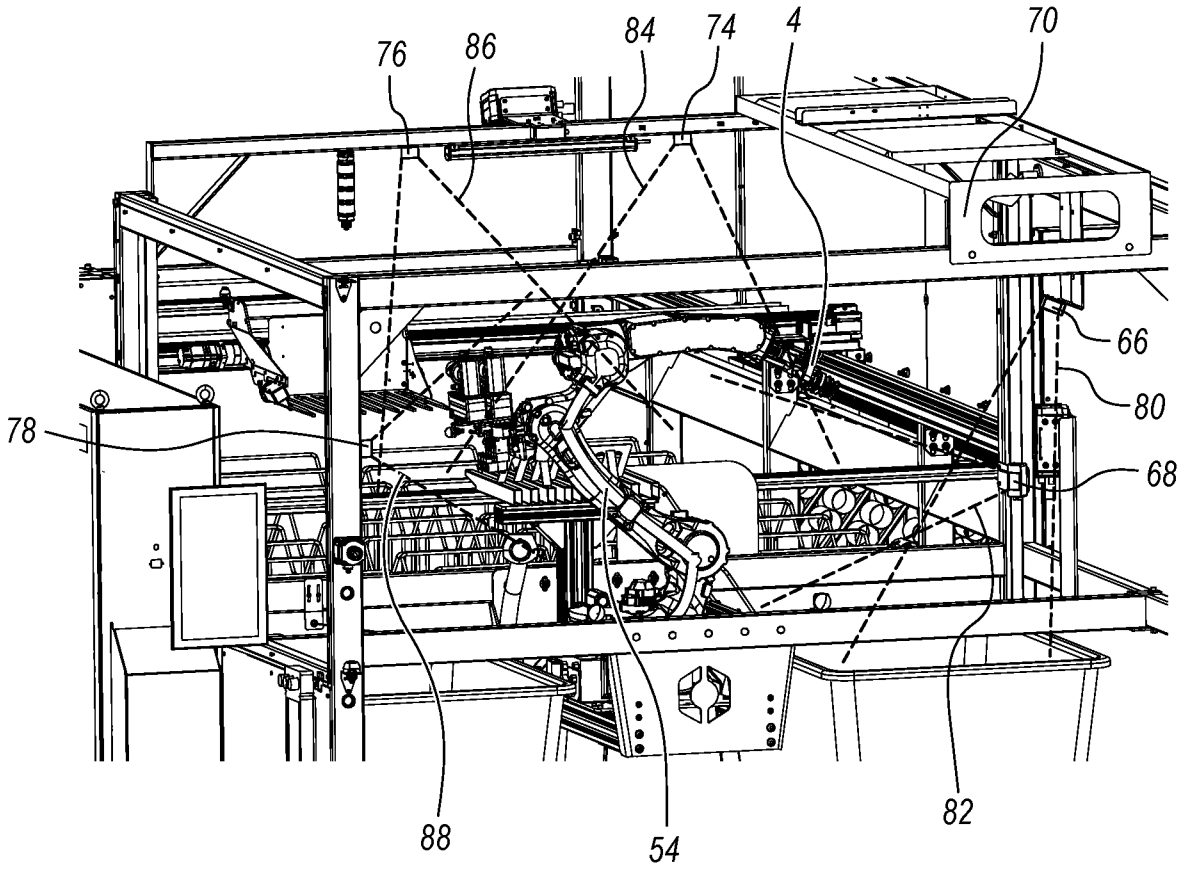


FIG. 7D

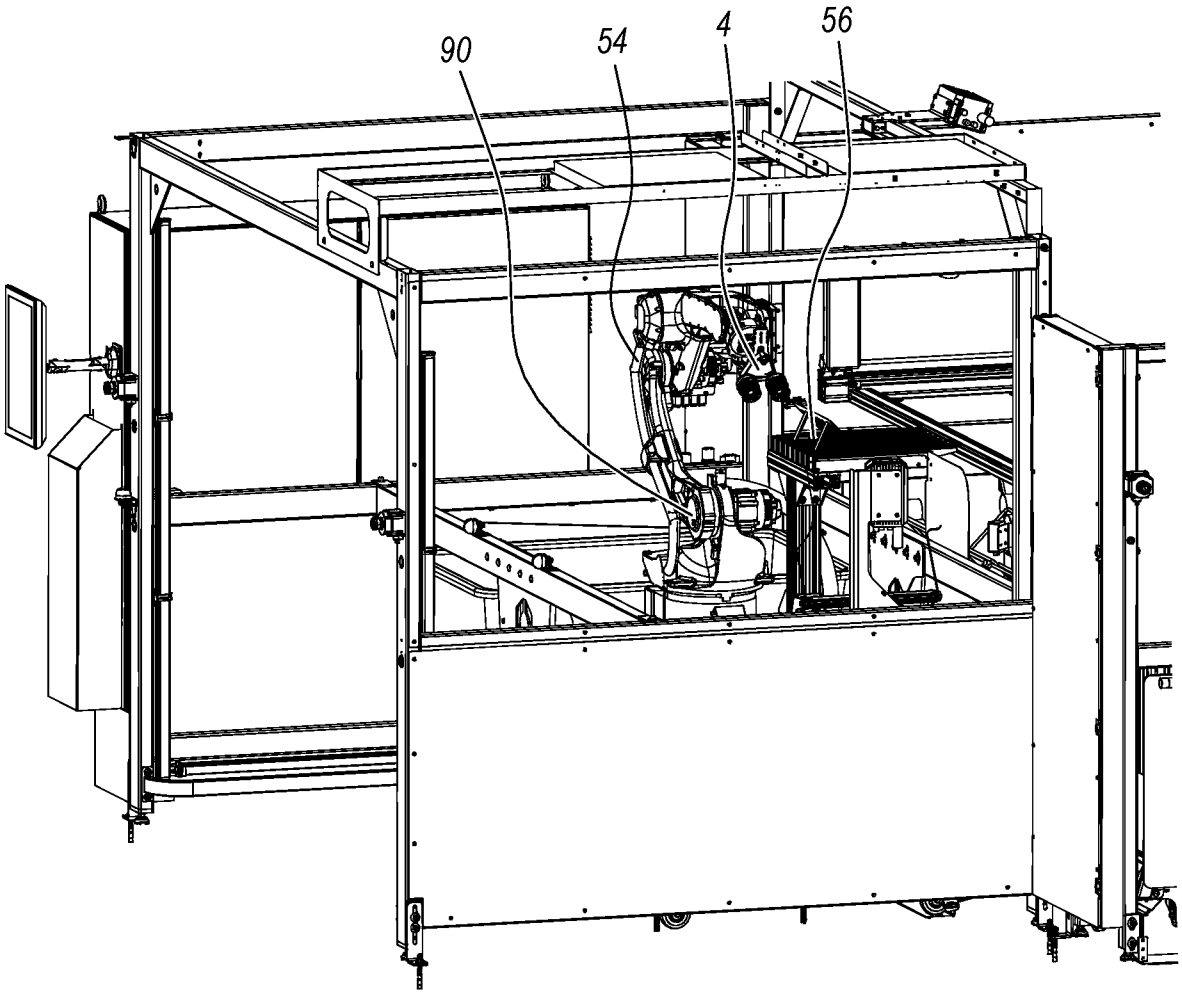


FIG. 7E

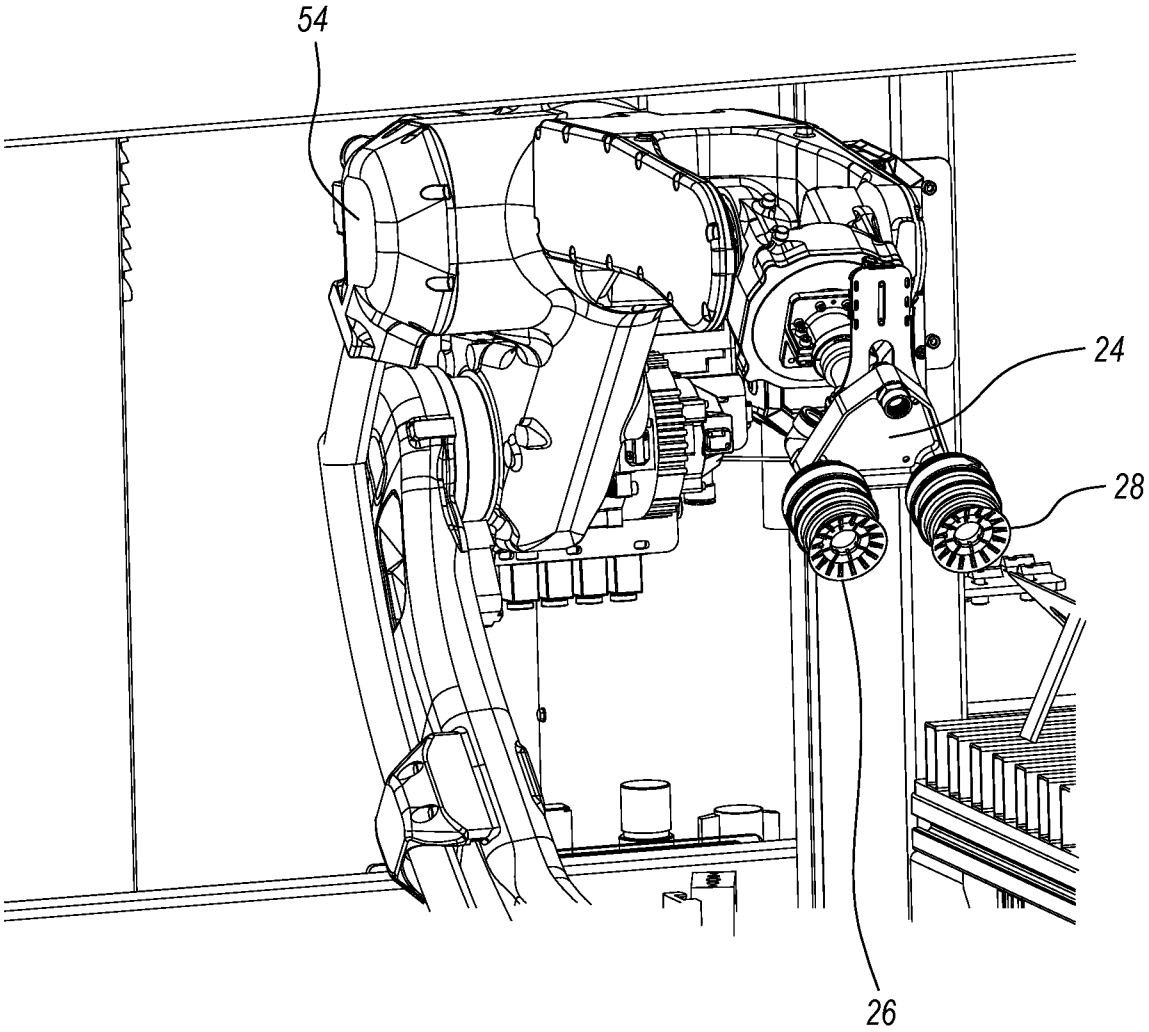


FIG. 7F

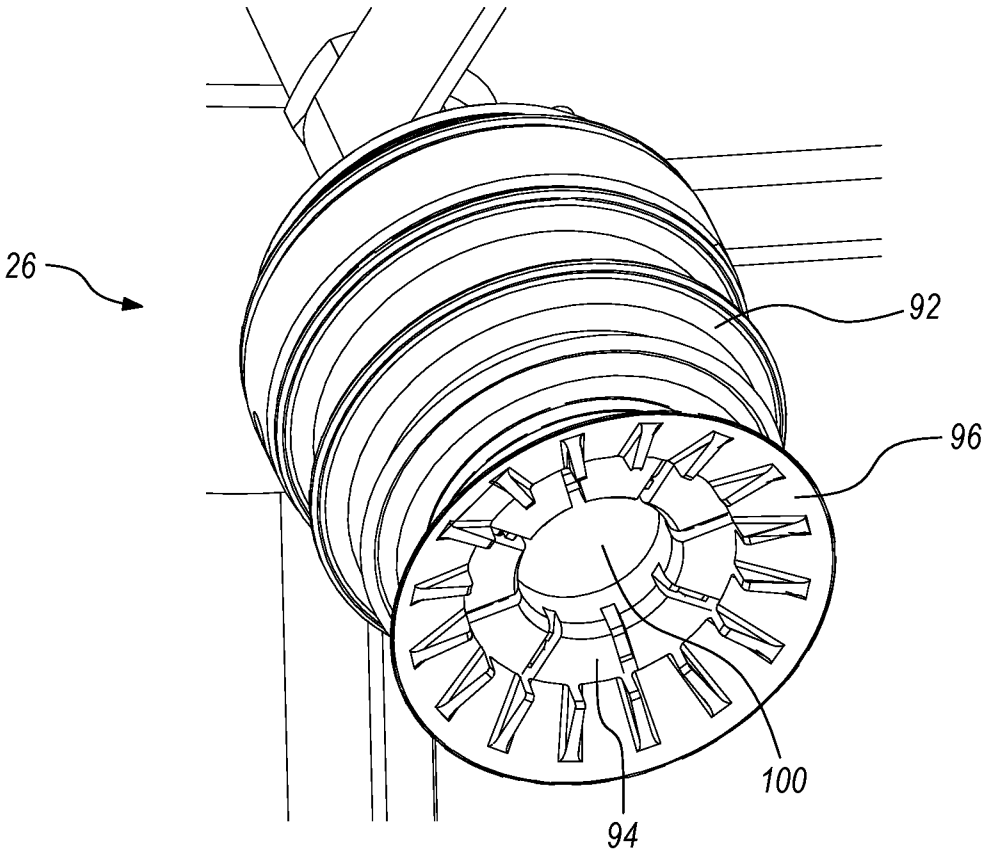


FIG. 7G

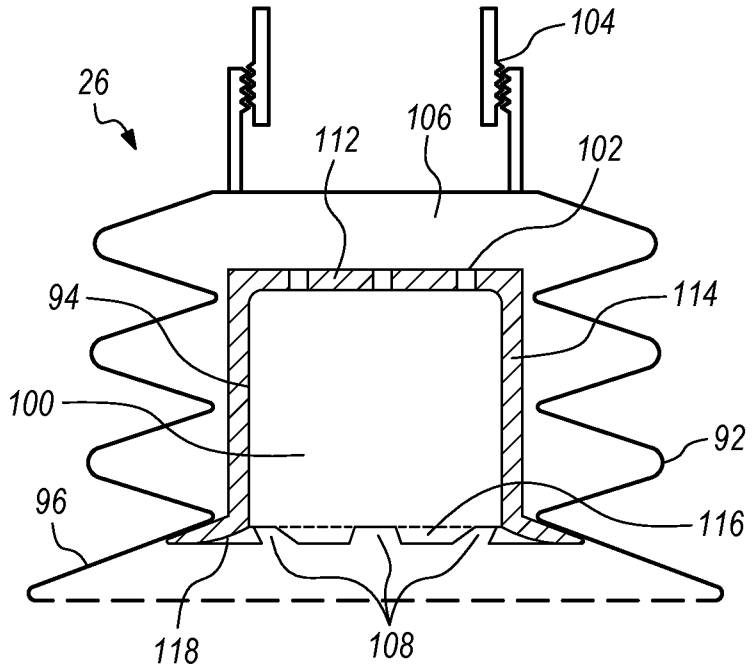


FIG. 8A

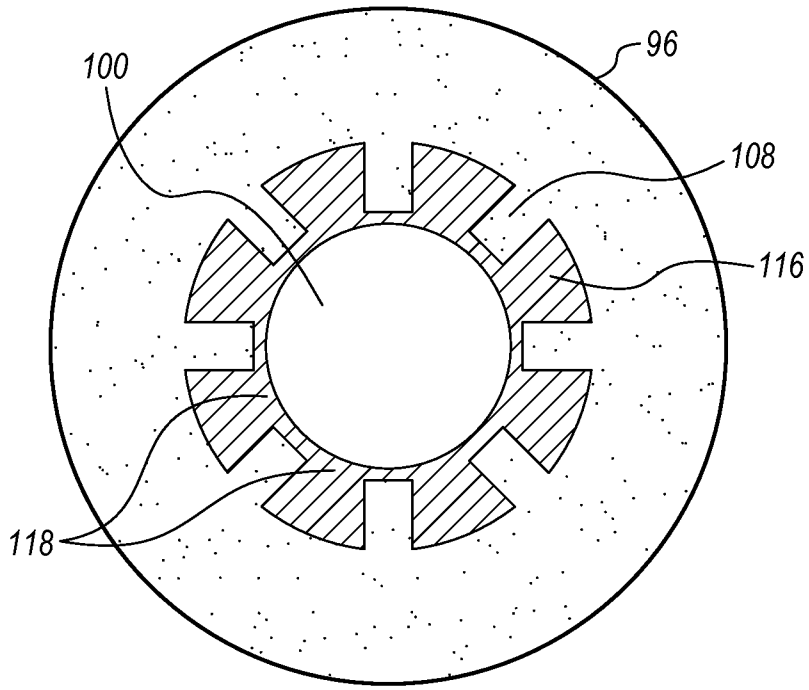


FIG. 8B

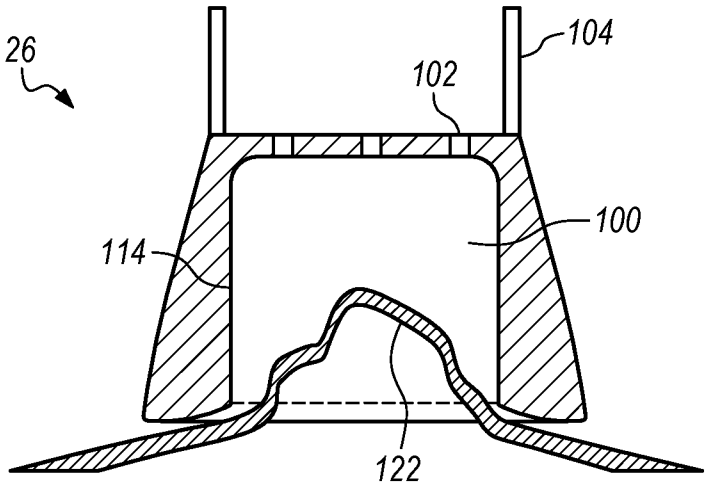


FIG. 9A

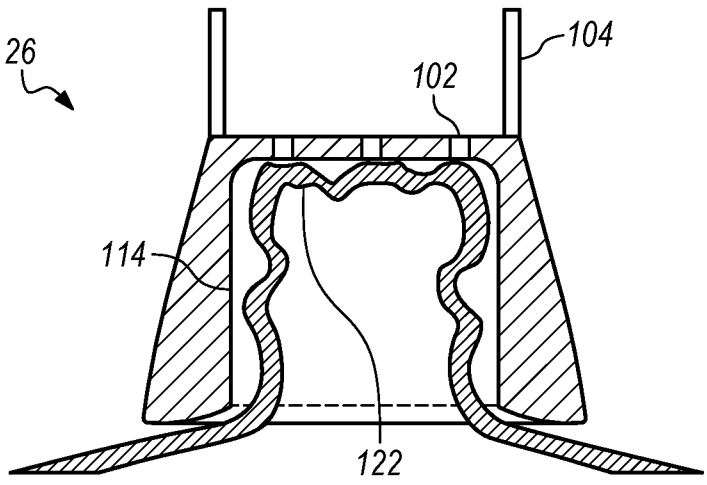


FIG. 9B

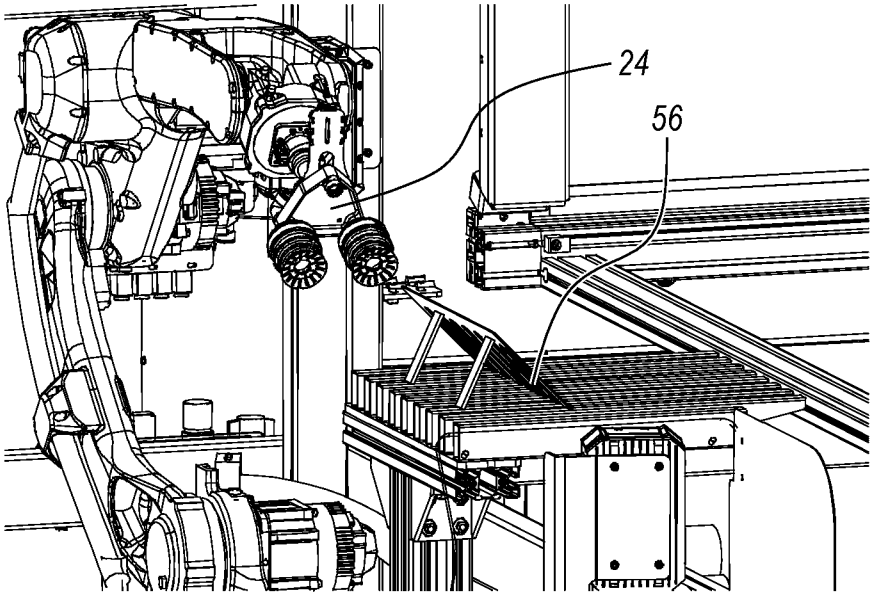


FIG. 10A

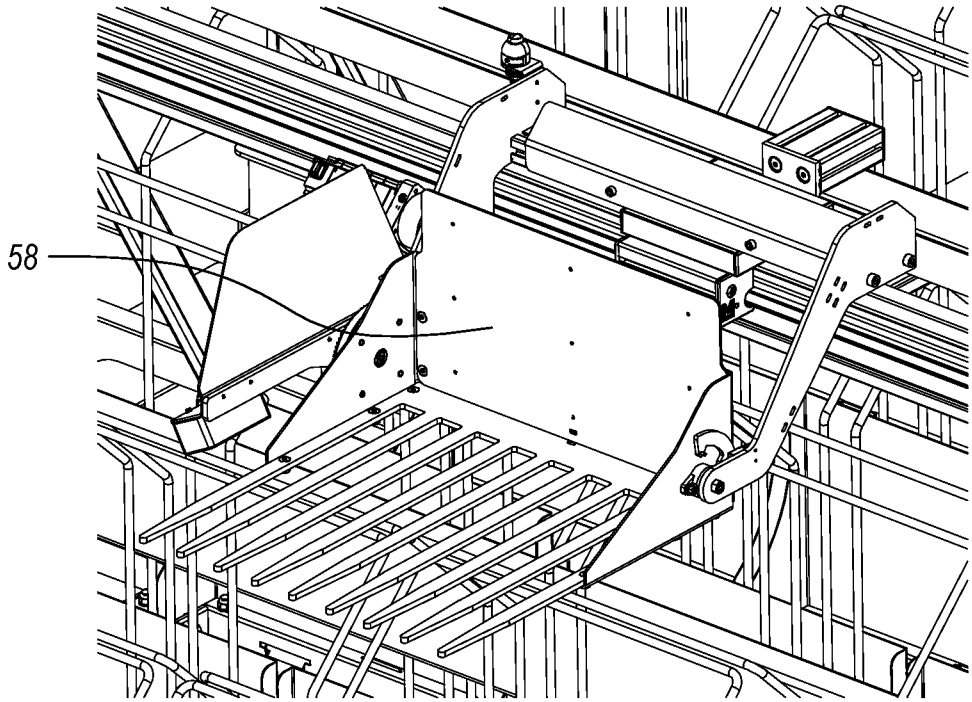


FIG. 10B

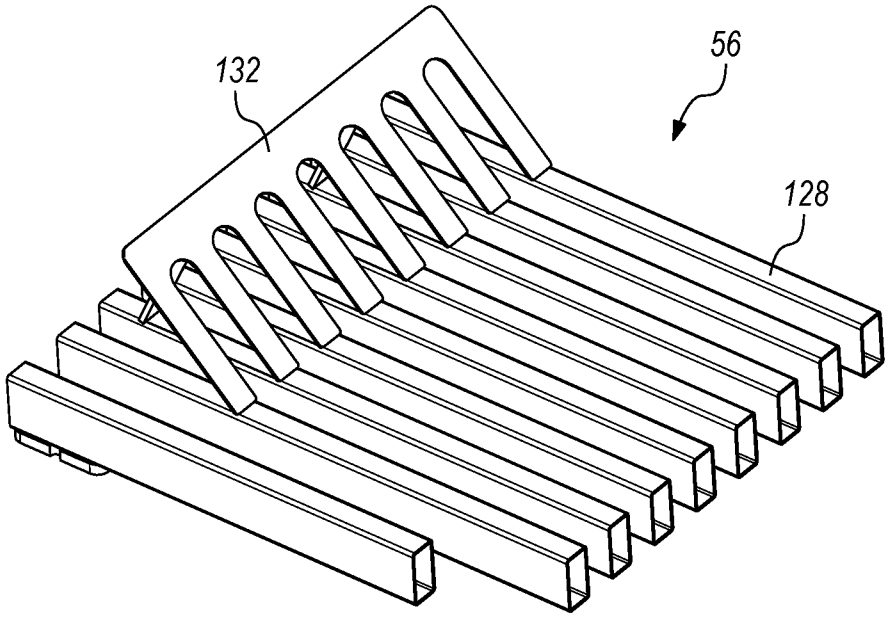


FIG. 10C

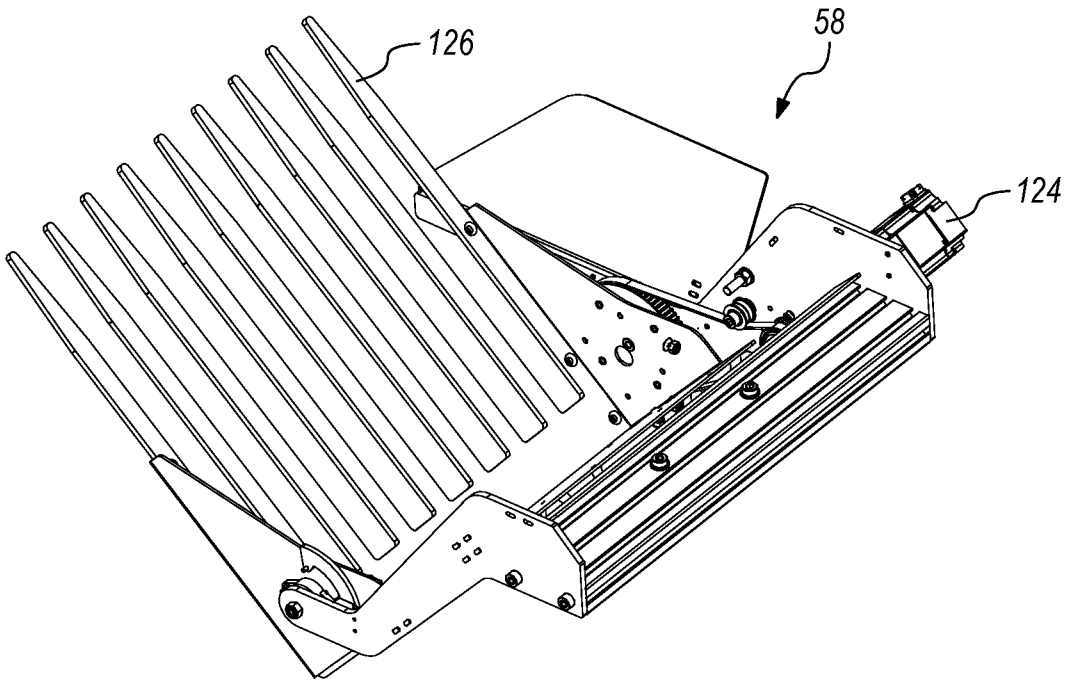


FIG. 10D

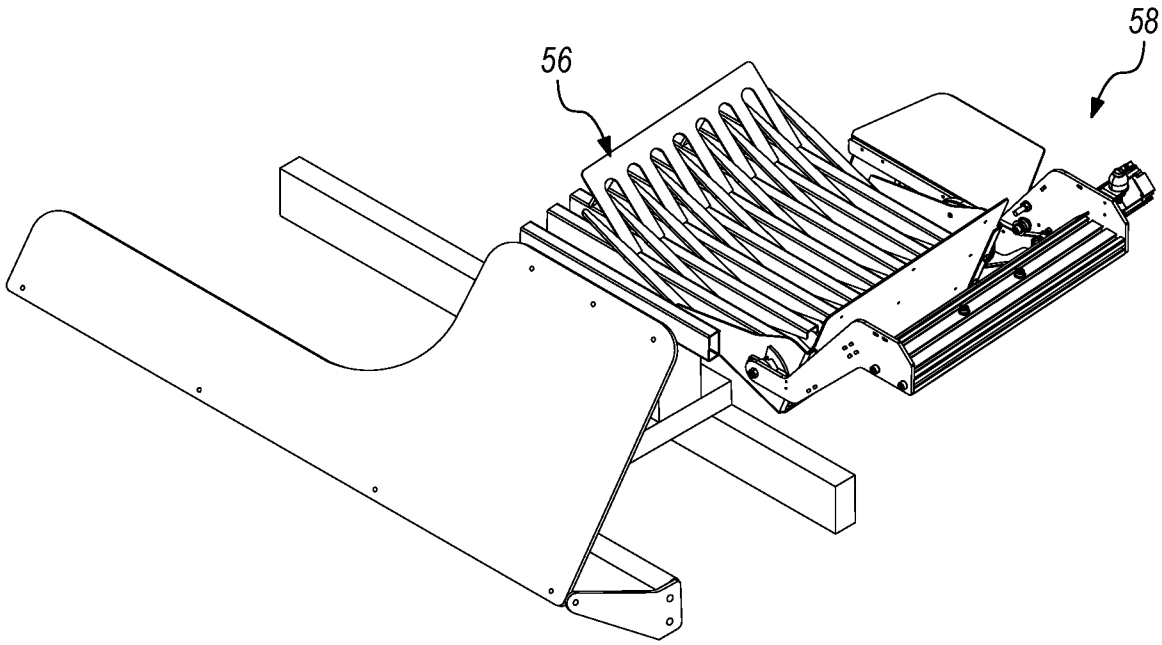


FIG. 10E

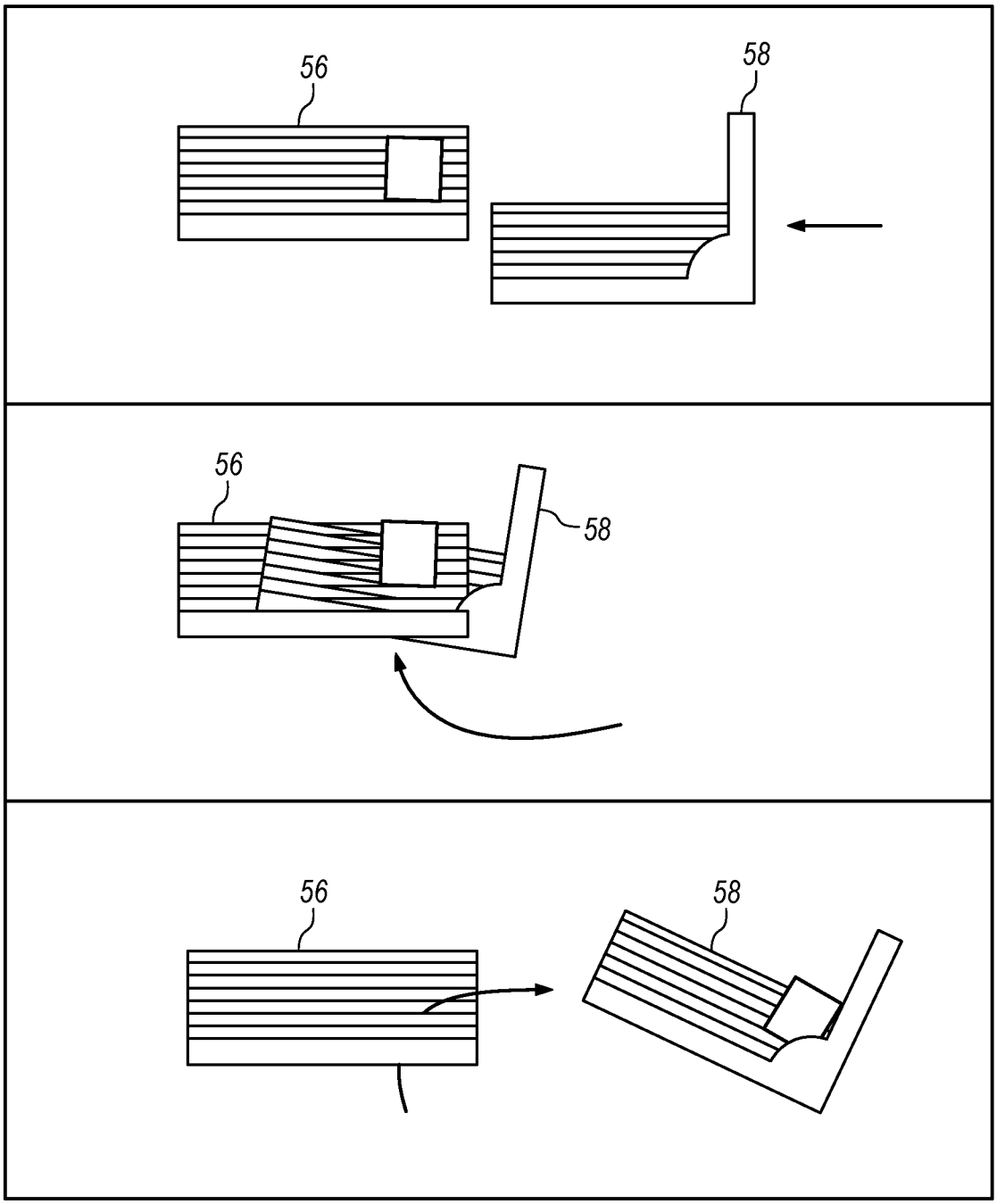


FIG. 10F

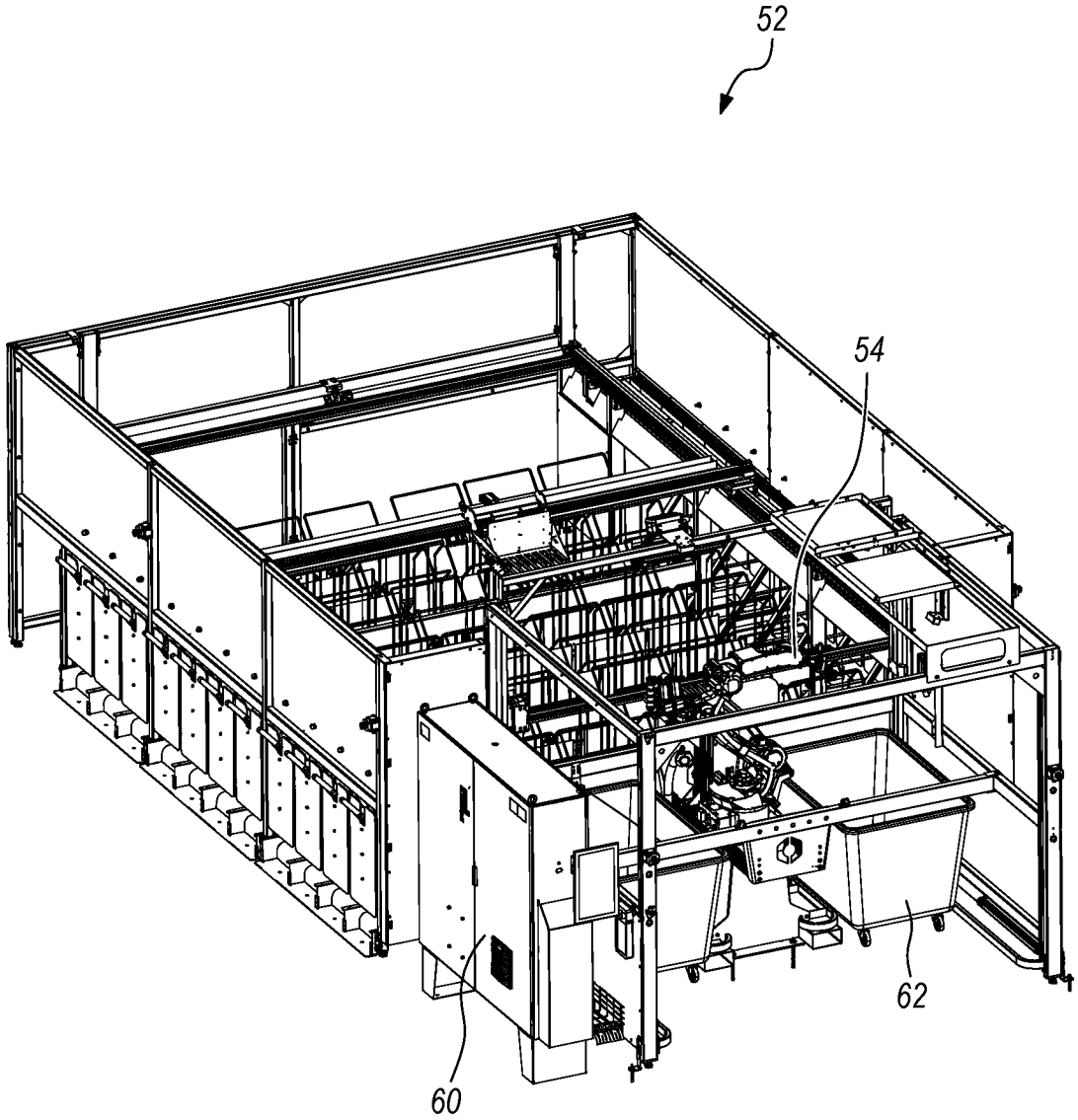


FIG. 11A

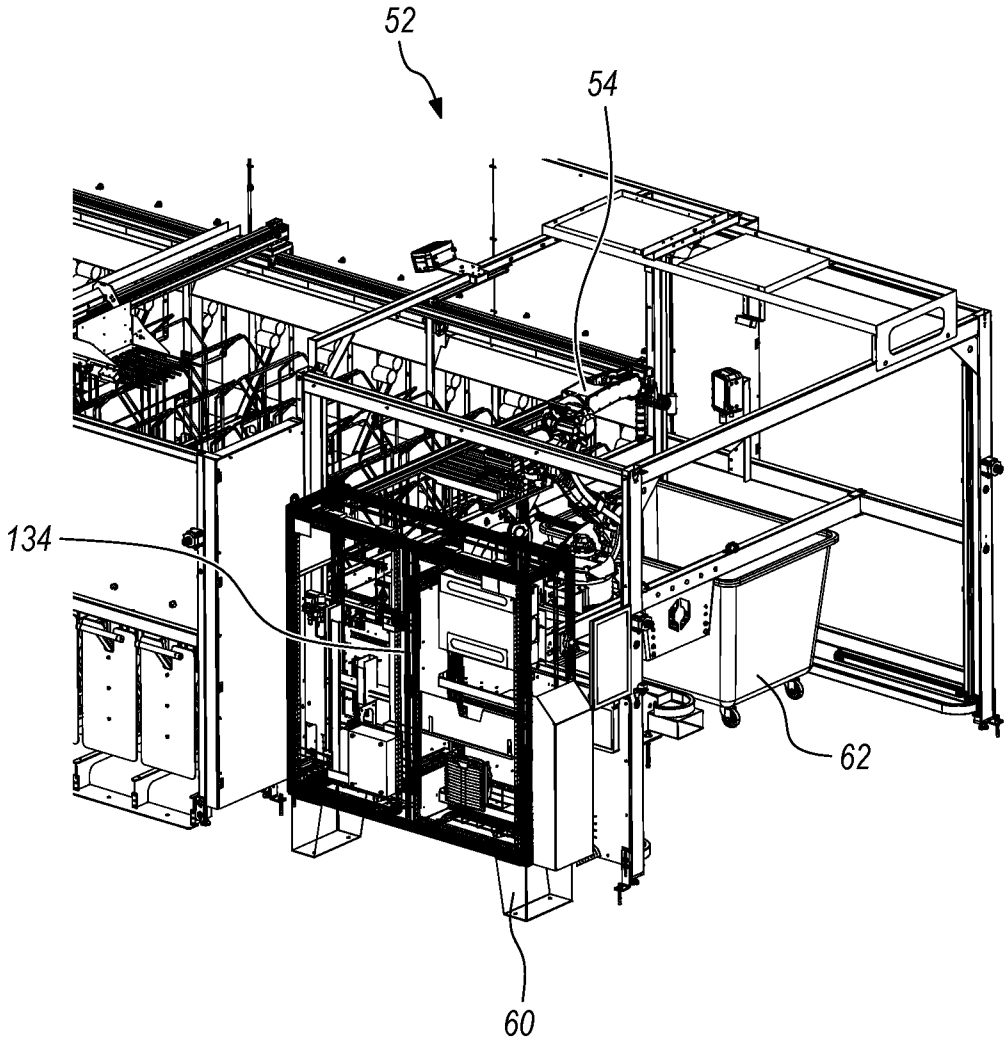


FIG. 11B

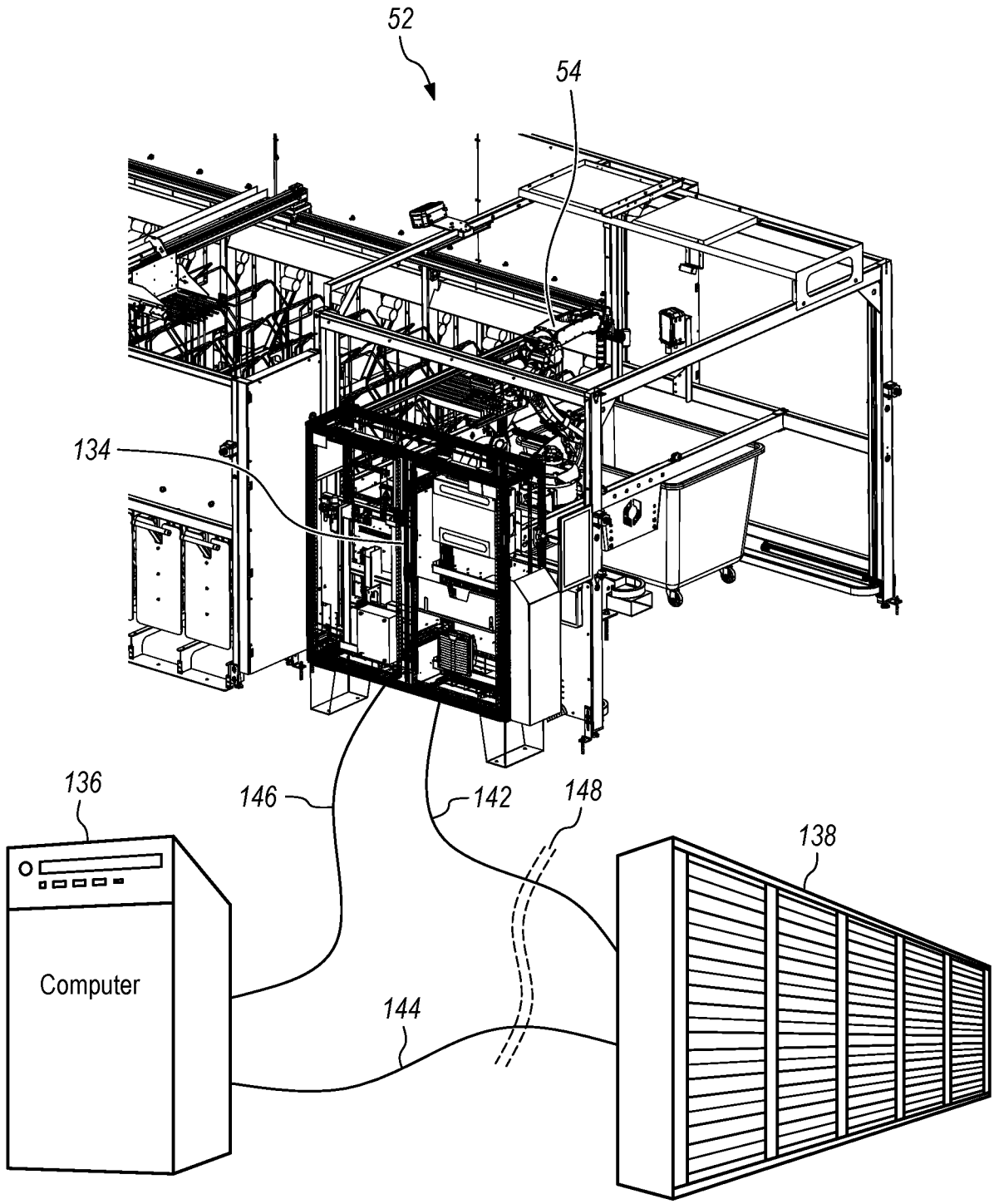


FIG. 11C

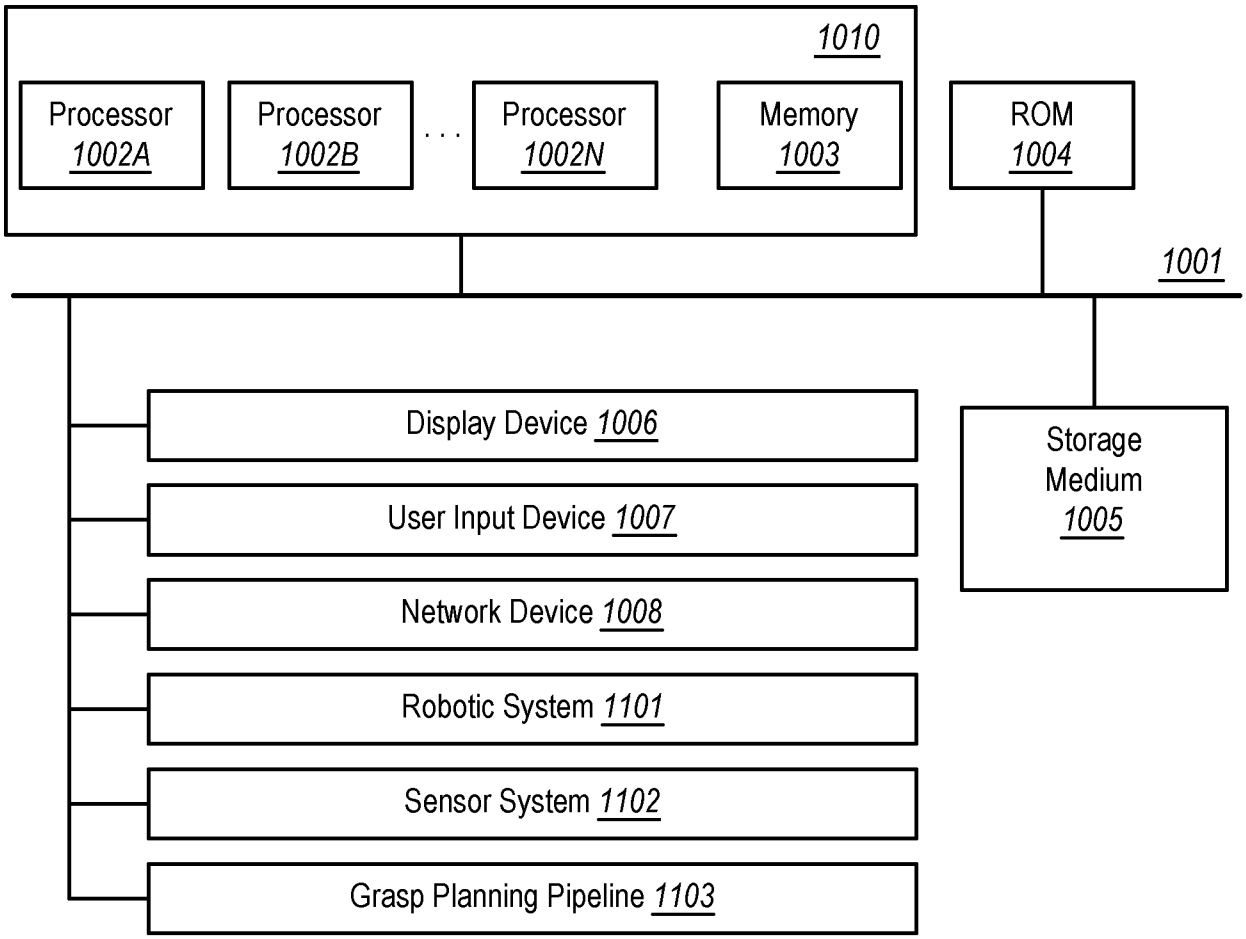

1010
Processor 1002A
Processor 1002B
. . .
Processor 1002N
Memory 1003
ROM 1004
1001
Display Device 1006
User Input Device 1007
Network Device 1008
Robotic System 1101
Sensor System 1102
Grasp Planning Pipeline 1103
Storage Medium 1005

FIG. 12

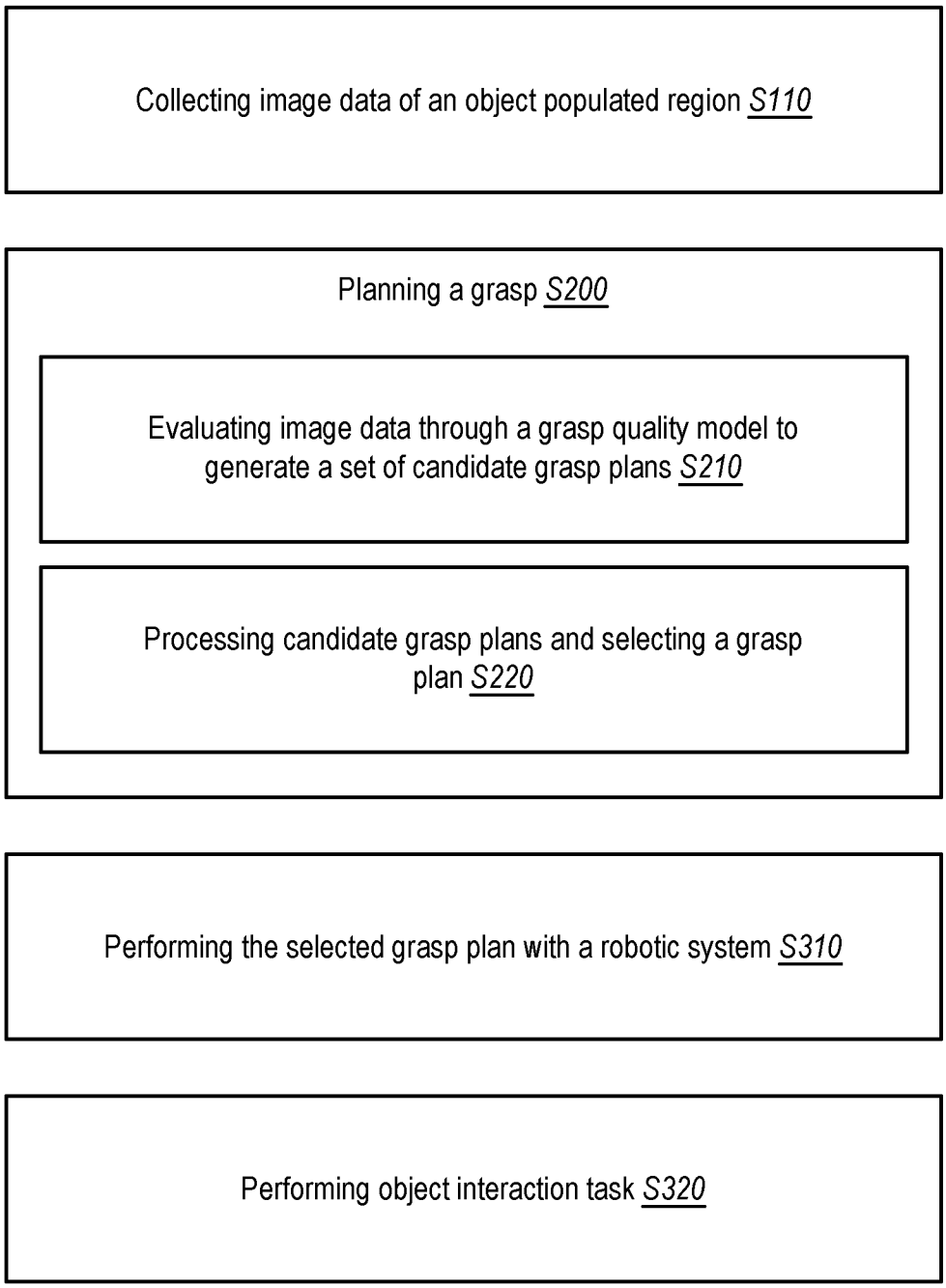

Collecting image data of an object populated region S110
Planning a grasp S200
Evaluating image data through a grasp quality model to generate a set of candidate grasp plans S210
Processing candidate grasp plans and selecting a grasp plan S220
Performing the selected grasp plan with a robotic system S310
Performing object interaction task S320

FIG. 13

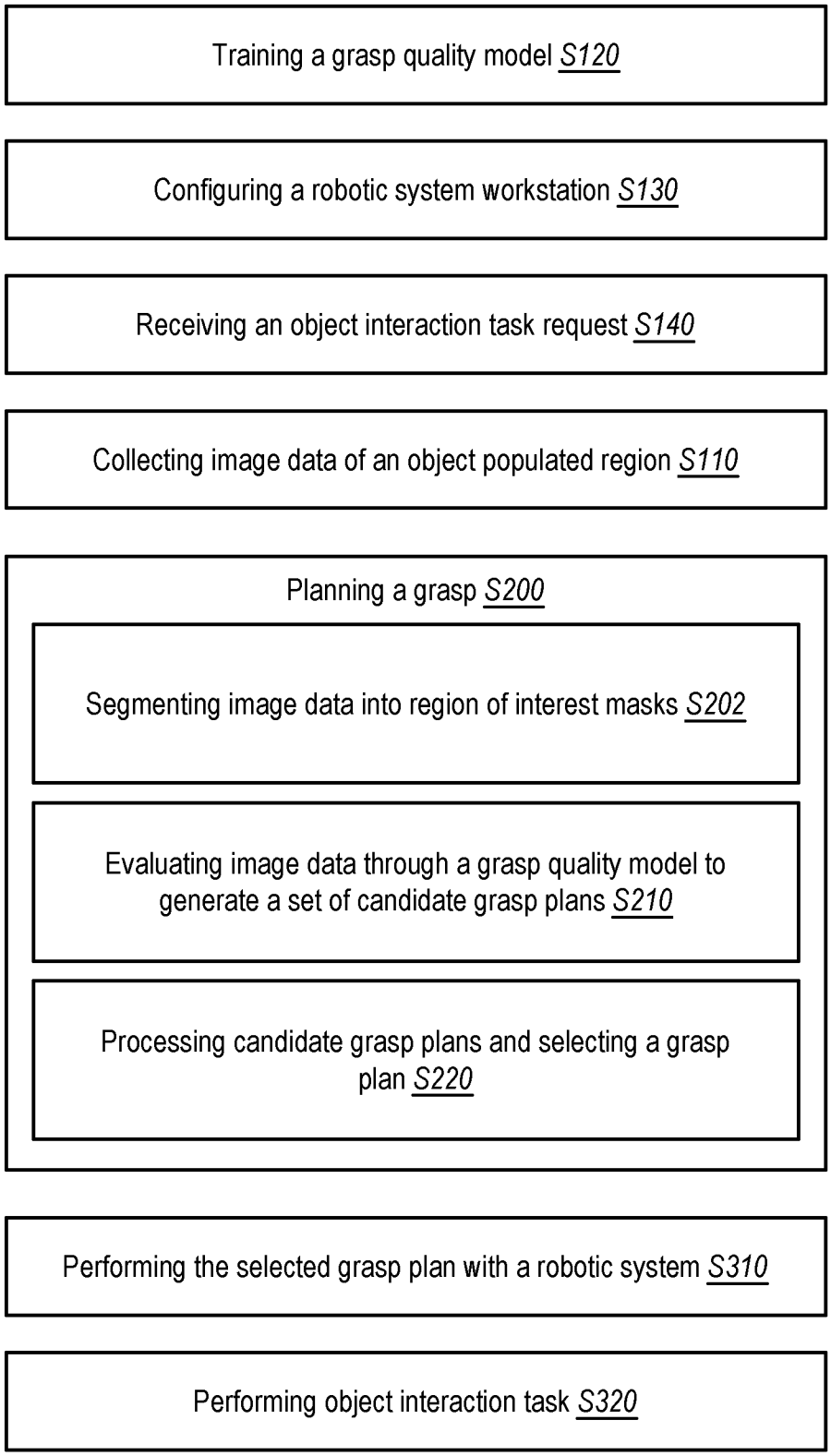

Training a grasp quality model S120
Configuring a robotic system workstation S130
Receiving an object interaction task request S140
Collecting image data of an object populated region S110
Planning a grasp S200
Segmenting image data into region of interest masks S202
Evaluating image data through a grasp quality model to generate a set of candidate grasp plans S210
Processing candidate grasp plans and selecting a grasp plan S220
Performing the selected grasp plan with a robotic system S310
Performing object interaction task S320

FIG. 14

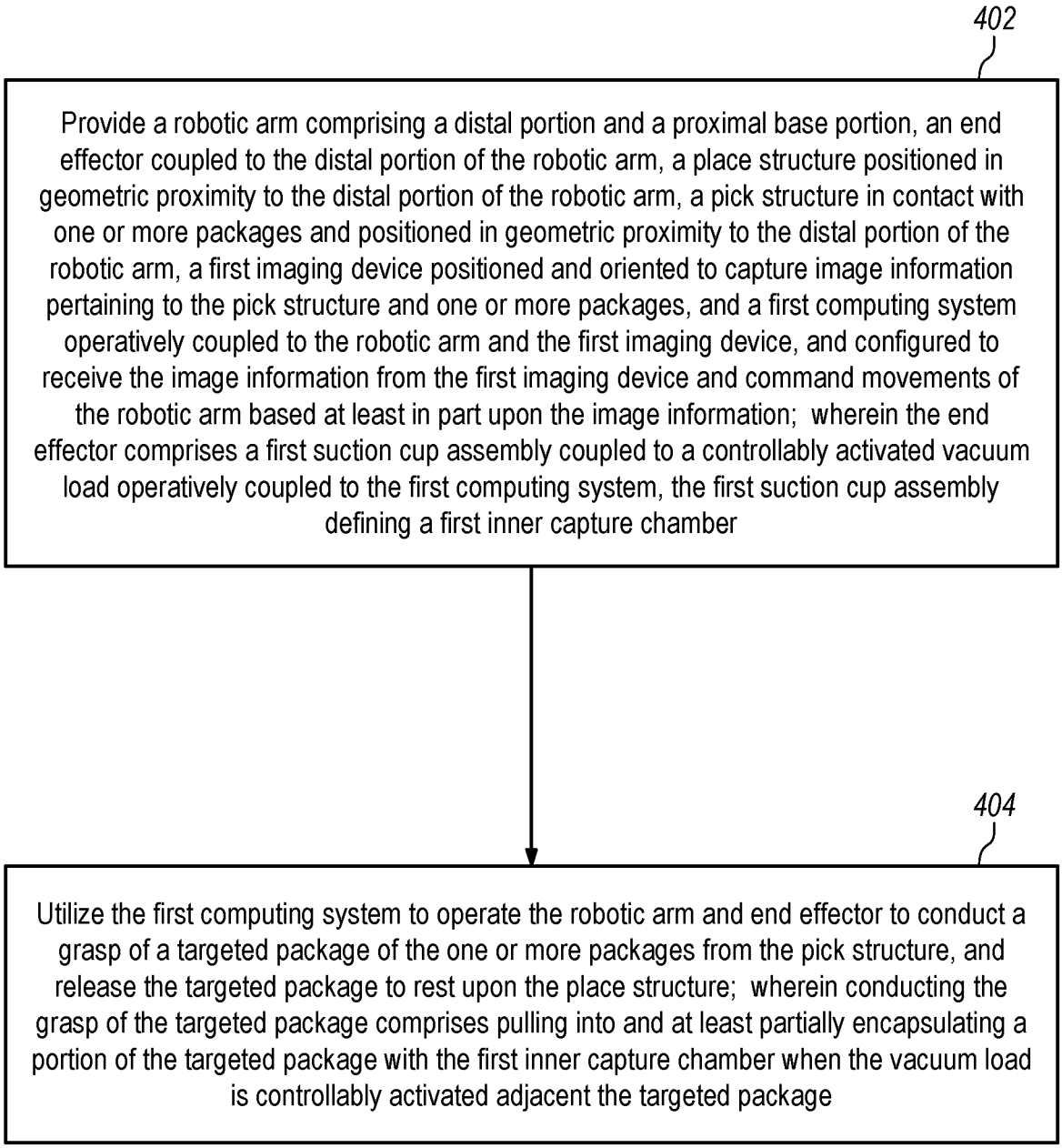

402
Provide a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, and a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly defining a first inner capture chamber
404
Utilize the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein conducting the grasp of the targeted package comprises pulling into and at least partially encapsulating a portion of the targeted package with the first inner capture chamber when the vacuum load is controllably activated adjacent the targeted package

FIG. 15

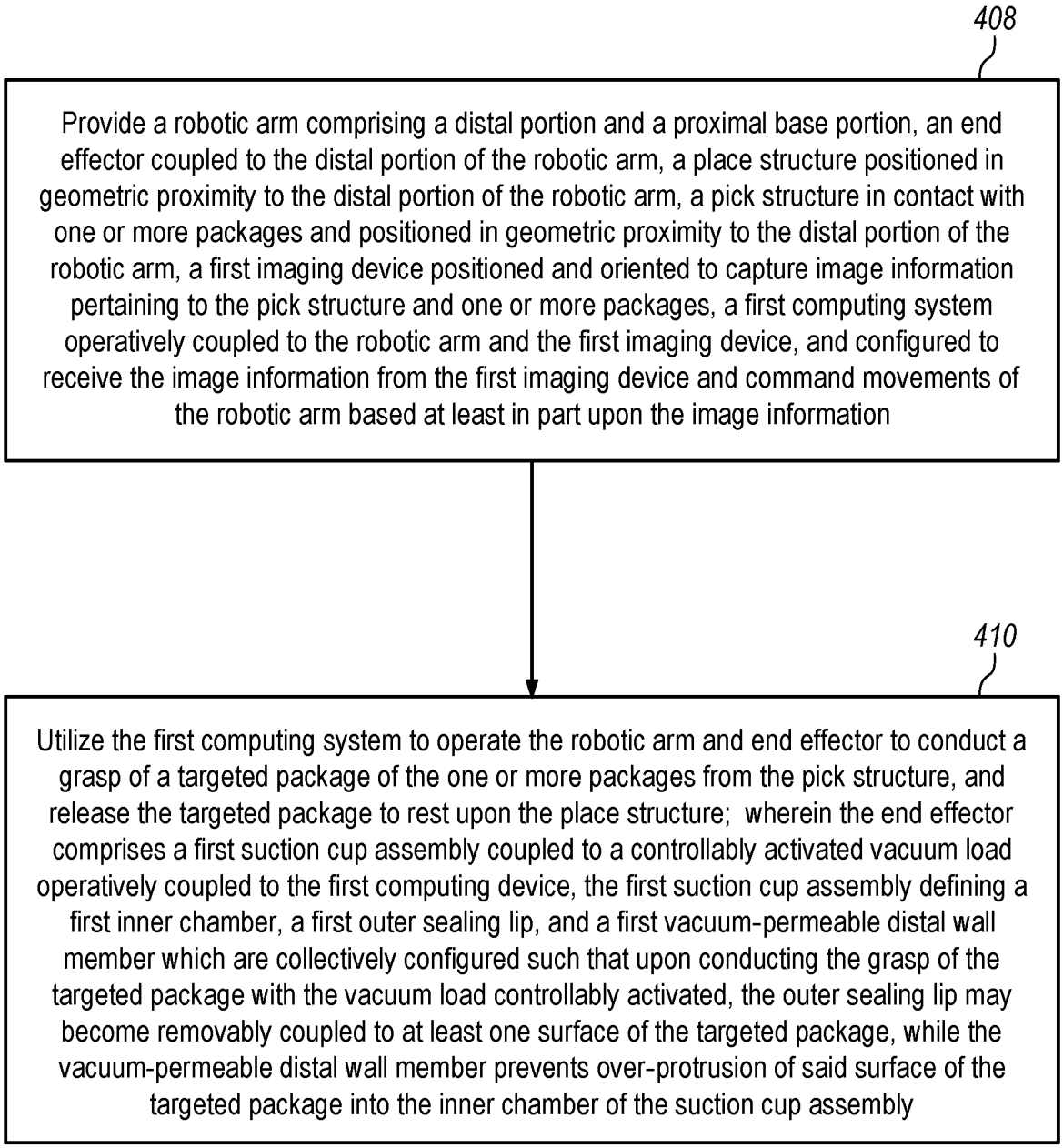

408
Provide a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information
410
Utilize the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing device, the first suction cup assembly defining a first inner chamber, a first outer sealing lip, and a first vacuum-permeable distal wall member which are collectively configured such that upon conducting the grasp of the targeted package with the vacuum load controllably activated, the outer sealing lip may become removably coupled to at least one surface of the targeted package, while the vacuum-permeable distal wall member prevents over-protrusion of said surface of the targeted package into the inner chamber of the suction cup assembly

FIG. 16

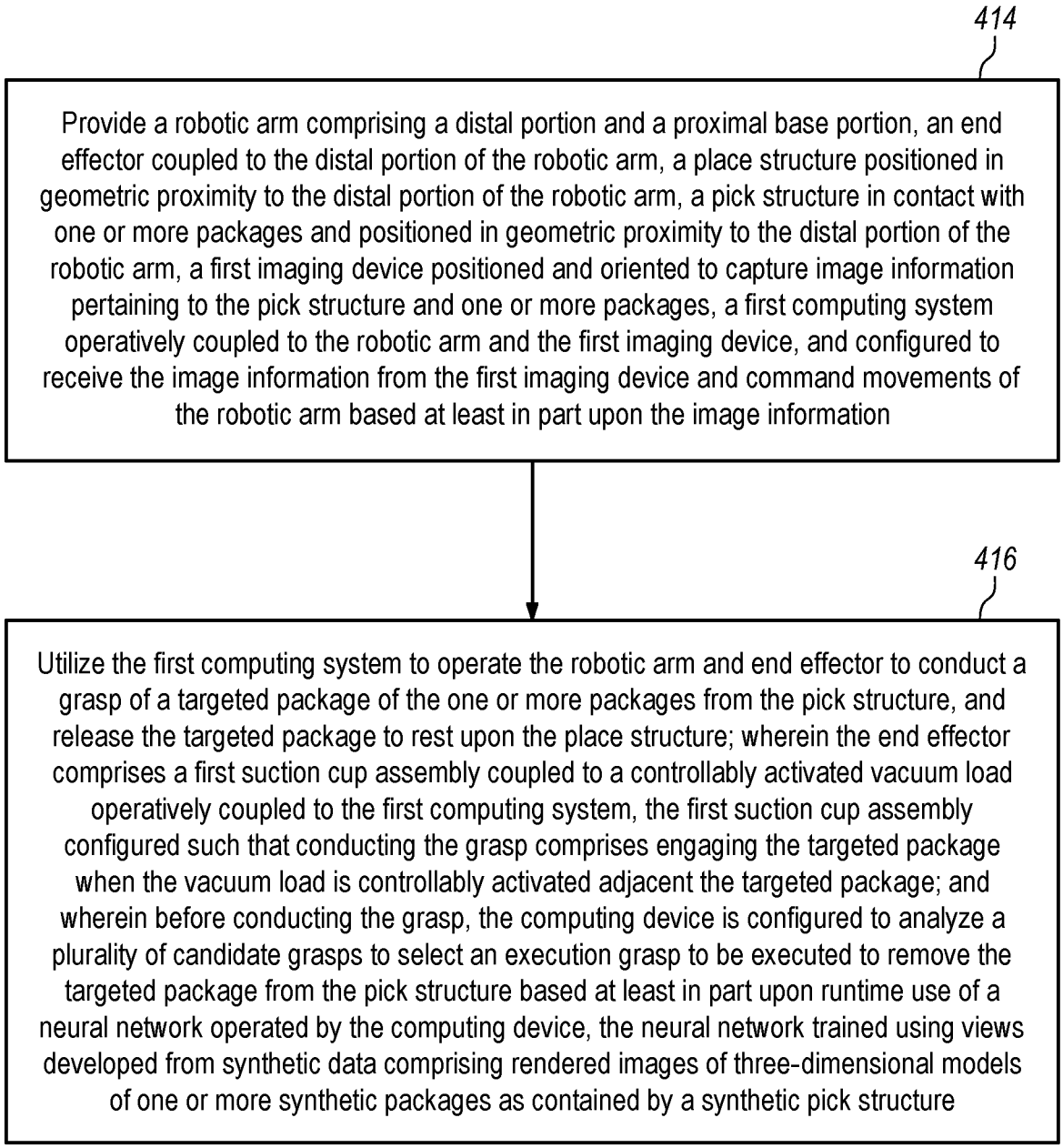

414
Provide a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information
416
Utilize the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package when the vacuum load is controllably activated adjacent the targeted package; and wherein before conducting the grasp, the computing device is configured to analyze a plurality of candidate grasps to select an execution grasp to be executed to remove the targeted package from the pick structure based at least in part upon runtime use of a neural network operated by the computing device, the neural network trained using views developed from synthetic data comprising rendered images of three-dimensional models of one or more synthetic packages as contained by a synthetic pick structure

FIG. 17

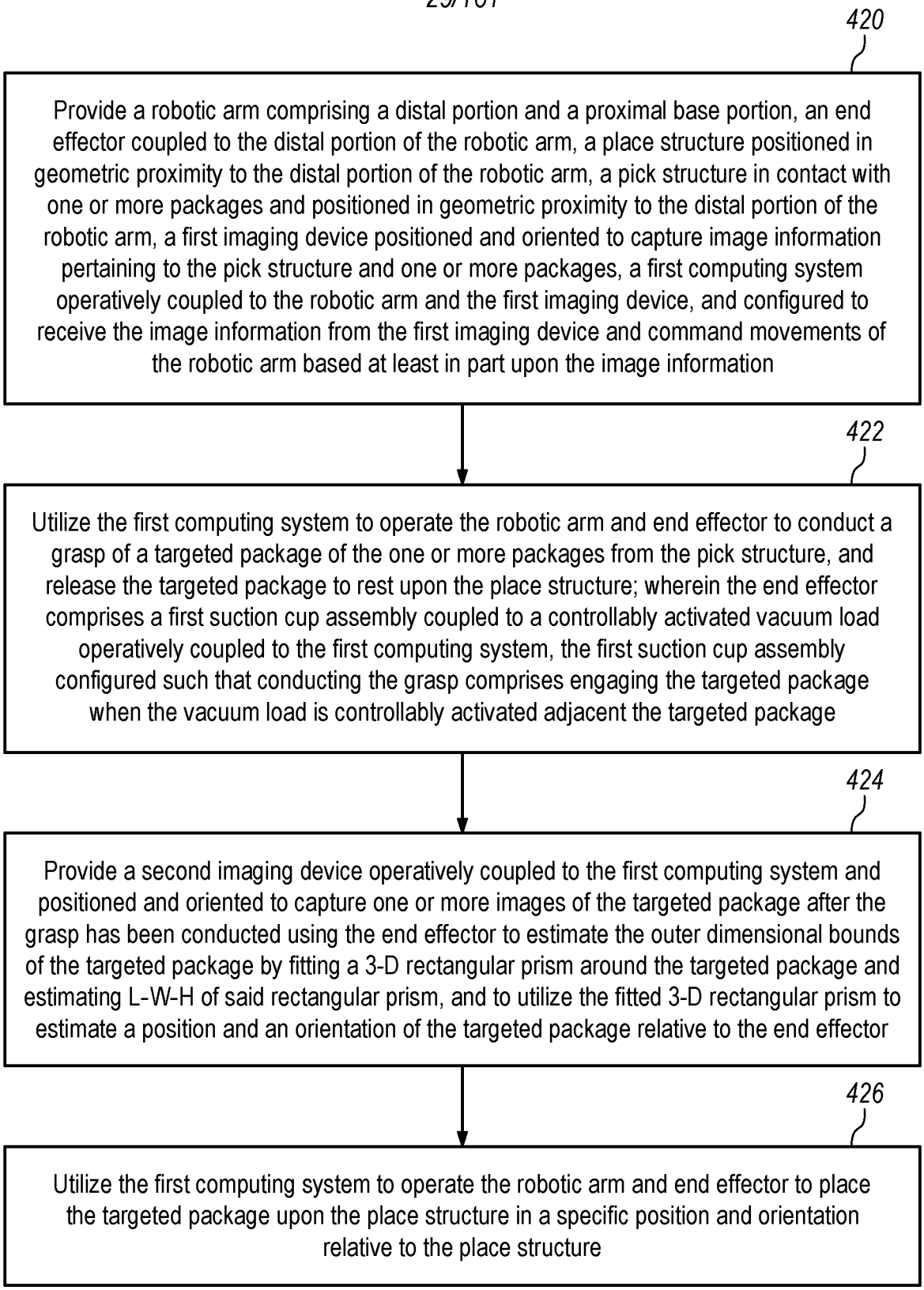

420
Provide a robotic arm comprising a distal portion and a proximal base portion, an end effector coupled to the distal portion of the robotic arm, a place structure positioned in geometric proximity to the distal portion of the robotic arm, a pick structure in contact with one or more packages and positioned in geometric proximity to the distal portion of the robotic arm, a first imaging device positioned and oriented to capture image information pertaining to the pick structure and one or more packages, a first computing system operatively coupled to the robotic arm and the first imaging device, and configured to receive the image information from the first imaging device and command movements of the robotic arm based at least in part upon the image information
422
Utilize the first computing system to operate the robotic arm and end effector to conduct a grasp of a targeted package of the one or more packages from the pick structure, and release the targeted package to rest upon the place structure; wherein the end effector comprises a first suction cup assembly coupled to a controllably activated vacuum load operatively coupled to the first computing system, the first suction cup assembly configured such that conducting the grasp comprises engaging the targeted package when the vacuum load is controllably activated adjacent the targeted package
424
Provide a second imaging device operatively coupled to the first computing system and positioned and oriented to capture one or more images of the targeted package after the grasp has been conducted using the end effector to estimate the outer dimensional bounds of the targeted package by fitting a 3-D rectangular prism around the targeted package and estimating L-W-H of said rectangular prism, and to utilize the fitted 3-D rectangular prism to estimate a position and an orientation of the targeted package relative to the end effector
426
Utilize the first computing system to operate the robotic arm and end effector to place the targeted package upon the place structure in a specific position and orientation relative to the place structure

FIG. 18

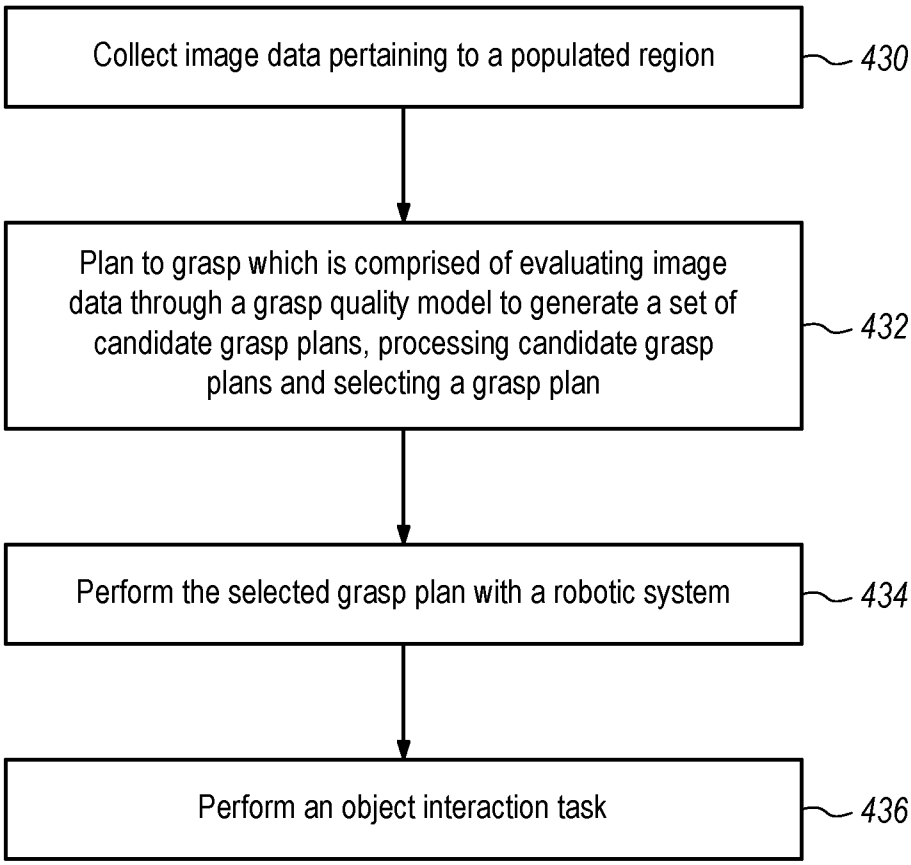

Collect image data pertaining to a populated region
430
Plan to grasp which is comprised of evaluating image data through a grasp quality model to generate a set of candidate grasp plans, processing candidate grasp plans and selecting a grasp plan
432
Perform the selected grasp plan with a robotic system
434
Perform an object interaction task
436

FIG. 19

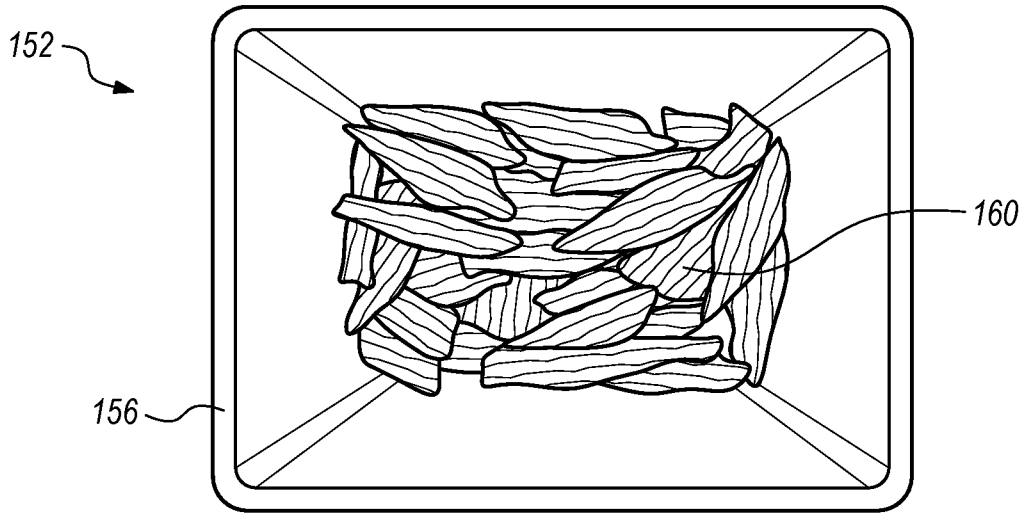


FIG. 20A

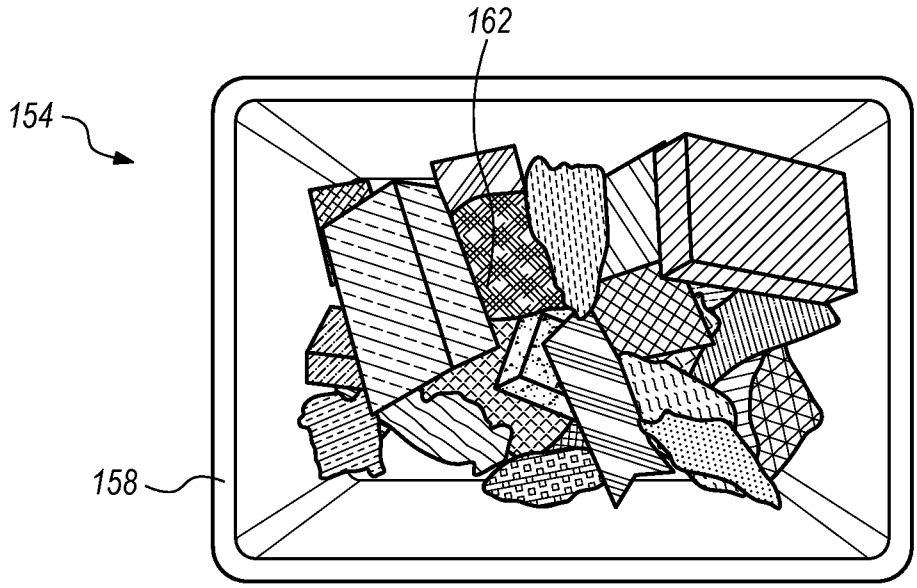


FIG. 20B

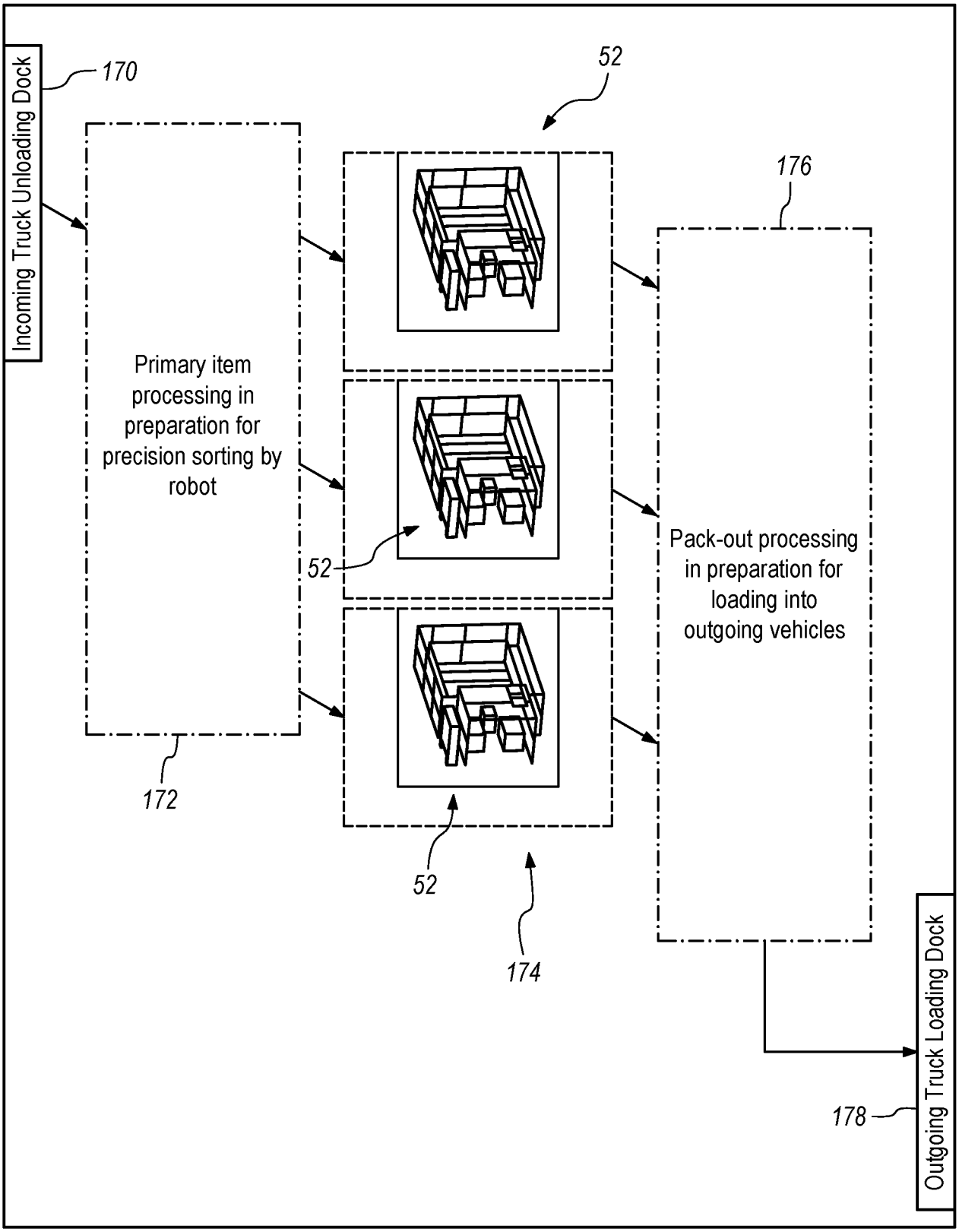

Incoming Truck Unloading Dock
170
52
176
Primary item processing in preparation for precision sorting by robot
52
Pack-out processing in preparation for loading into outgoing vehicles
172
52
174
178
Outgoing Truck Loading Dock

FIG. 21A

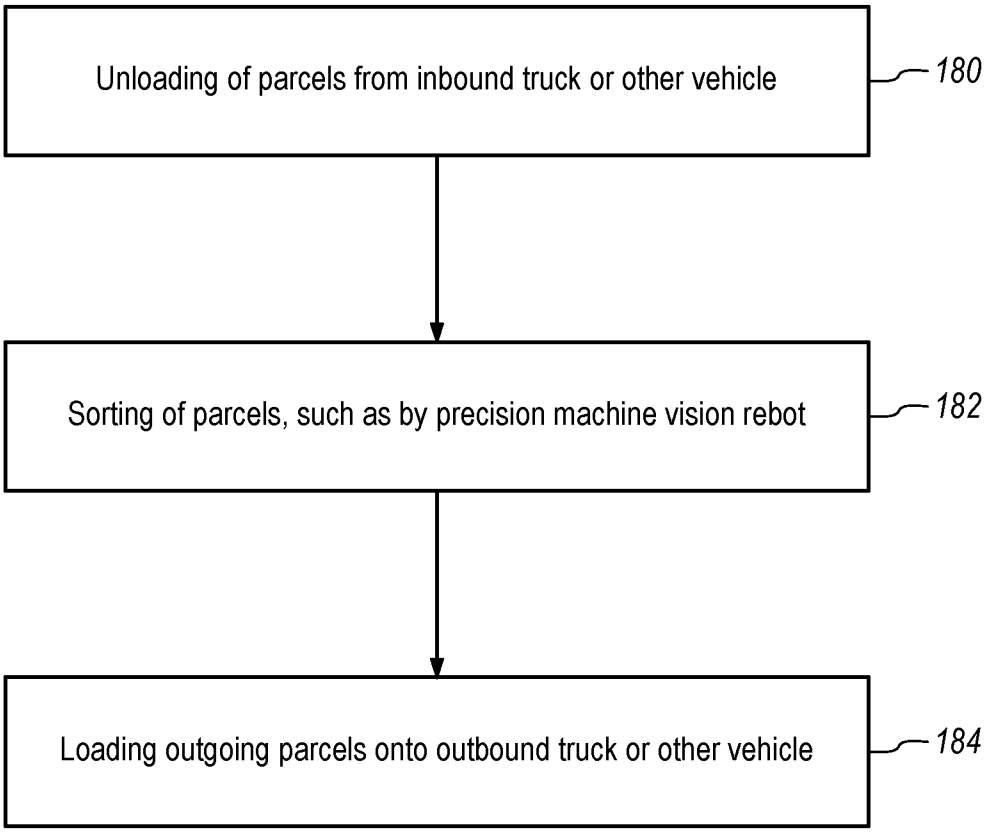

Unloading of parcels from inbound truck or other vehicle
180
Sorting of parcels, such as by precision machine vision rebot
182
Loading outgoing parcels onto outbound truck or other vehicle
184

FIG. 21B

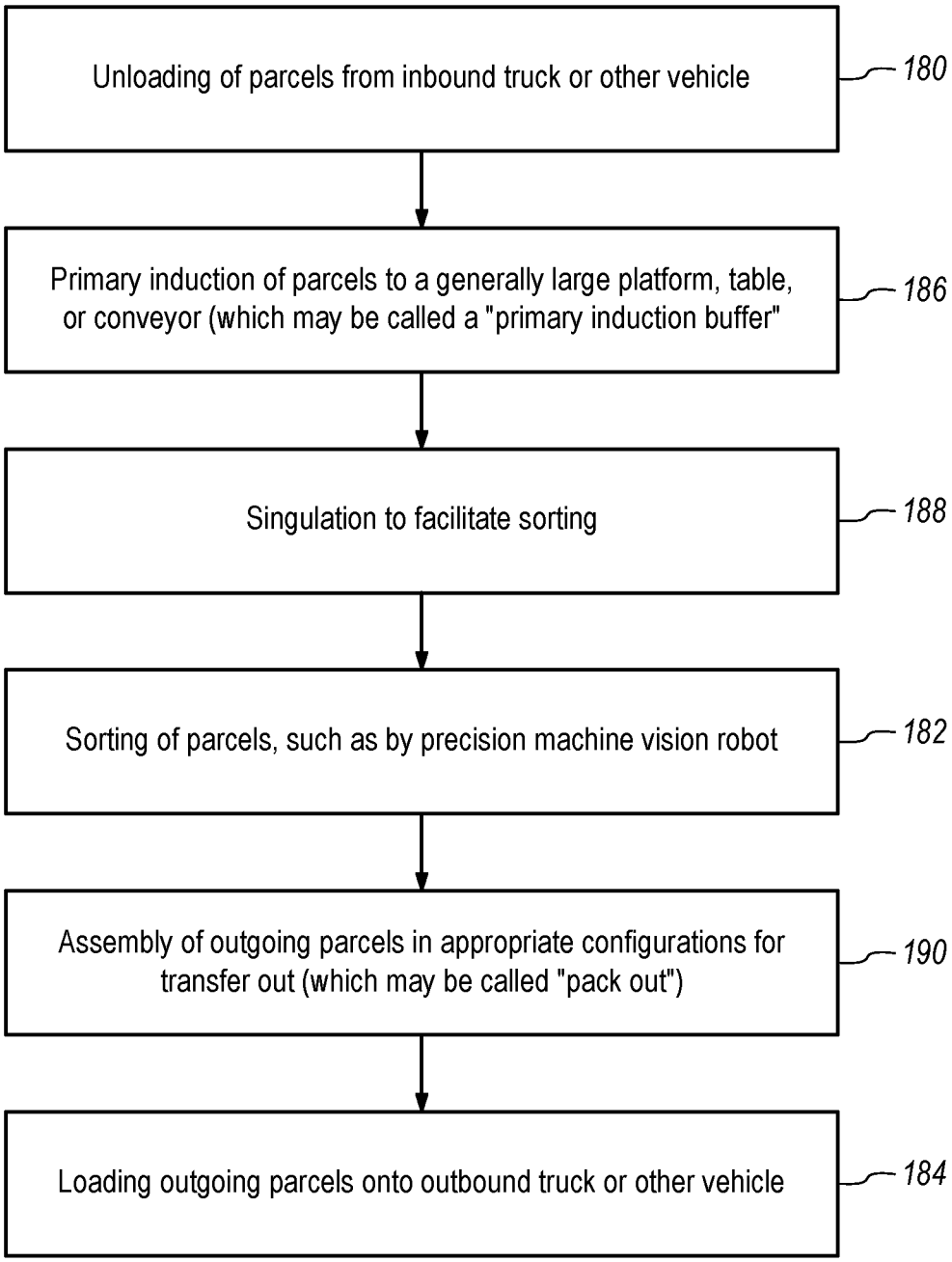

Unloading of parcels from inbound truck or other vehicle
180
Primary induction of parcels to a generally large platform, table, or conveyor (which may be called a "primary induction buffer"
186
Singulation to facilitate sorting
188
Sorting of parcels, such as by precision machine vision robot
182
Assembly of outgoing parcels in appropriate configurations for transfer out (which may be called "pack out")
190
Loading outgoing parcels onto outbound truck or other vehicle
184

FIG. 22A

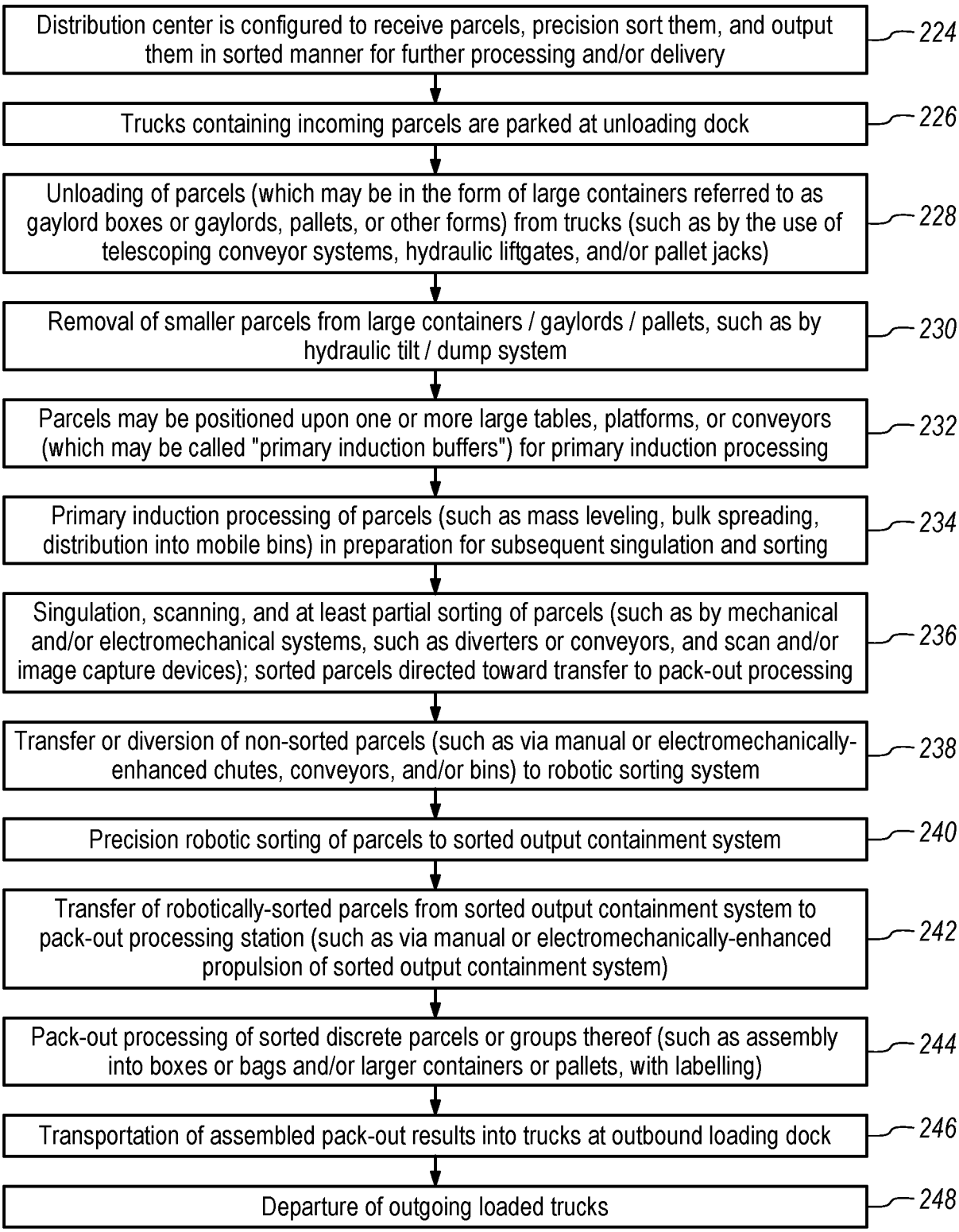

Distribution center is configured to receive parcels, precision sort them, and output them in sorted manner for further processing and/or delivery
224
Trucks containing incoming parcels are parked at unloading dock
226
Unloading of parcels (which may be in the form of large containers referred to as gaylord boxes or gaylords, pallets, or other forms) from trucks (such as by the use of telescoping conveyor systems, hydraulic liftgates, and/or pallet jacks)
228
Removal of smaller parcels from large containers / gaylords / pallets, such as by hydraulic tilt / dump system
230
Parcels may be positioned upon one or more large tables, platforms, or conveyors (which may be called "primary induction buffers") for primary induction processing
232
Primary induction processing of parcels (such as mass leveling, bulk spreading, distribution into mobile bins) in preparation for subsequent singulation and sorting
234
Singulation, scanning, and at least partial sorting of parcels (such as by mechanical and/or electromechanical systems, such as diverters or conveyors, and scan and/or image capture devices); sorted parcels directed toward transfer to pack-out processing
236
Transfer or diversion of non-sorted parcels (such as via manual or electromechanically-enhanced chutes, conveyors, and/or bins) to robotic sorting system
238
Precision robotic sorting of parcels to sorted output containment system
240
Transfer of robotically-sorted parcels from sorted output containment system to pack-out processing station (such as via manual or electromechanically-enhanced propulsion of sorted output containment system)
242
Pack-out processing of sorted discrete parcels or groups thereof (such as assembly into boxes or bags and/or larger containers or pallets, with labelling)
244
Transportation of assembled pack-out results into trucks at outbound loading dock
246
Departure of outgoing loaded trucks
248

FIG. 22B

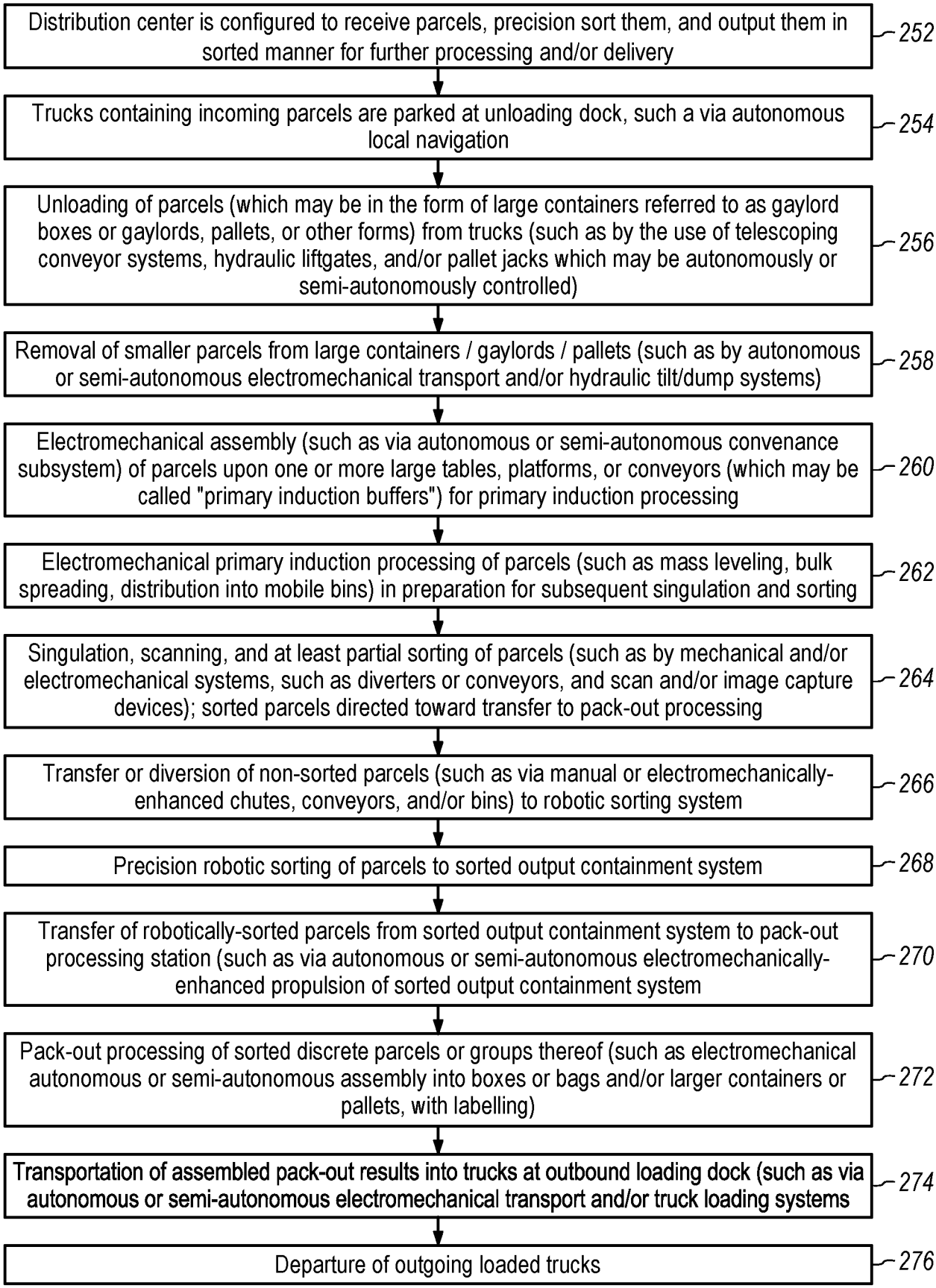

Distribution center is configured to receive parcels, precision sort them, and output them in sorted manner for further processing and/or delivery
252
Trucks containing incoming parcels are parked at unloading dock, such a via autonomous local navigation
254
Unloading of parcels (which may be in the form of large containers referred to as gaylord boxes or gaylords, pallets, or other forms) from trucks (such as by the use of telescoping conveyor systems, hydraulic liftgates, and/or pallet jacks which may be autonomously or semi-autonomously controlled)
256
Removal of smaller parcels from large containers / gaylords / pallets (such as by autonomous or semi-autonomous electromechanical transport and/or hydraulic tilt/dump systems)
258
Electromechanical assembly (such as via autonomous or semi-autonomous convenance subsystem) of parcels upon one or more large tables, platforms, or conveyors (which may be called "primary induction buffers") for primary induction processing
260
Electromechanical primary induction processing of parcels (such as mass leveling, bulk spreading, distribution into mobile bins) in preparation for subsequent singulation and sorting
262
Singulation, scanning, and at least partial sorting of parcels (such as by mechanical and/or electromechanical systems, such as diverters or conveyors, and scan and/or image capture devices); sorted parcels directed toward transfer to pack-out processing
264
Transfer or diversion of non-sorted parcels (such as via manual or electromechanically-enhanced chutes, conveyors, and/or bins) to robotic sorting system
266
Precision robotic sorting of parcels to sorted output containment system
268
Transfer of robotically-sorted parcels from sorted output containment system to pack-out processing station (such as via autonomous or semi-autonomous electromechanically-enhanced propulsion of sorted output containment system
270
Pack-out processing of sorted discrete parcels or groups thereof (such as electromechanical autonomous or semi-autonomous assembly into boxes or bags and/or larger containers or pallets, with labelling)
272
Transportation of assembled pack-out results into trucks at outbound loading dock (such as via autonomous or semi-autonomous electromechanical transport and/or truck loading systems
274
Departure of outgoing loaded trucks
276

FIG. 22C

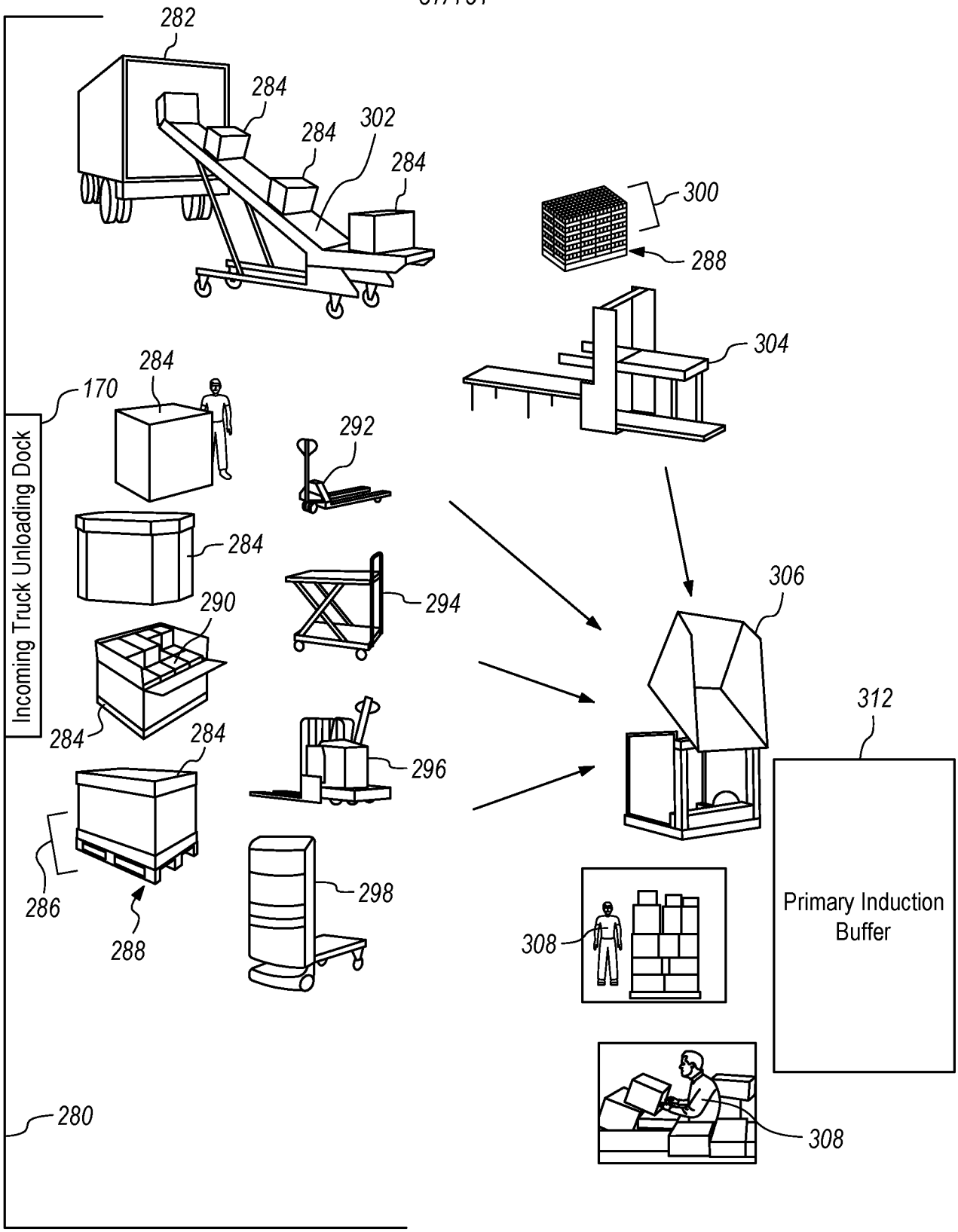

282
284
284
302
284
300
288
304
284
170
292
284
294
290
306
284
284
296
312
286
288
298
Primary Induction Buffer
308
280
308
Incoming Truck Unloading Dock

FIG. 23

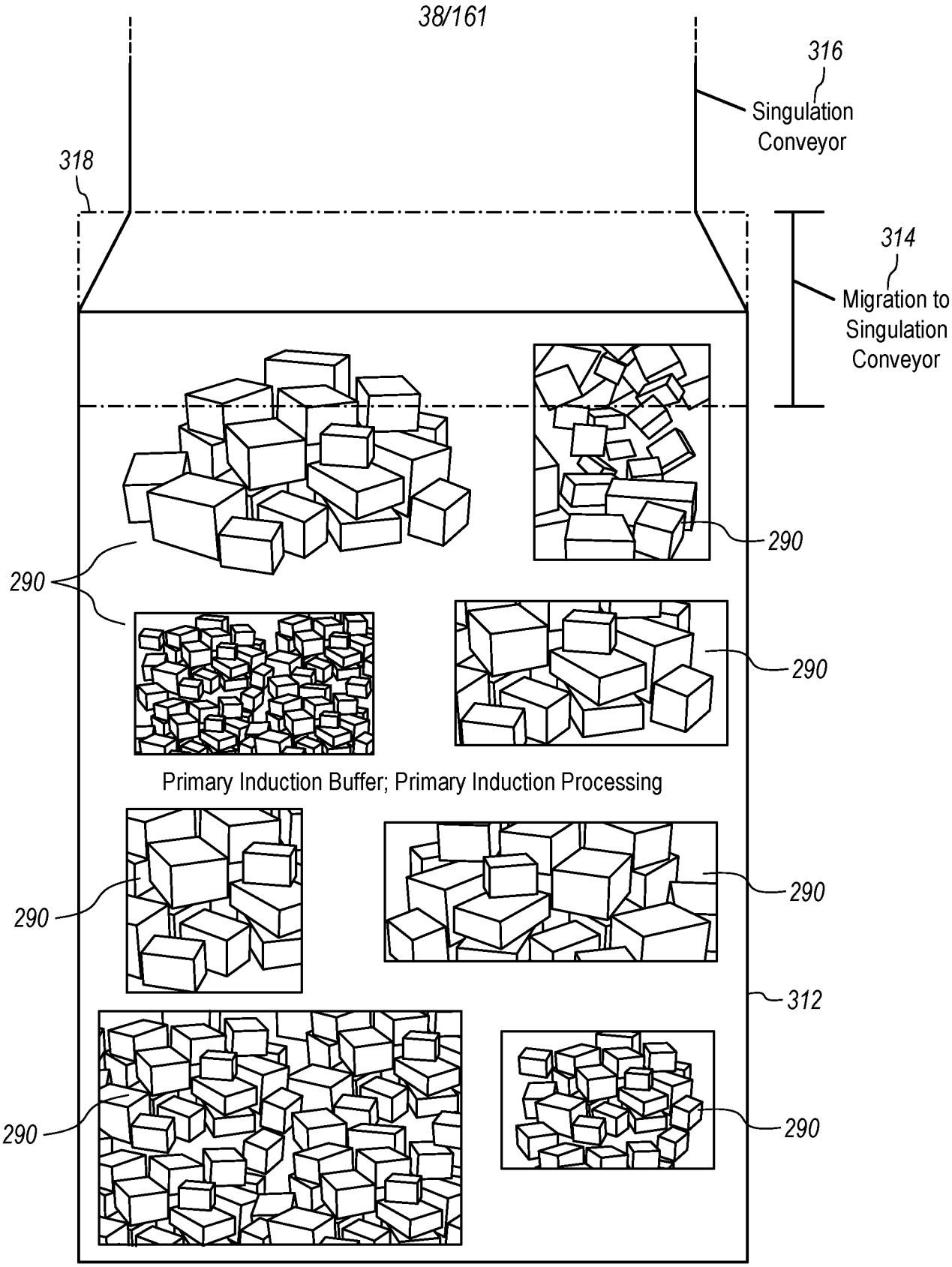

38/161
316
Singulation Conveyor
318
314
Migration to Singulation Conveyor
290
290
290
290
290
Primary Induction Buffer; Primary Induction Processing
290
290
312
290
290

FIG. 24A

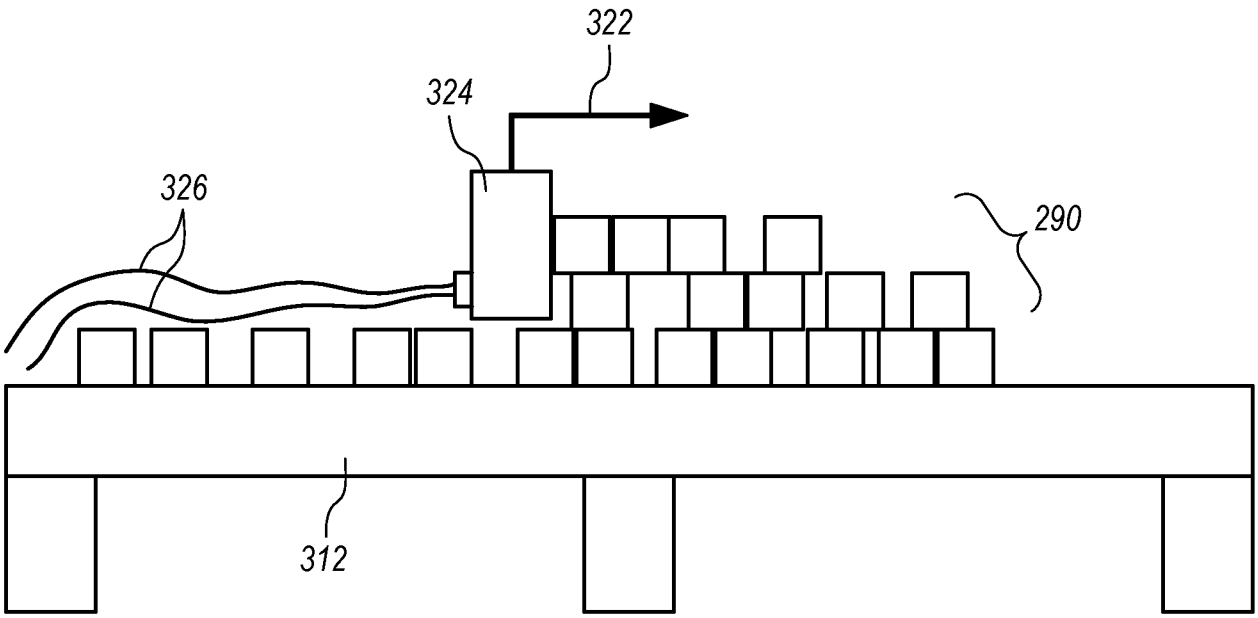


FIG. 24B

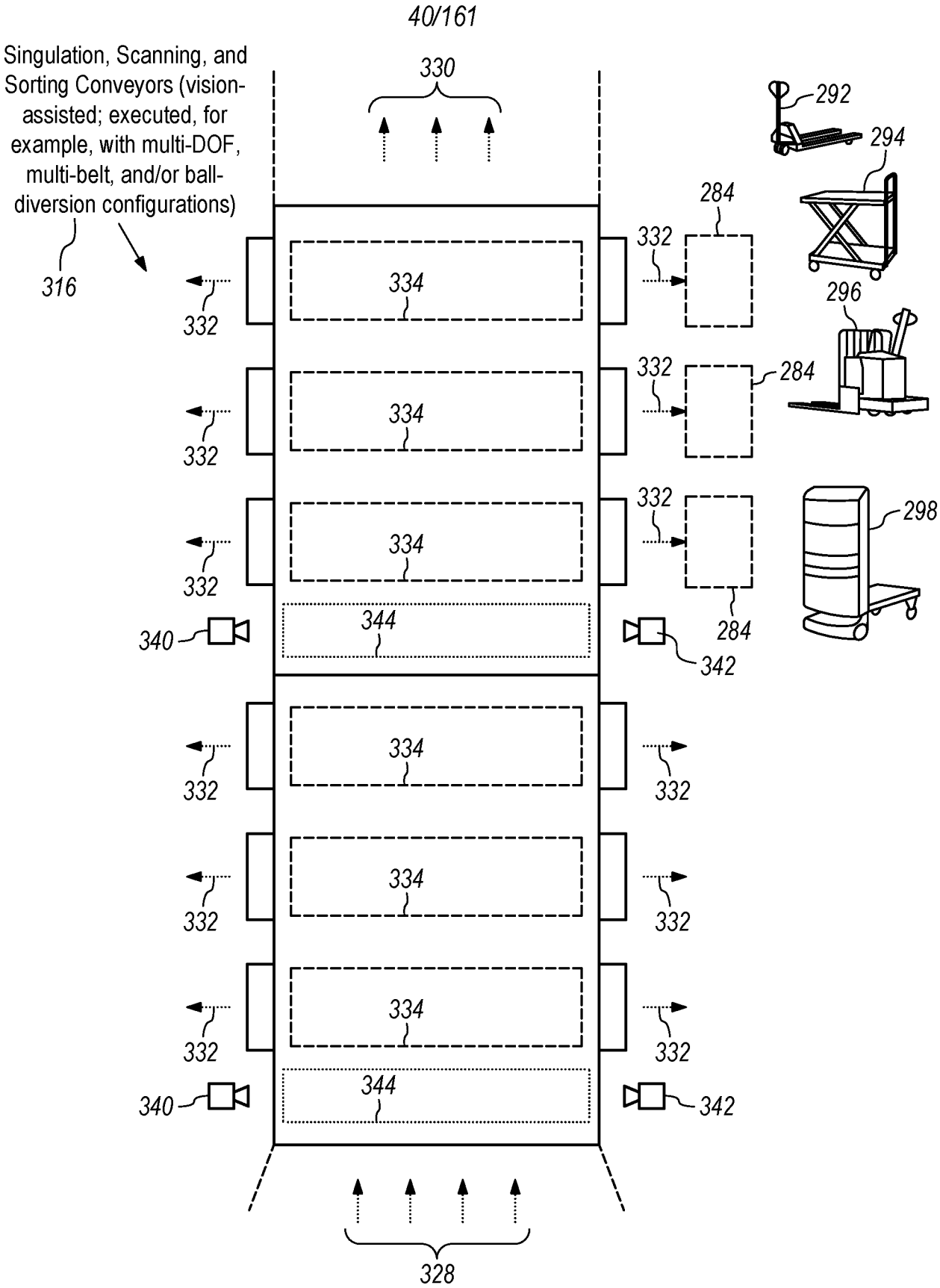

40/161
Singulation, Scanning, and Sorting Conveyors (vision-assisted; executed, for example, with multi-DOF, multi-belt, and/or ball-diversion configurations)
316
330
292
294
284
332
334
296
298
340
342
344
328

FIG. 25

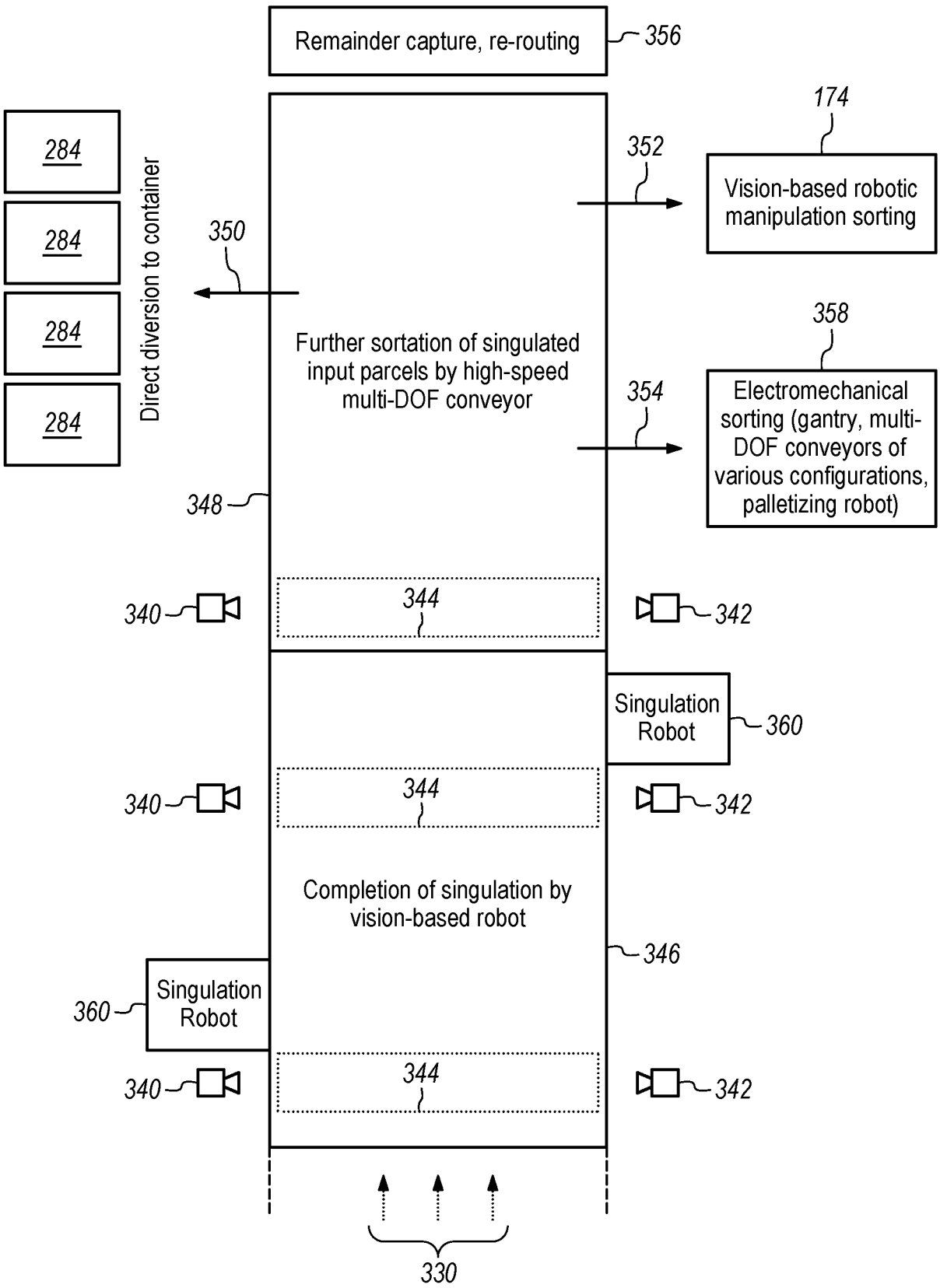

Remainder capture, re-routing
356
174
352
Vision-based robotic manipulation sorting
284
284
284
284
Direct diversion to container
350
Further sortation of singulated input parcels by high-speed multi-DOF conveyor
358
354
Electromechanical sorting (gantry, multi-DOF conveyors of various configurations, palletizing robot)
348
340
344
342
Singulation Robot
360
340
344
342
Completion of singulation by vision-based robot
346
360
Singulation Robot
340
344
342
330

FIG. 26A

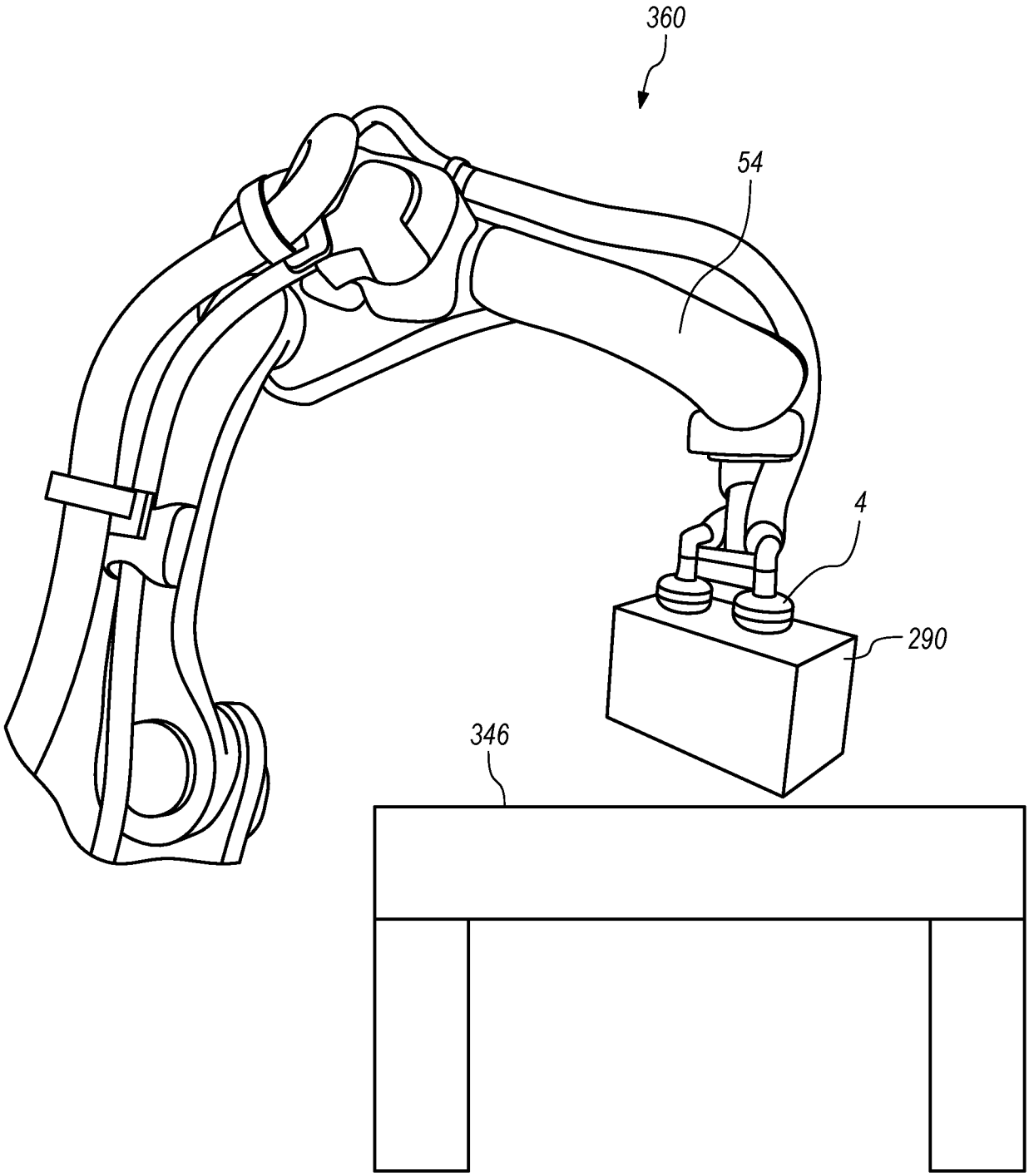


FIG. 26B

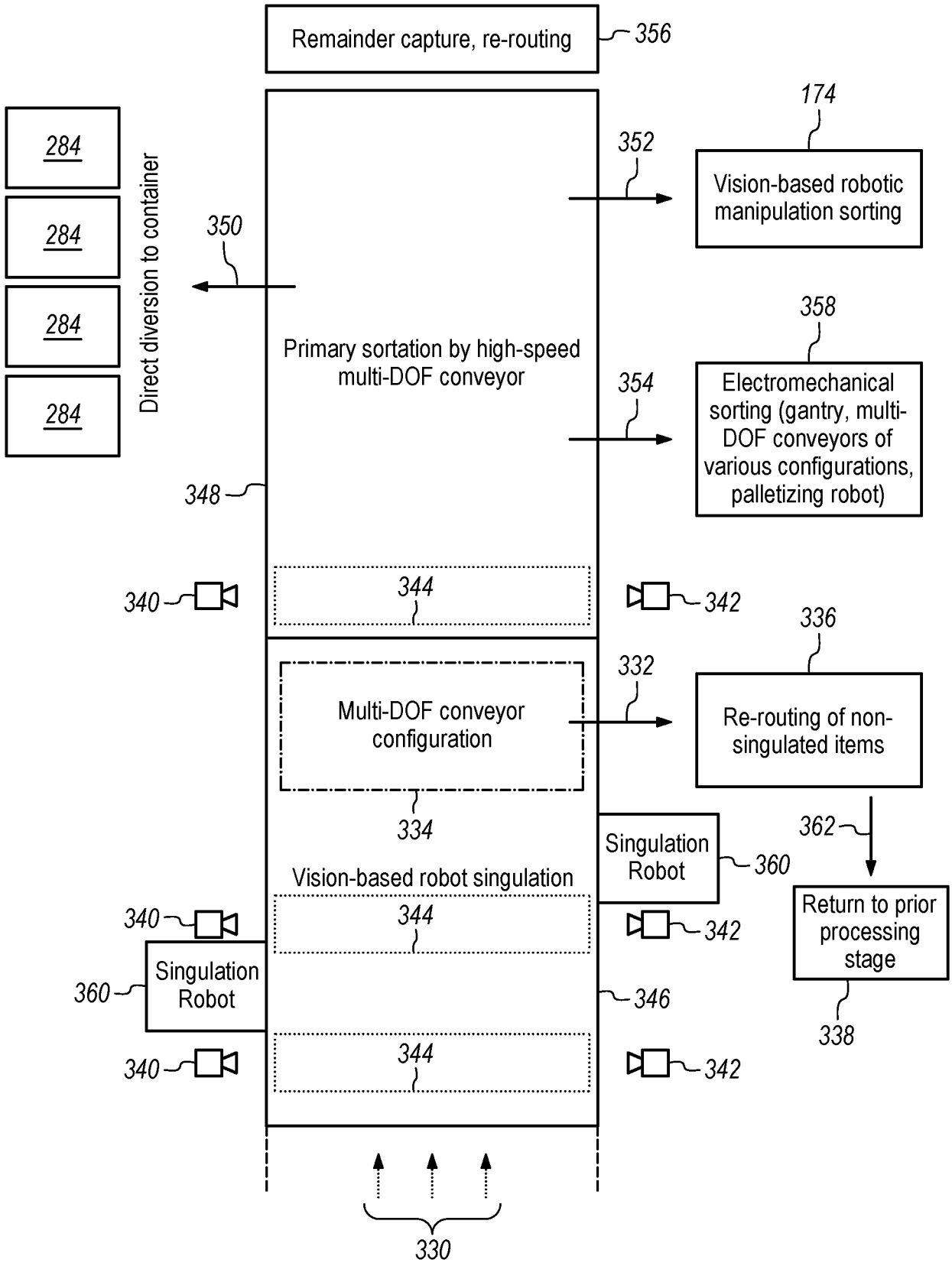

Remainder capture, re-routing
356
174
284
284
284
284
Direct diversion to container
352
Vision-based robotic manipulation sorting
350
358
Primary sortation by high-speed multi-DOF conveyor
354
Electromechanical sorting (gantry, multi-DOF conveyors of various configurations, palletizing robot)
348
340
344
342
336
332
Multi-DOF conveyor configuration
Re-routing of non-singulated items
334
362
Singulation Robot
360
Vision-based robot singulation
340
344
342
Return to prior processing stage
Singulation Robot
360
346
340
344
342
338
330

FIG. 26C

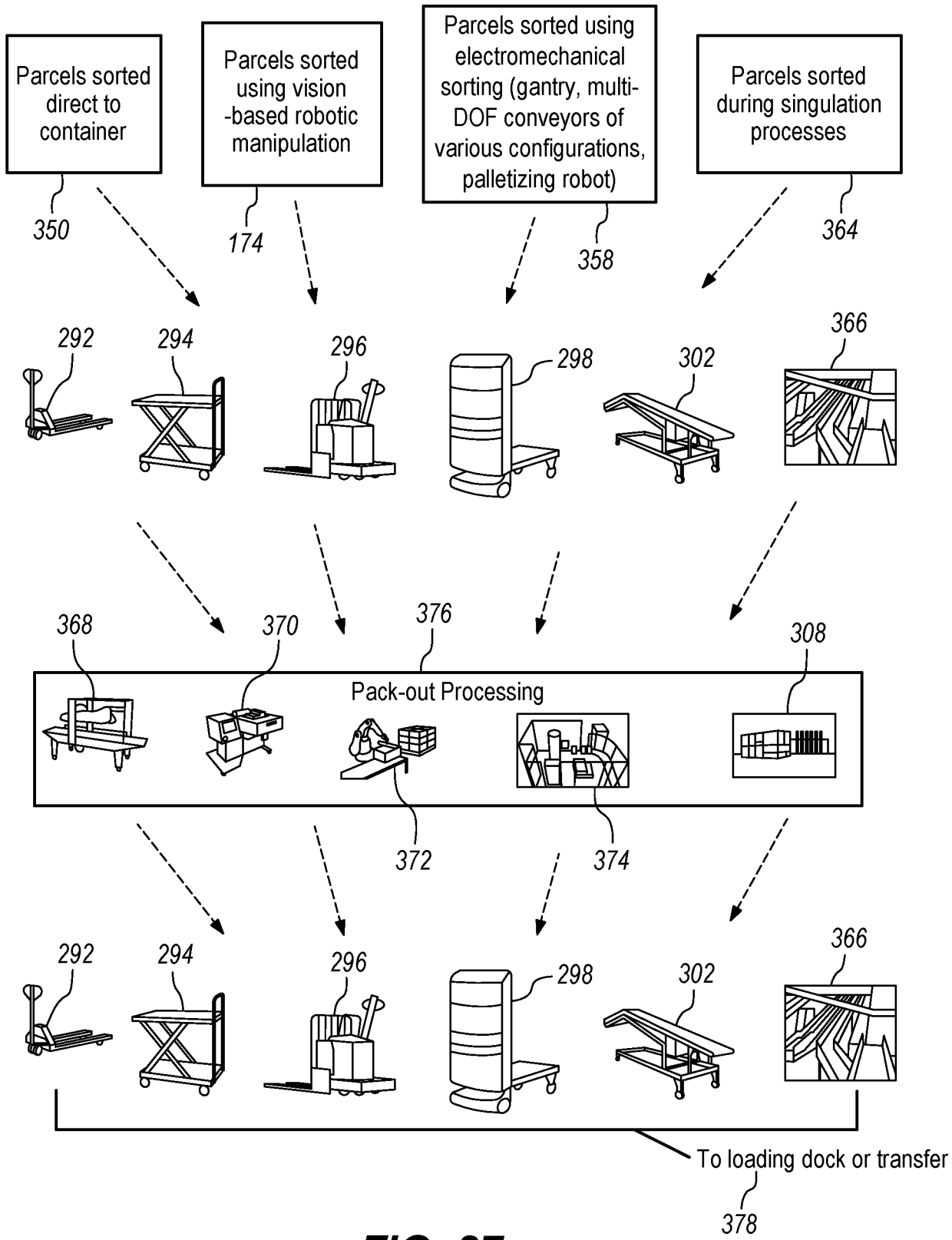

Parcels sorted direct to container
Parcels sorted using vision -based robotic manipulation
Parcels sorted using electromechanical sorting (gantry, multi-DOF conveyors of various configurations, palletizing robot)
Parcels sorted during singulation processes
350
174
358
364
292
294
296
298
302
366
368
370
376
308
Pack-out Processing
372
374
292
294
296
298
302
366
To loading dock or transfer
378

FIG. 27

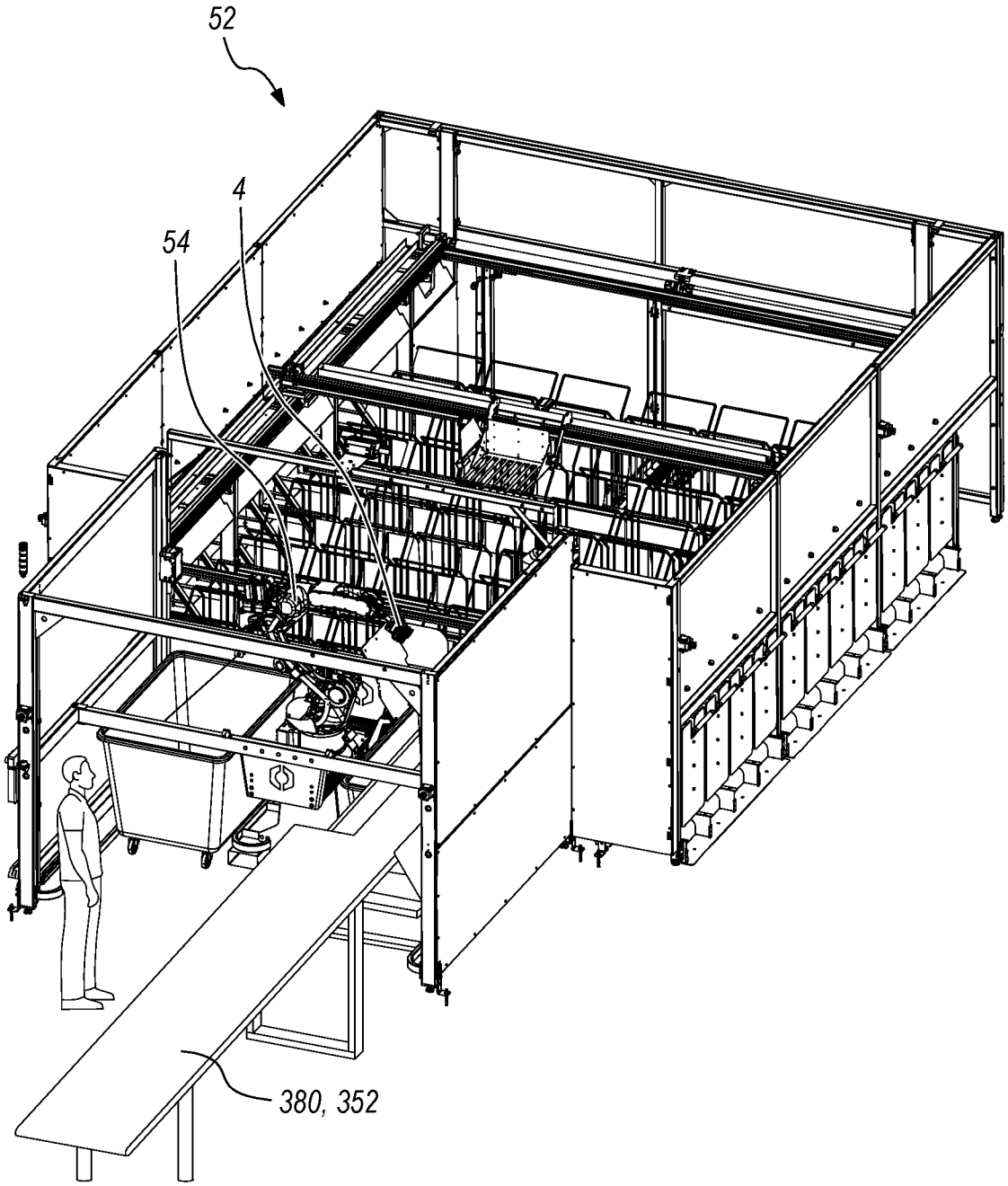


FIG. 28A

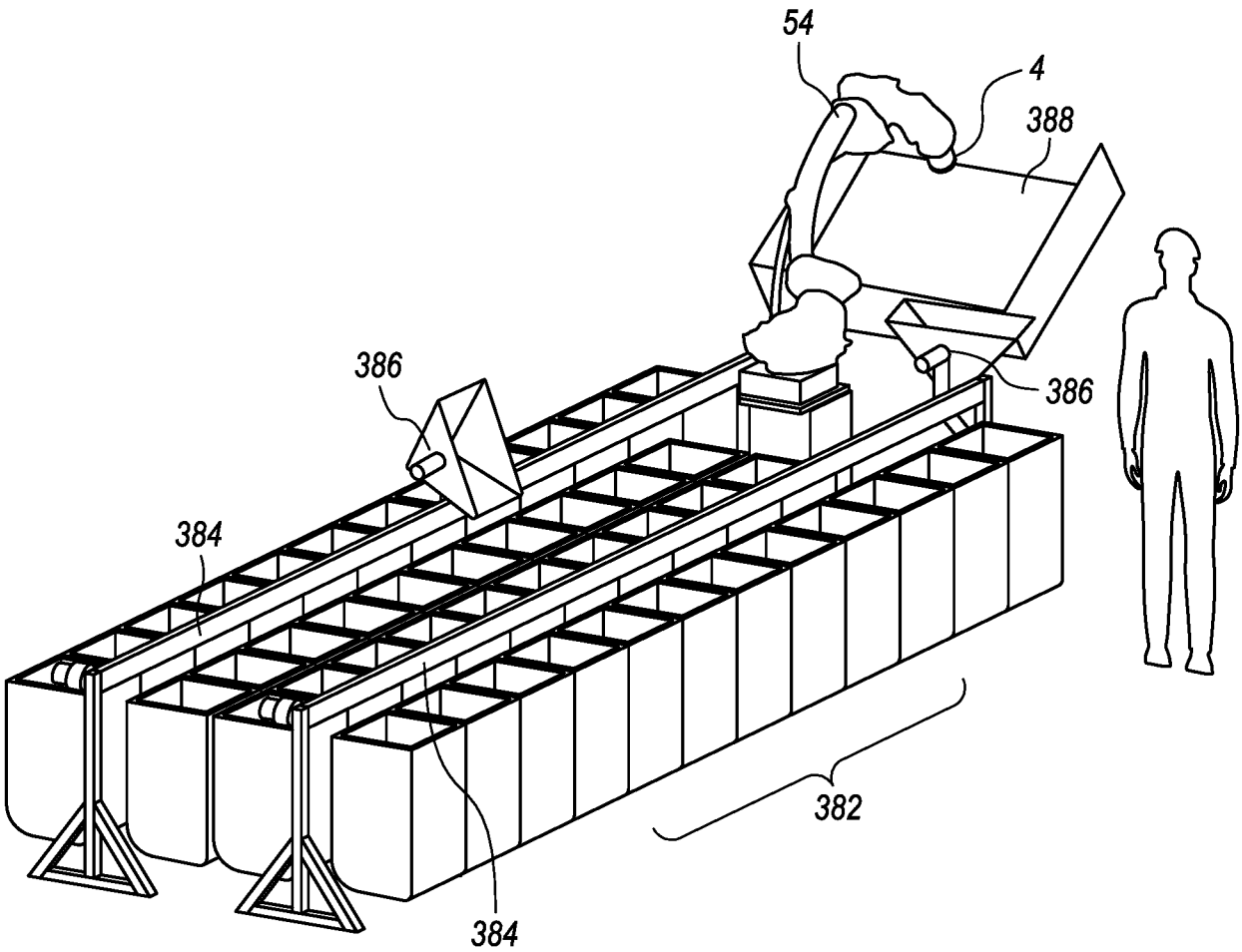


FIG. 28B

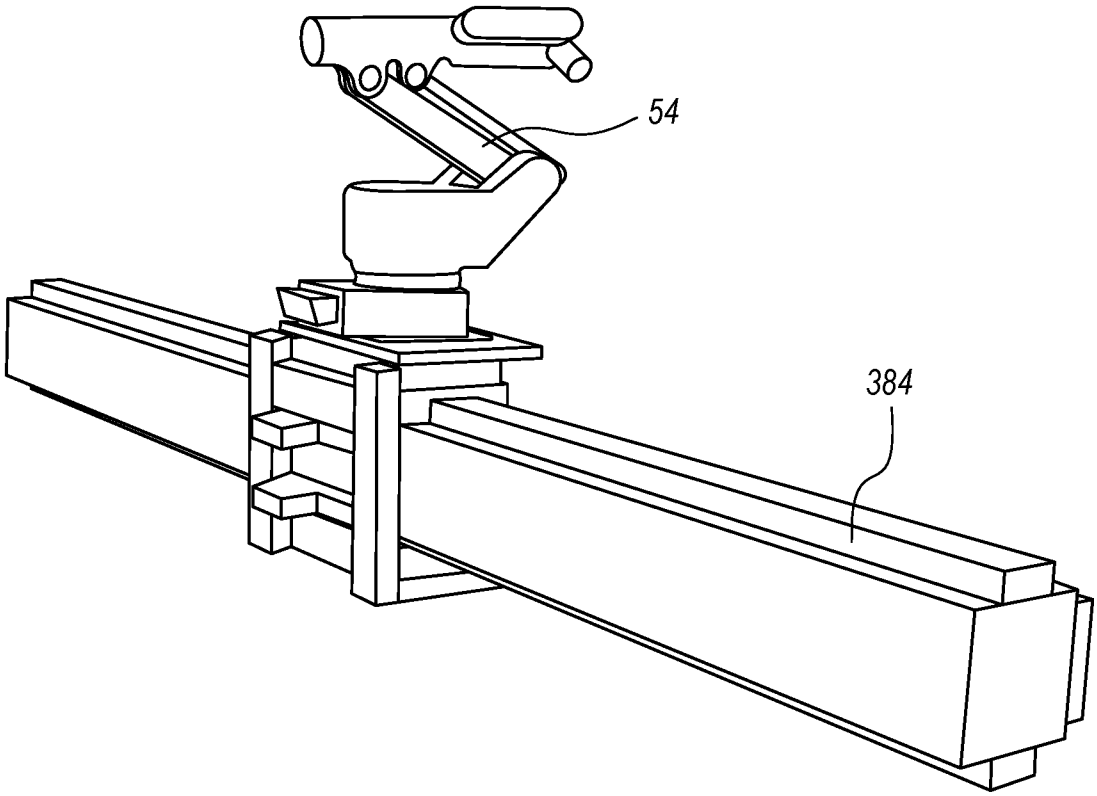


FIG. 28C

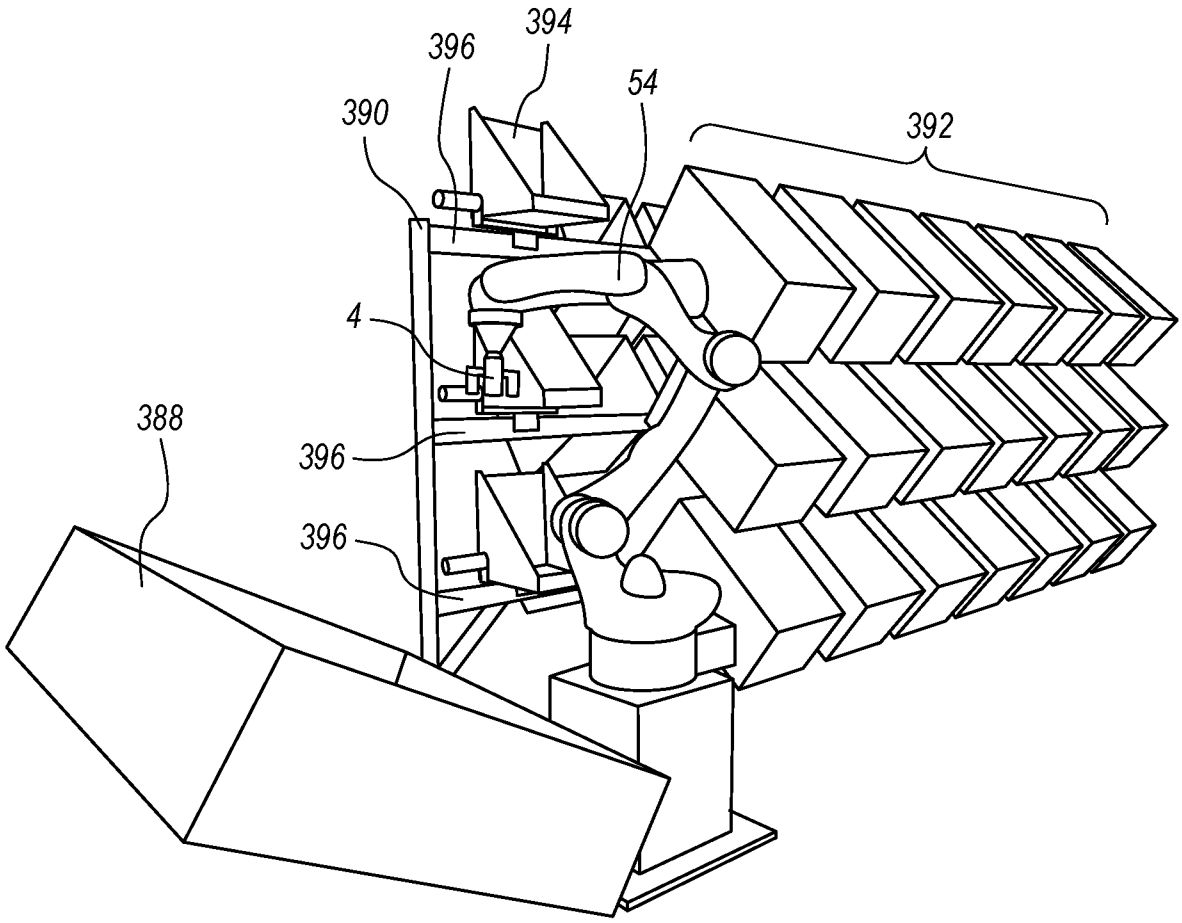


FIG. 28D

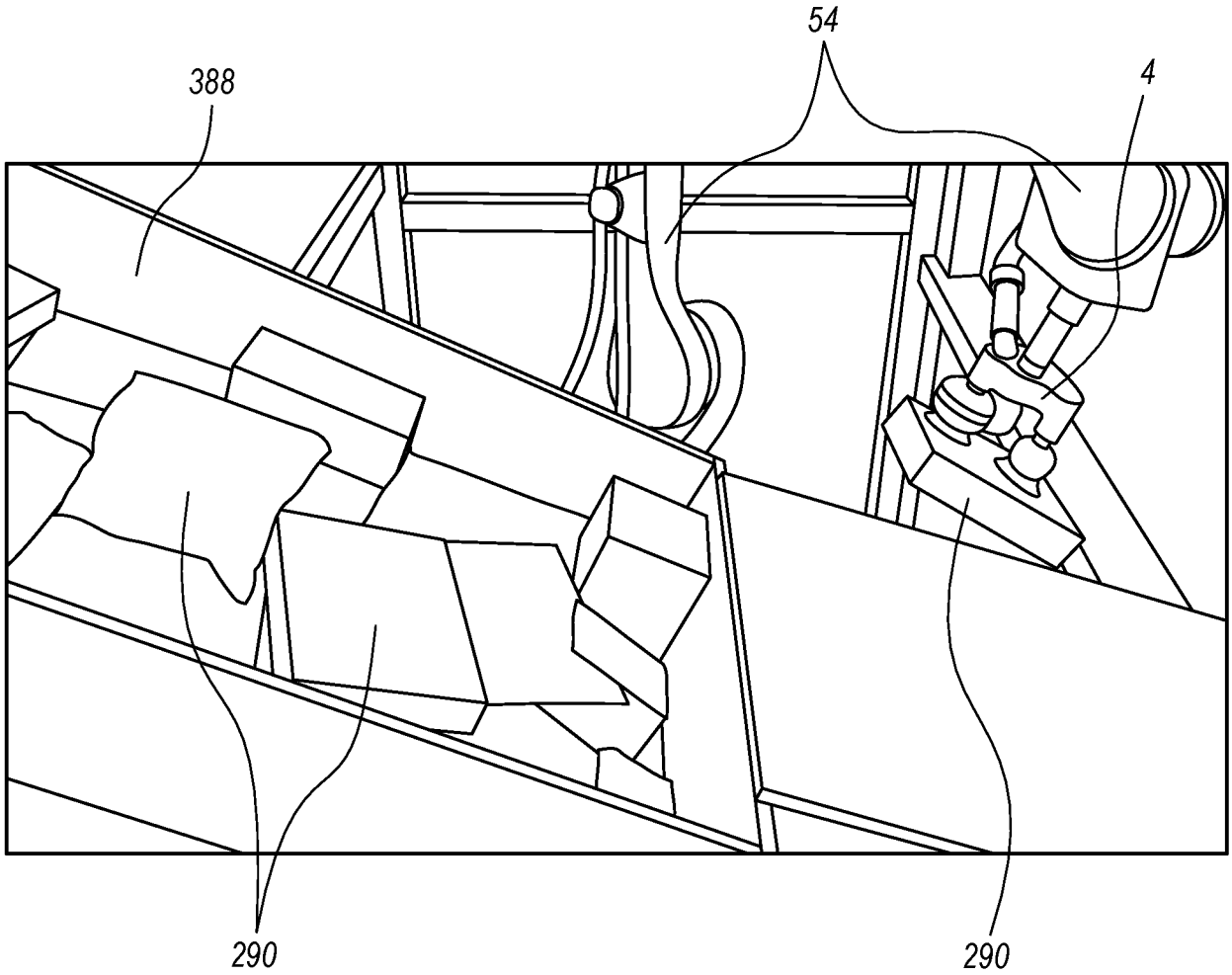


FIG. 28E

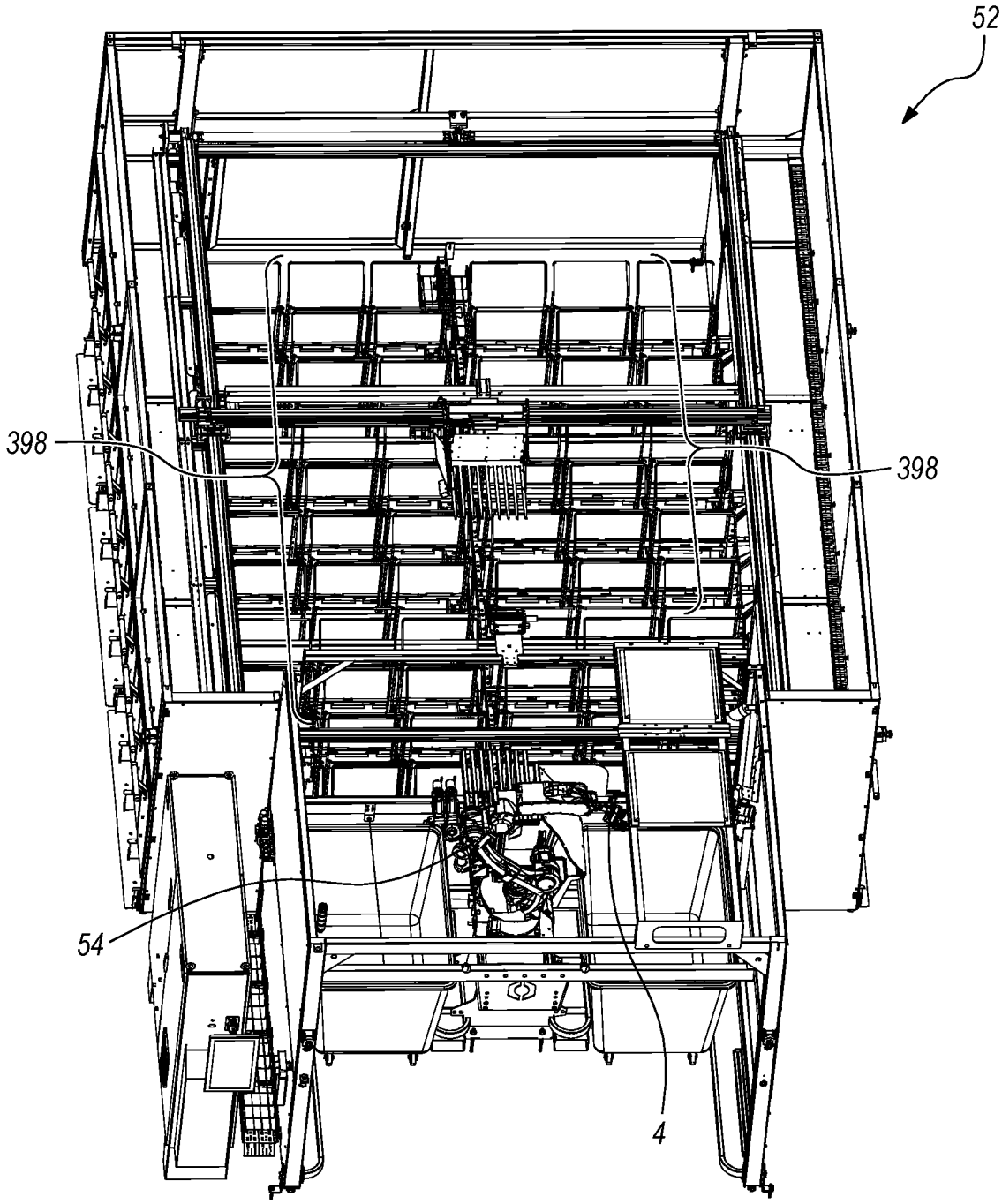


FIG. 29A

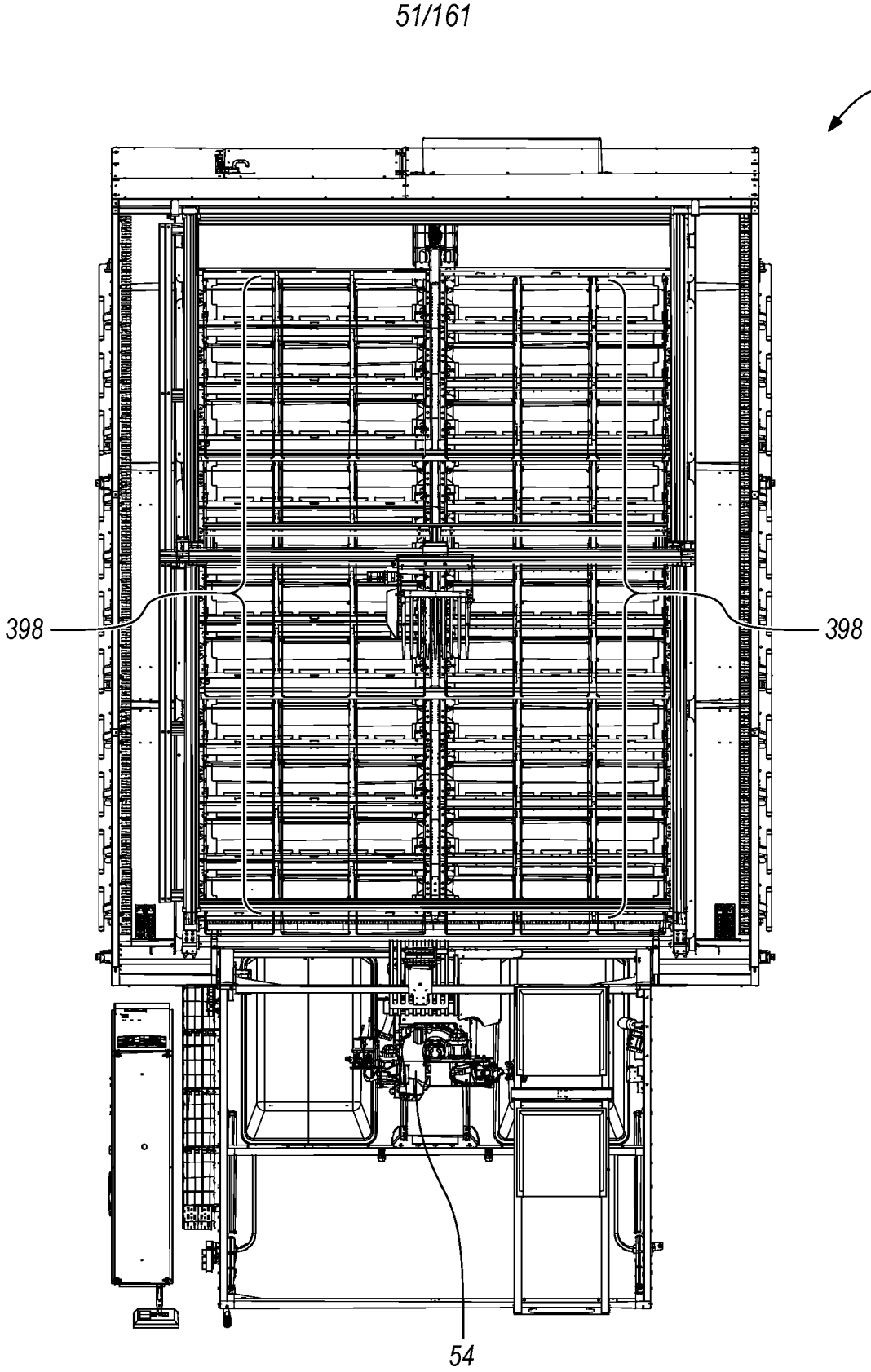


FIG. 29B

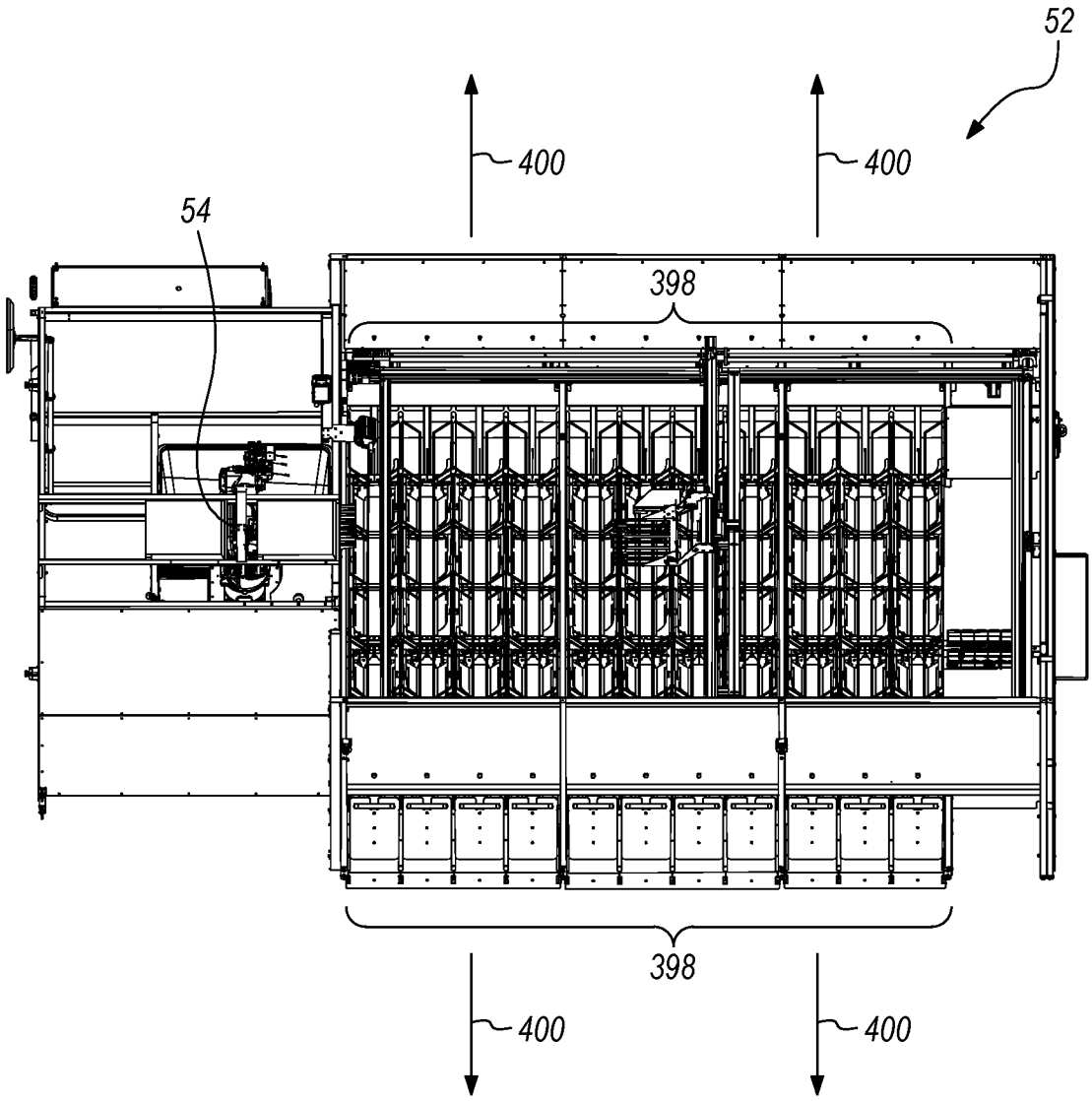


FIG. 29C

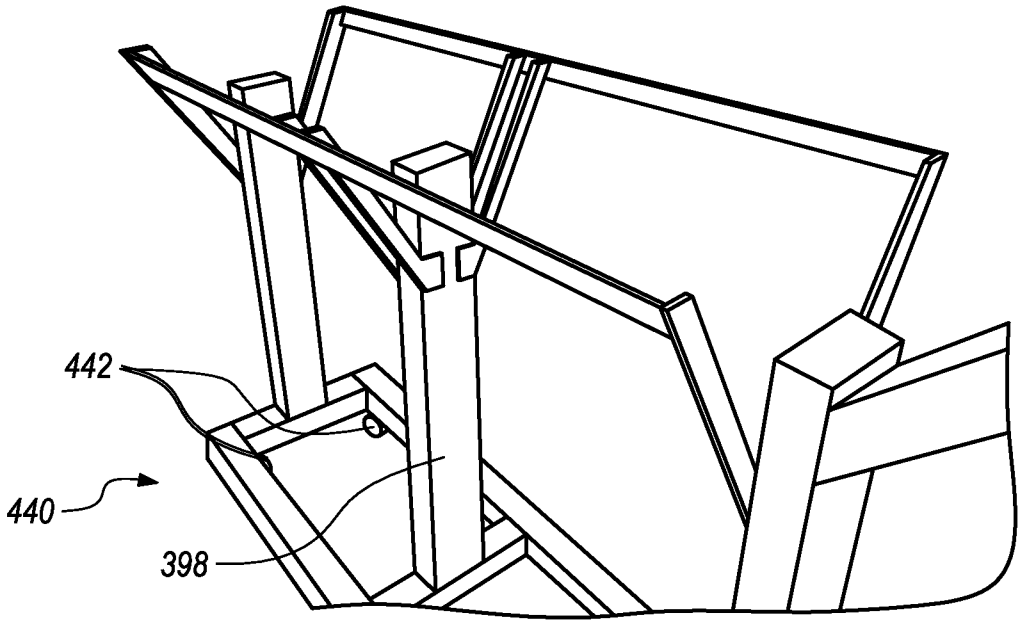


FIG. 29D

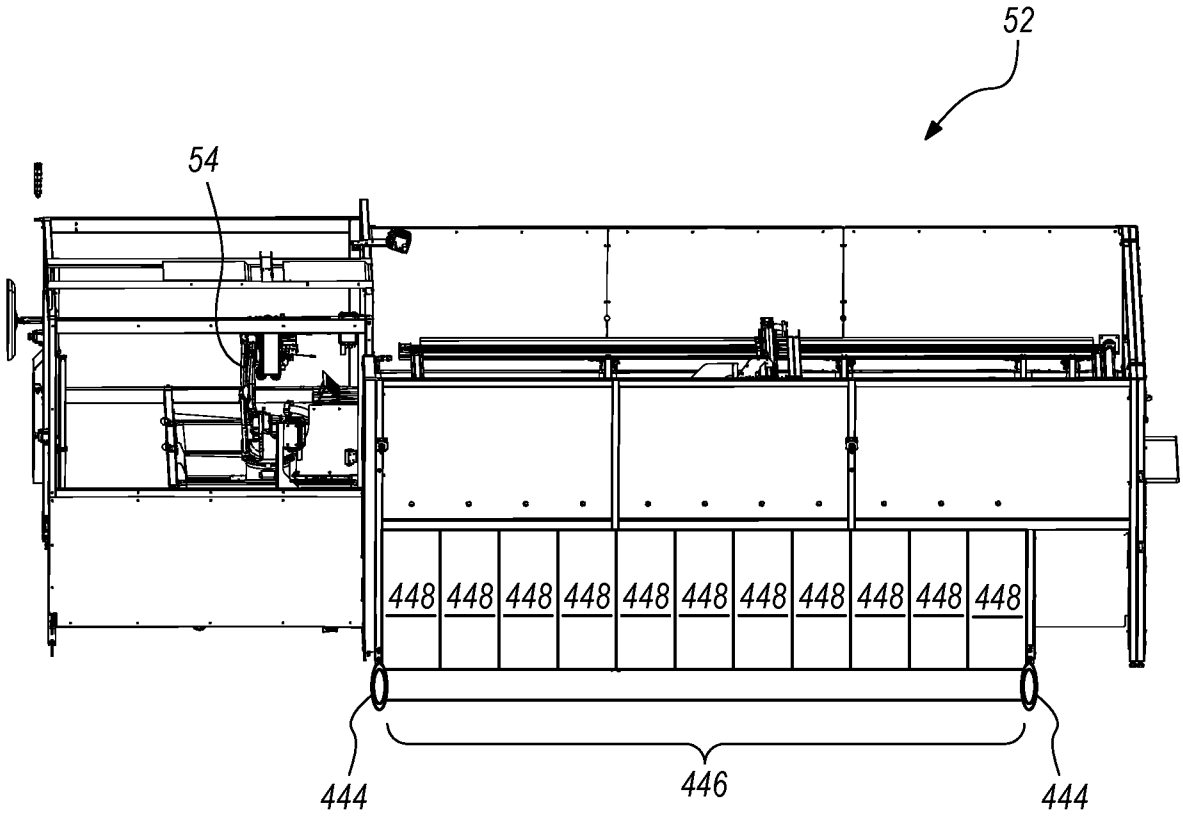


FIG. 29E

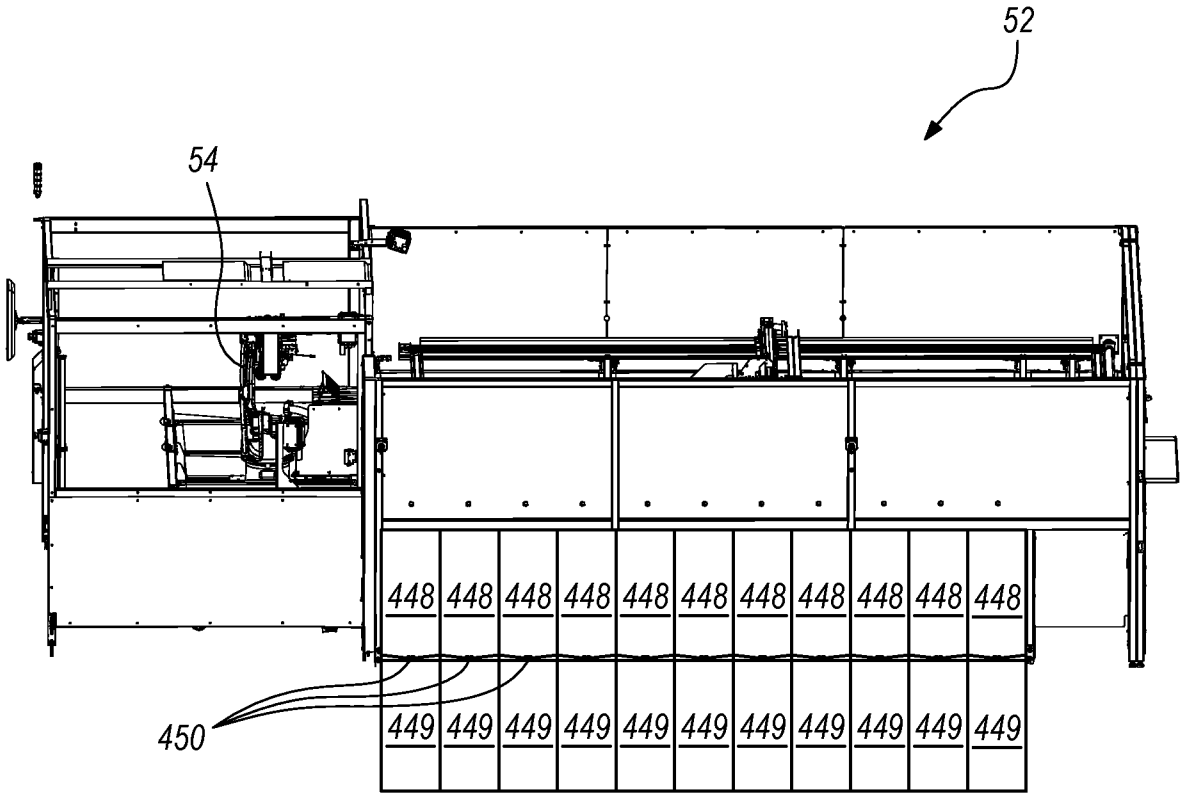

52
54
448 448 448 448 448 448 448 448 448 448 448
449 449 449 449 449 449 449 449 449 449 449
450

FIG. 29F

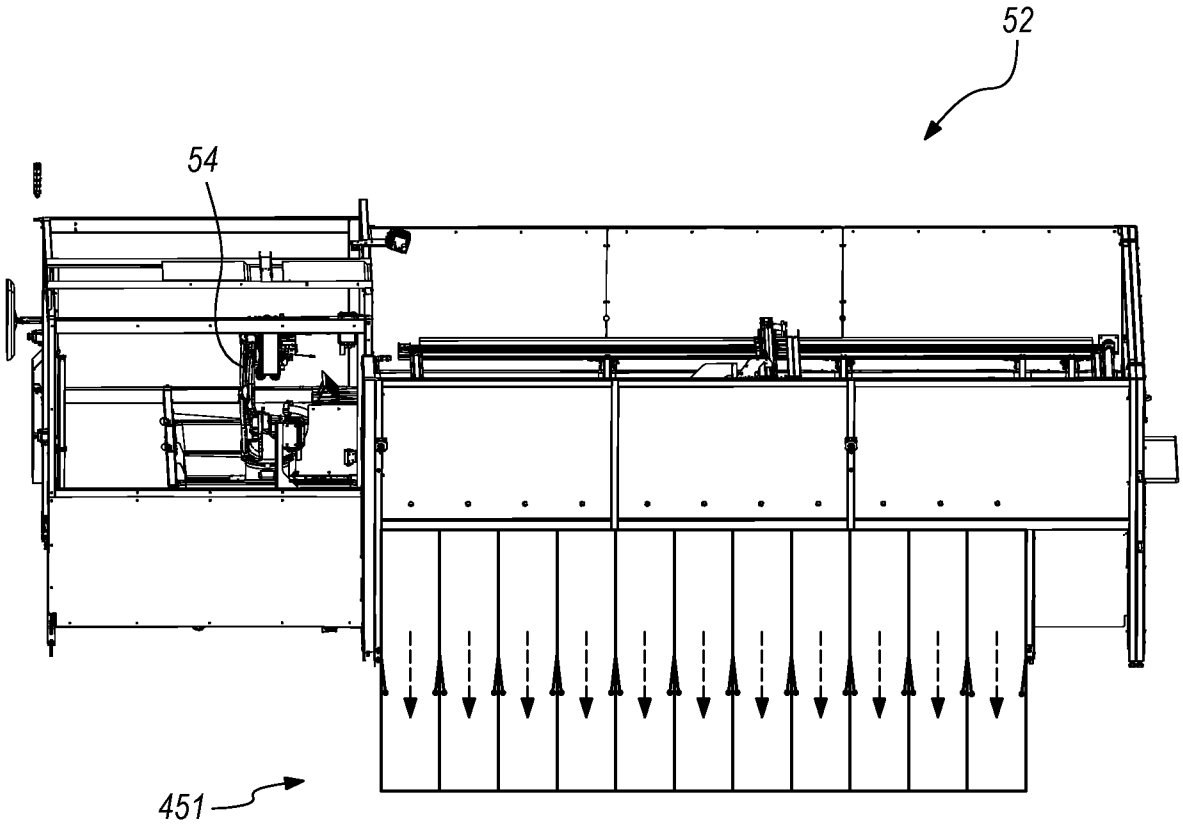


FIG. 29G

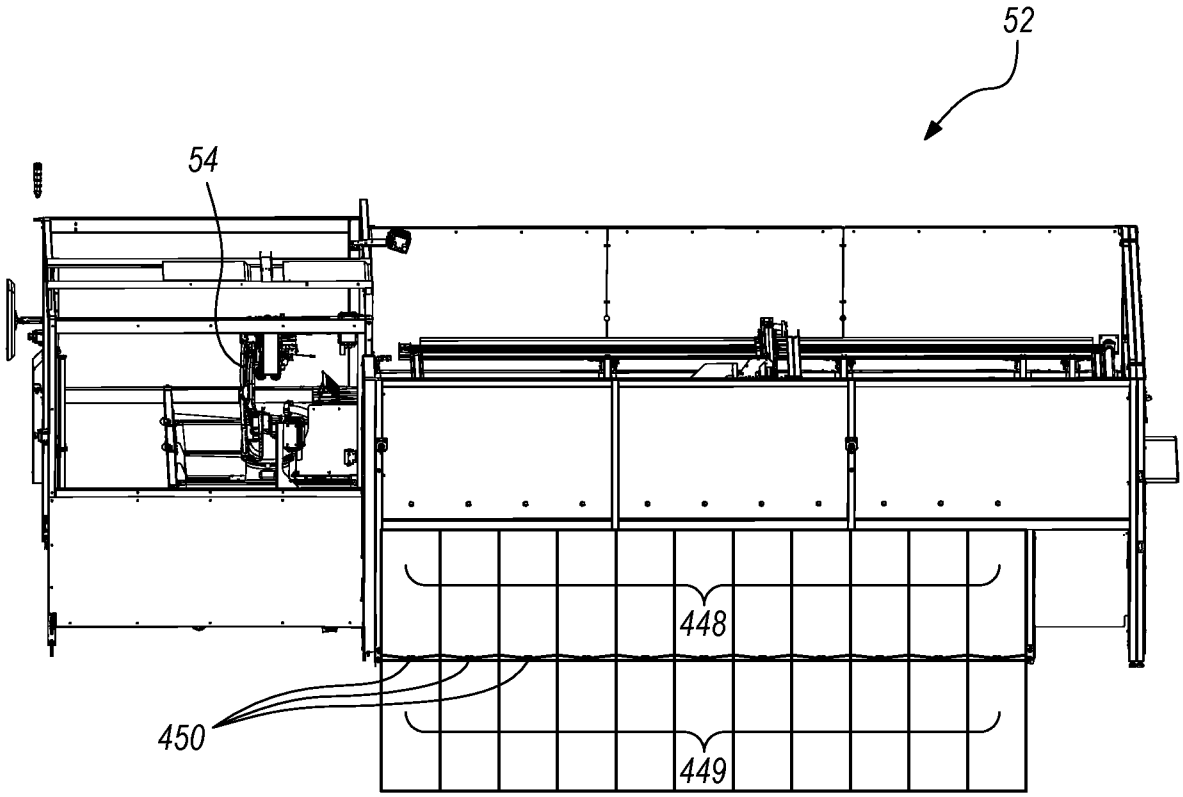


FIG. 29H

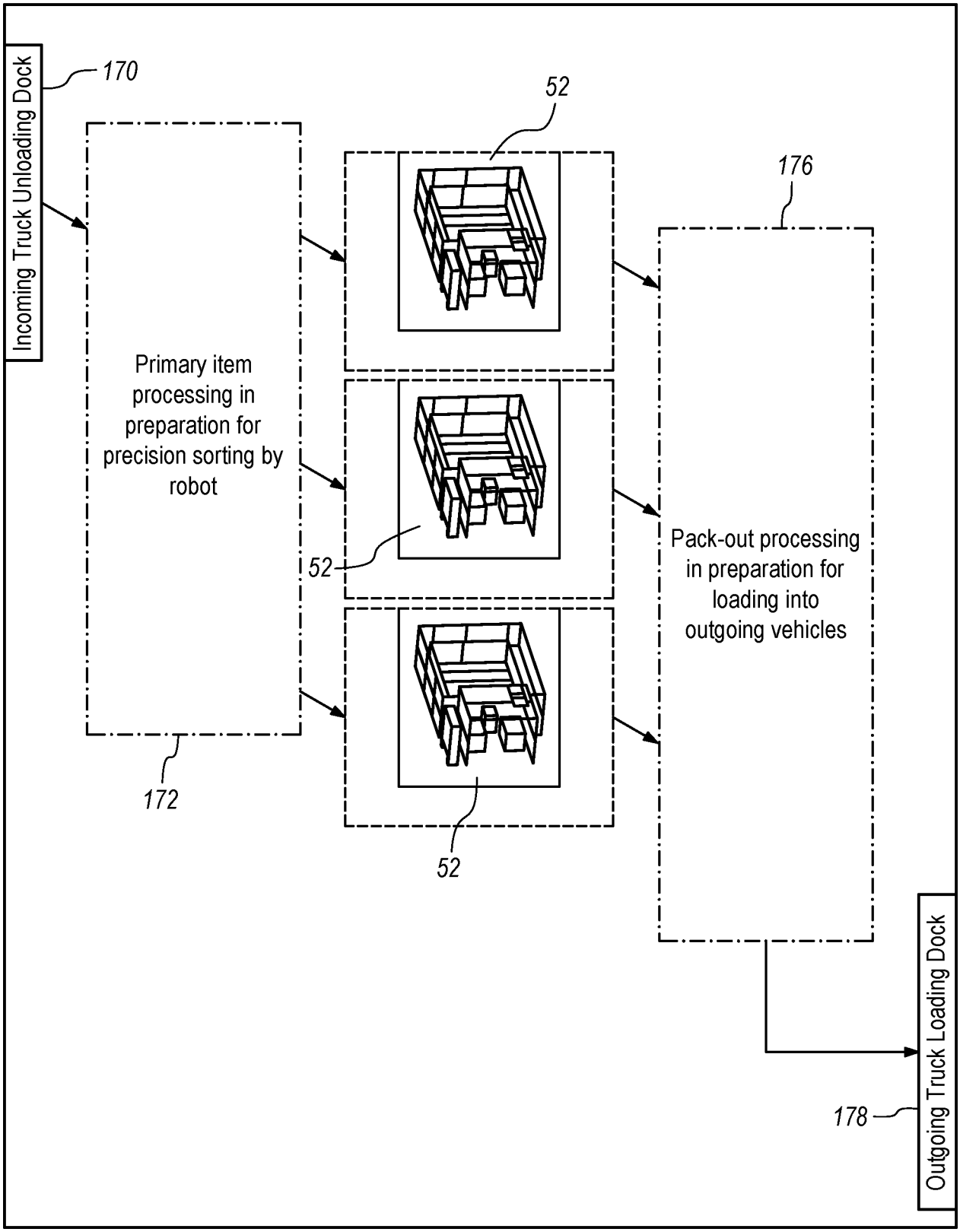

Incoming Truck Unloading Dock
170
Primary item processing in preparation for precision sorting by robot
172
52
52
52
176
Pack-out processing in preparation for loading into outgoing vehicles
178
Outgoing Truck Loading Dock

FIG. 30

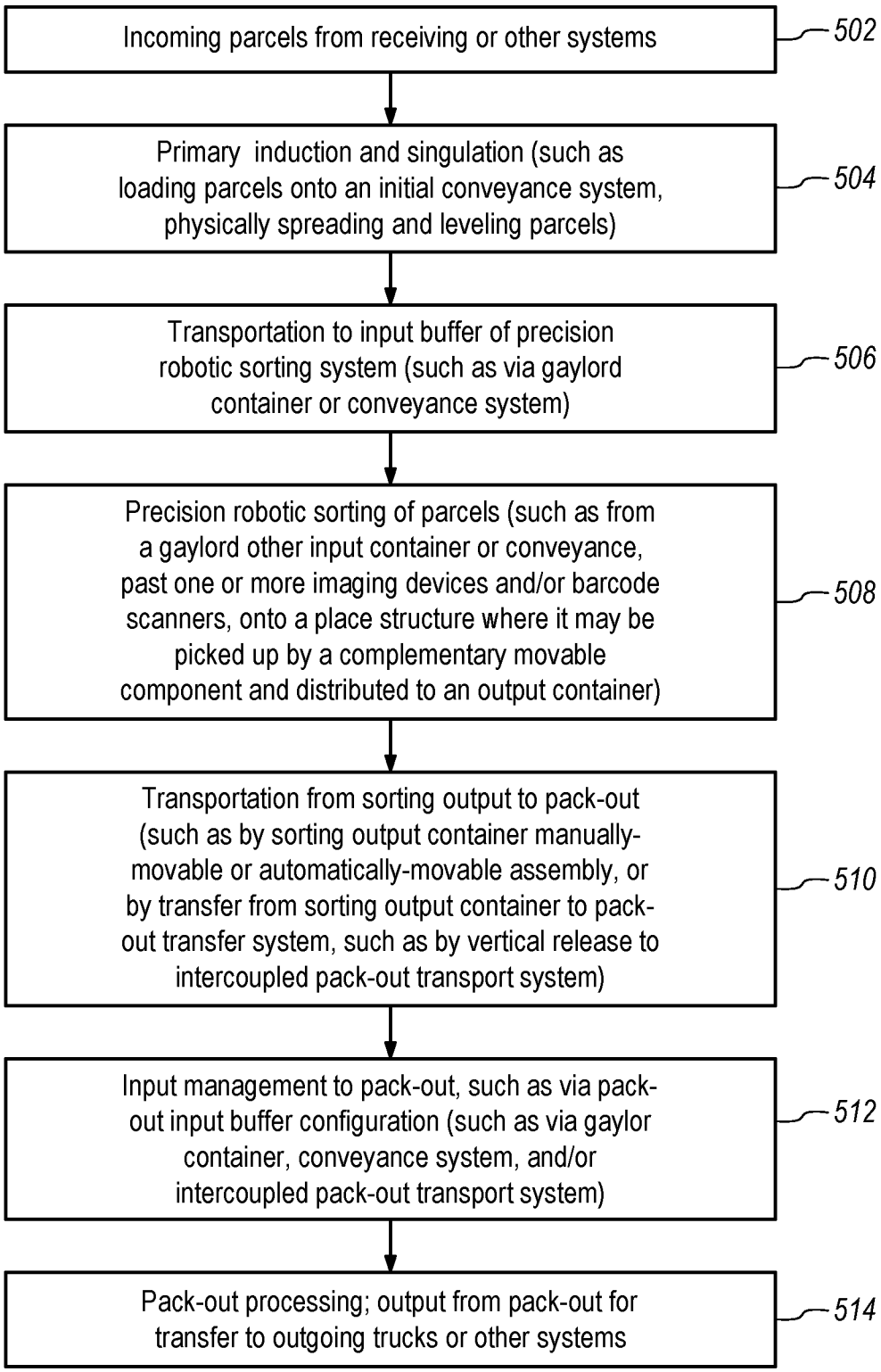

Incoming parcels from receiving or other systems
502
Primary induction and singulation (such as loading parcels onto an initial conveyance system, physically spreading and leveling parcels)
504
Transportation to input buffer of precision robotic sorting system (such as via gaylord container or conveyance system)
506
Precision robotic sorting of parcels (such as from a gaylord other input container or conveyance, past one or more imaging devices and/or barcode scanners, onto a place structure where it may be picked up by a complementary movable component and distributed to an output container)
508
Transportation from sorting output to pack-out (such as by sorting output container manually-movable or automatically-movable assembly, or by transfer from sorting output container to pack-out transfer system, such as by vertical release to intercoupled pack-out transport system)
510
Input management to pack-out, such as via pack-out input buffer configuration (such as via gaylor container, conveyance system, and/or intercoupled pack-out transport system)
512
Pack-out processing; output from pack-out for transfer to outgoing trucks or other systems
514

FIG. 31

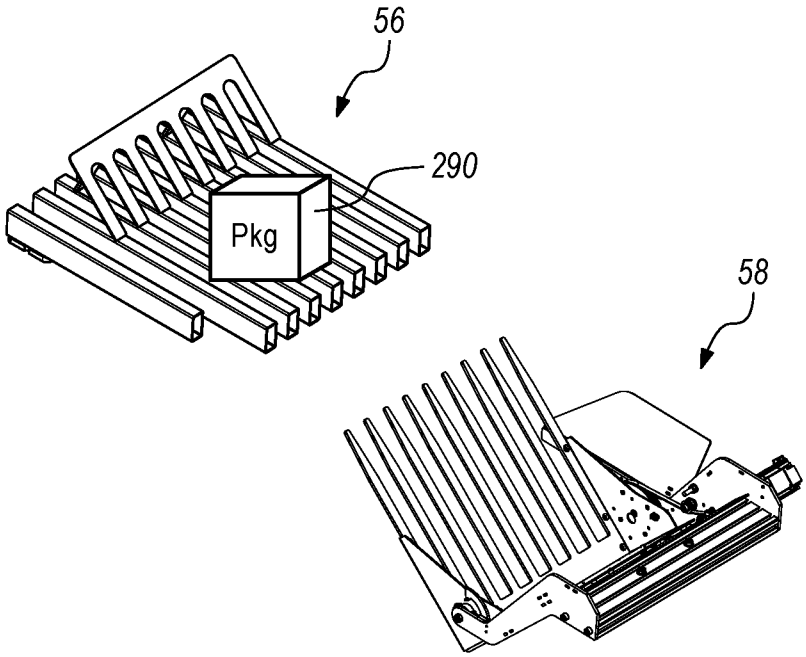


FIG. 32A

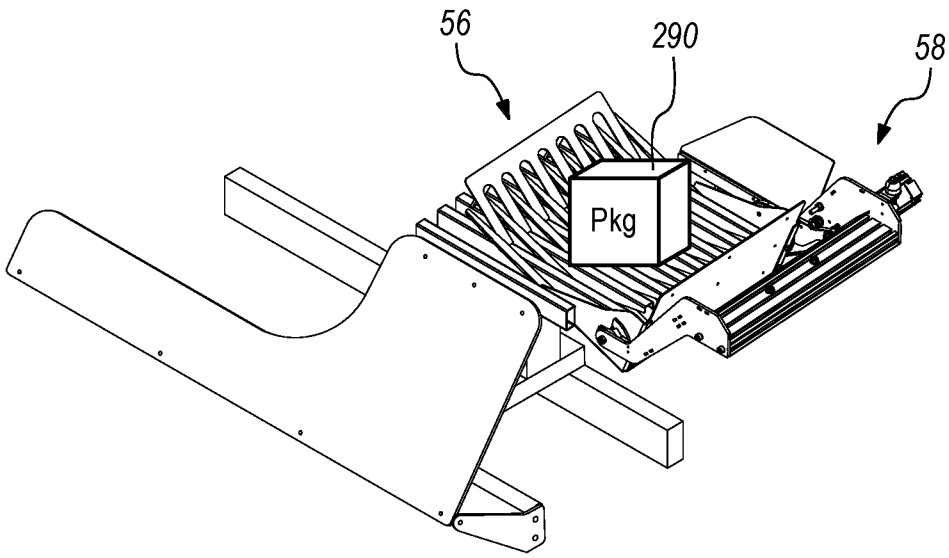


FIG. 32B

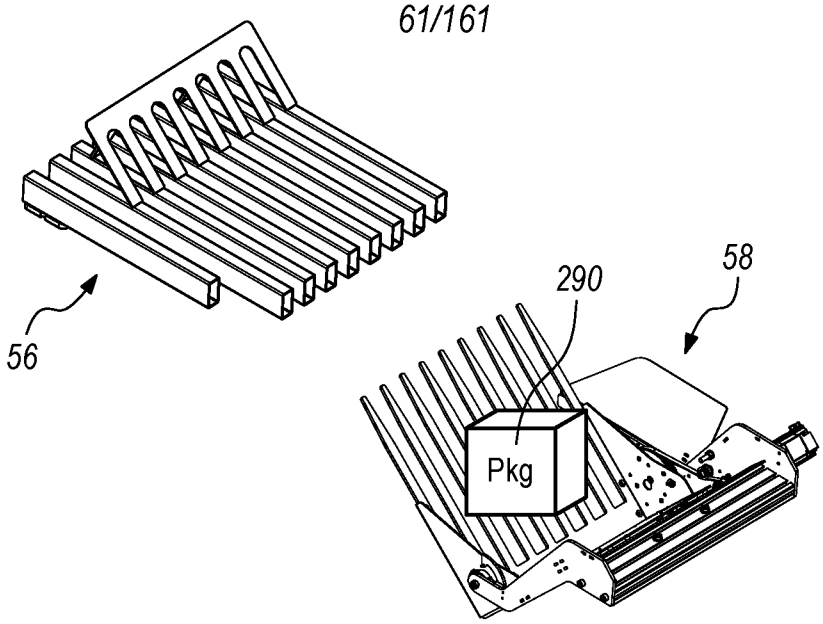


FIG. 32C

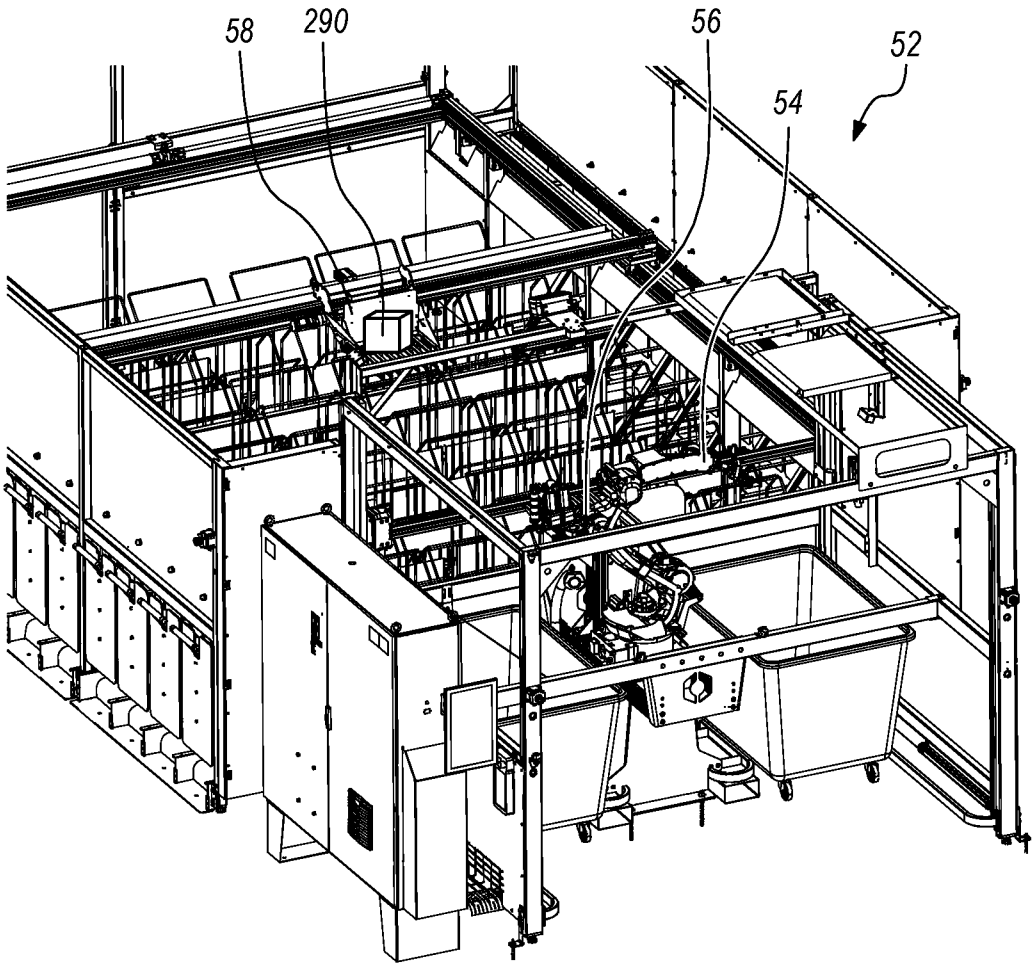


FIG. 32D

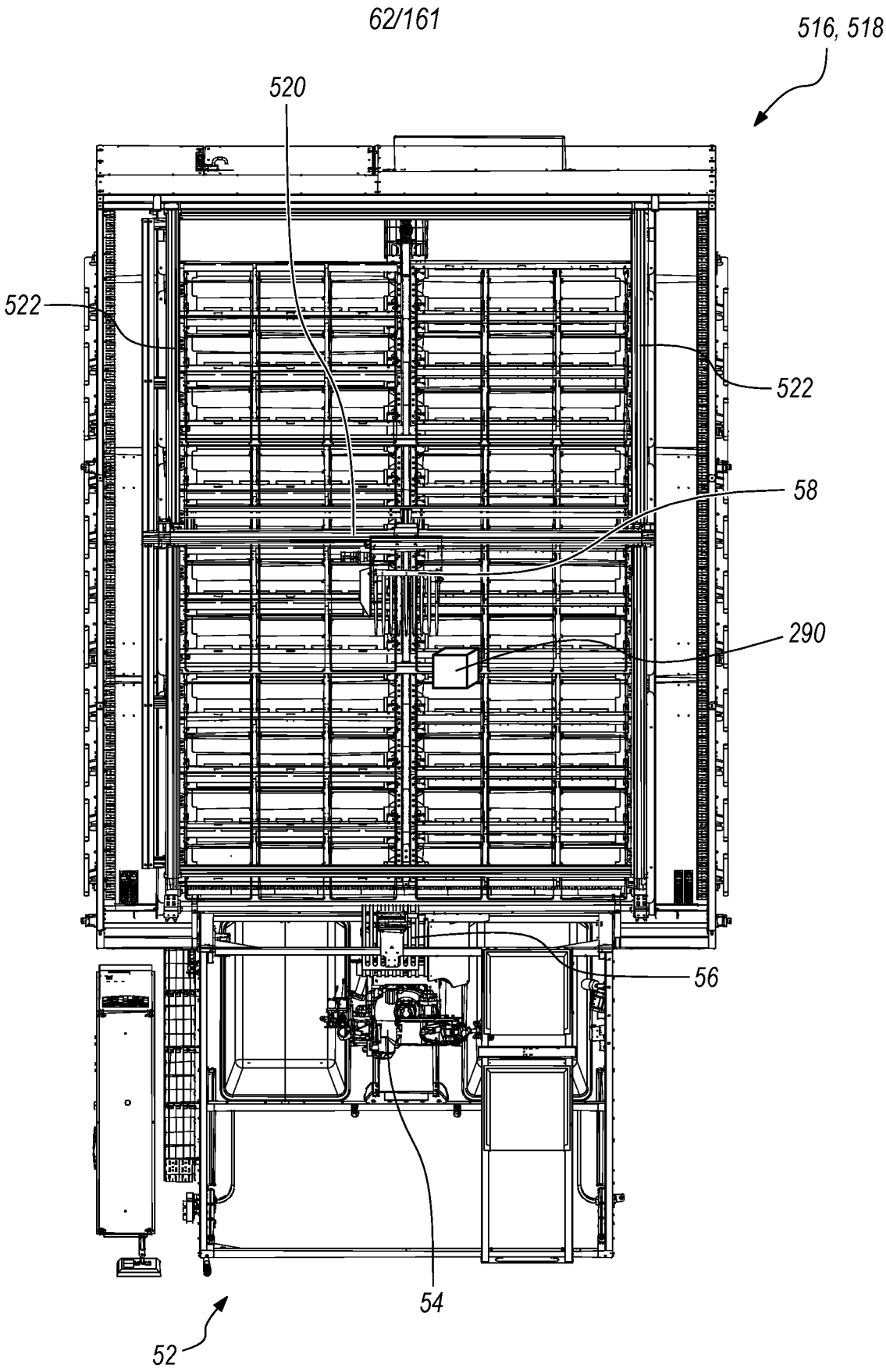


FIG. 32F

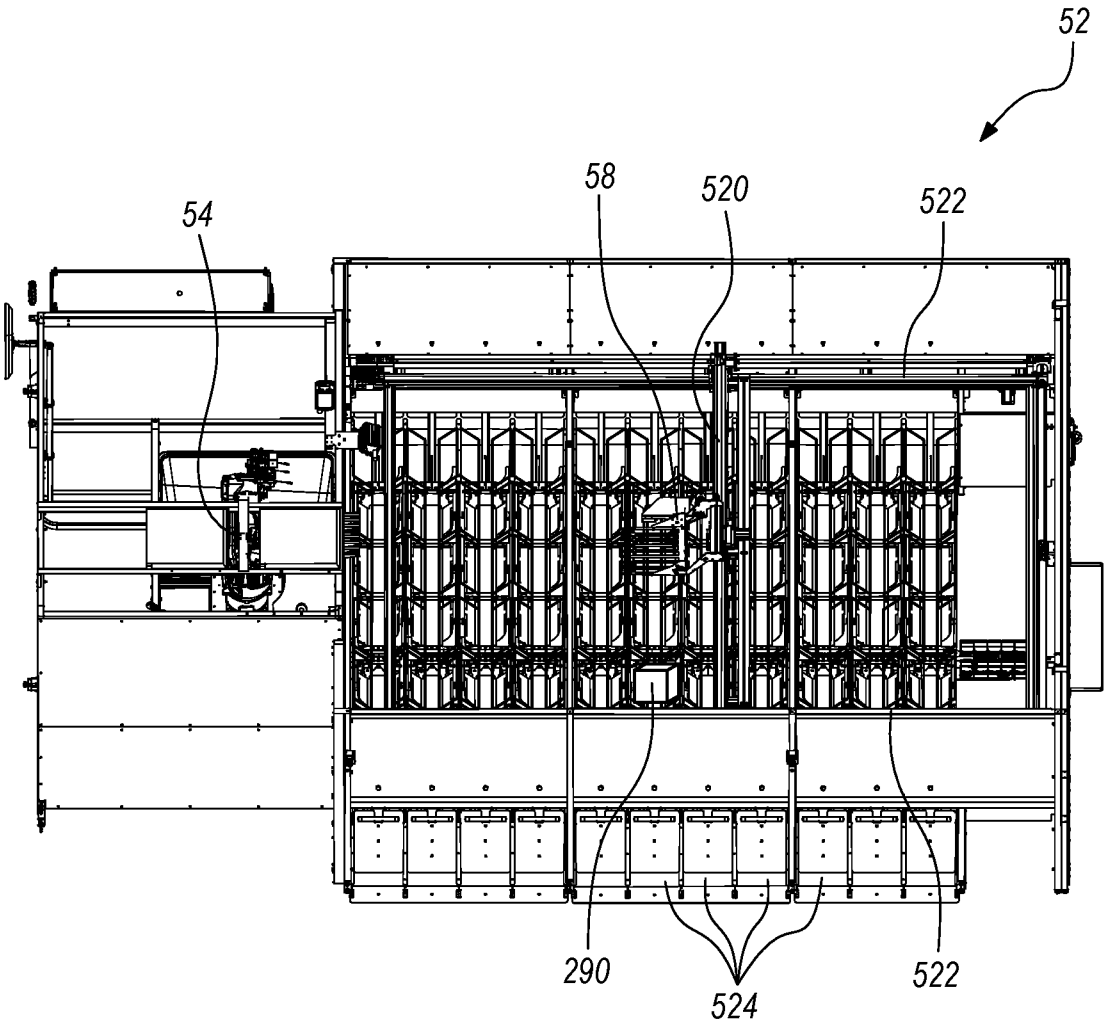


FIG. 32G

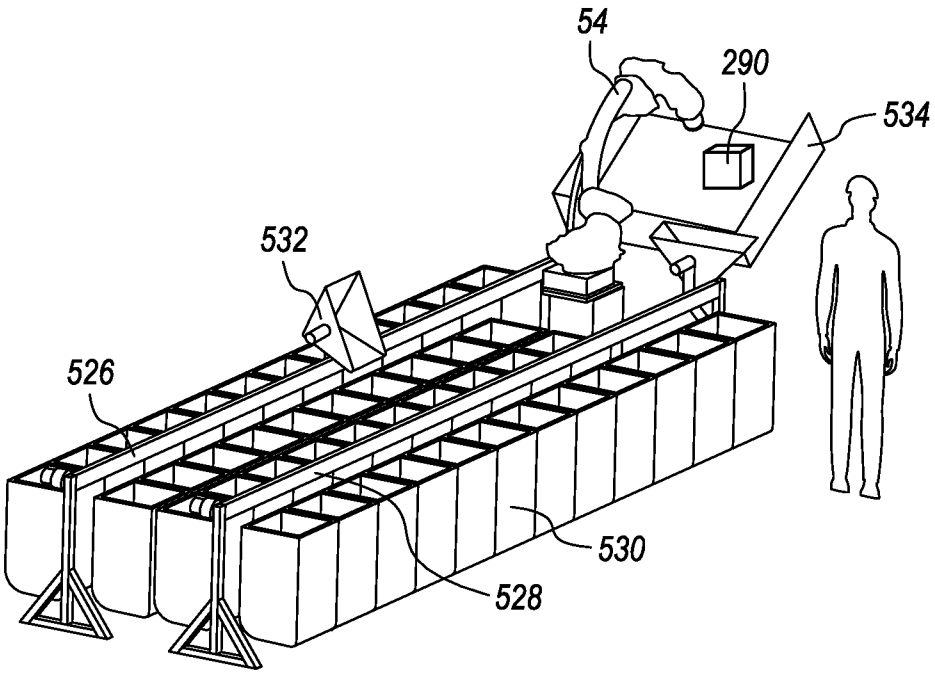


FIG. 33A

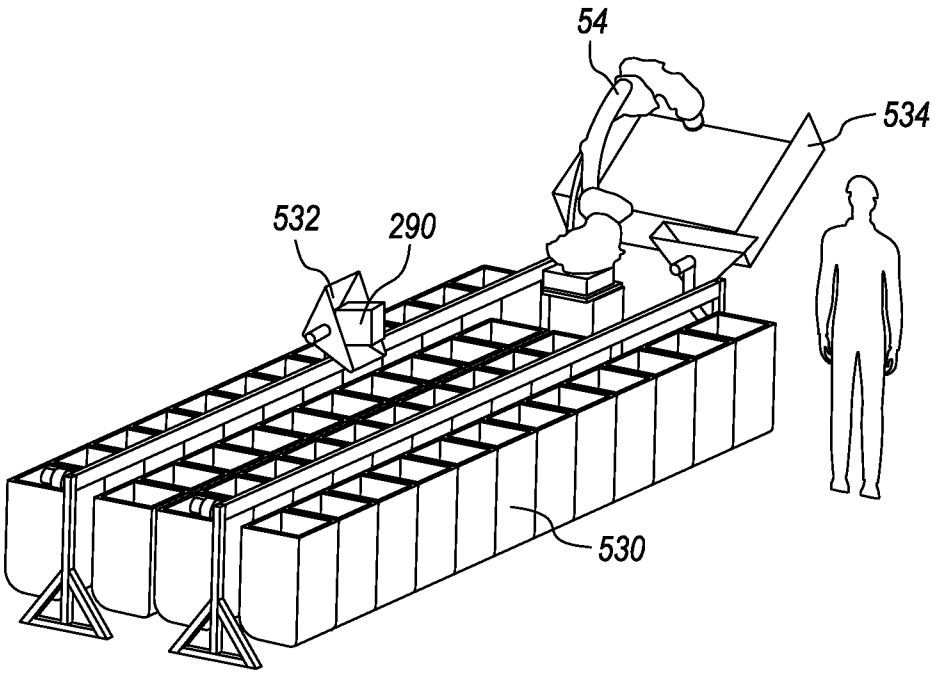


FIG. 33B

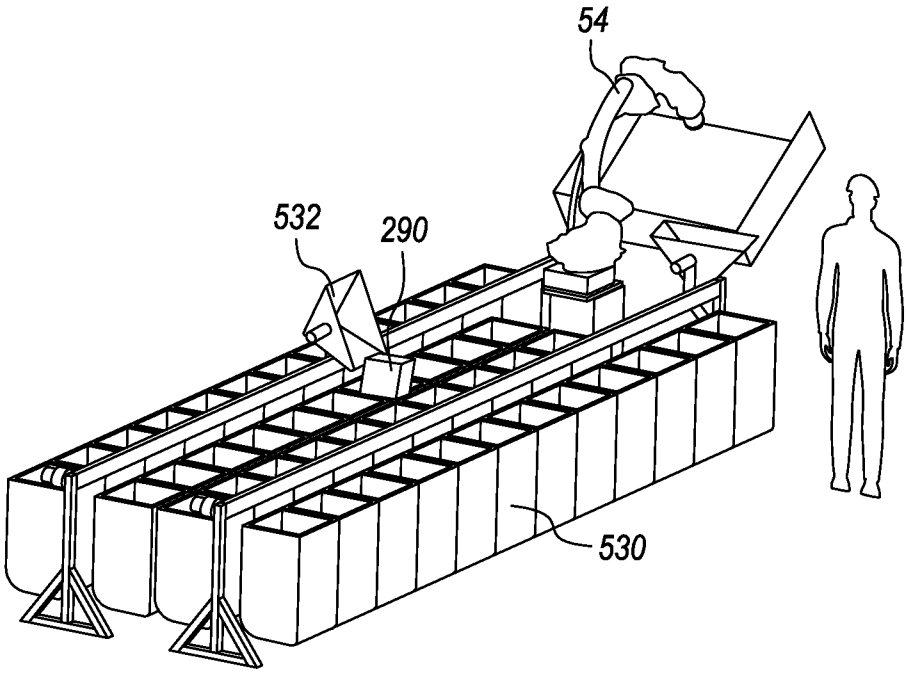


FIG. 33C

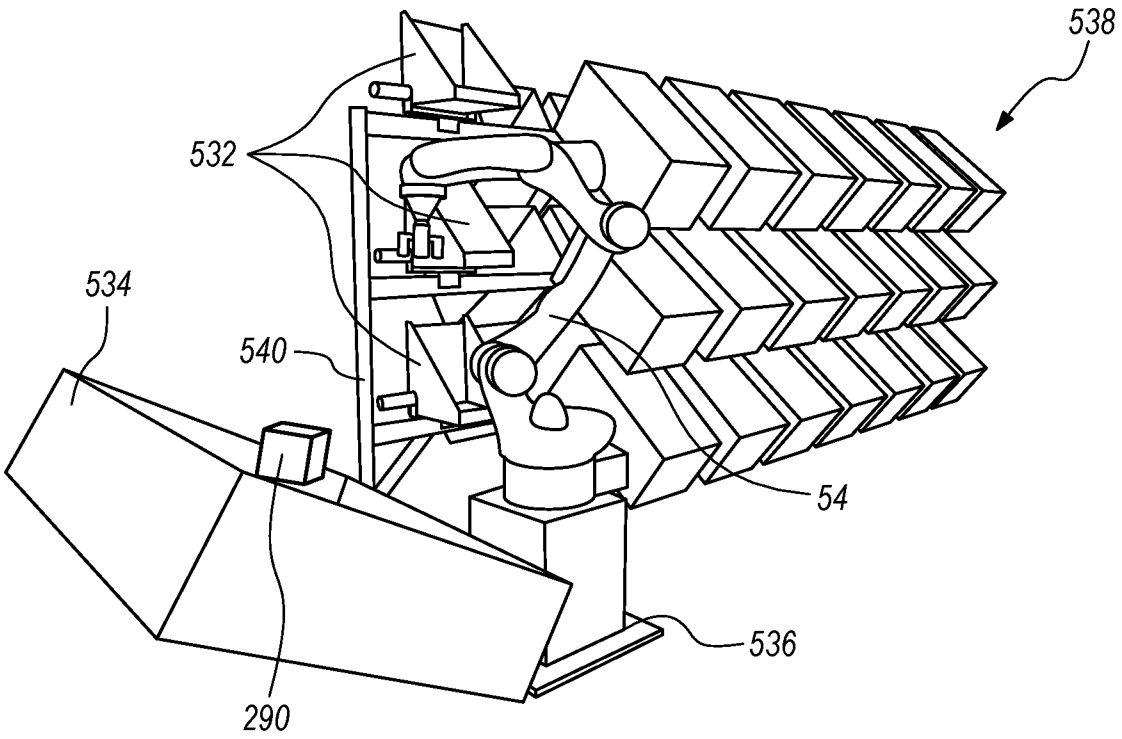


FIG. 34A

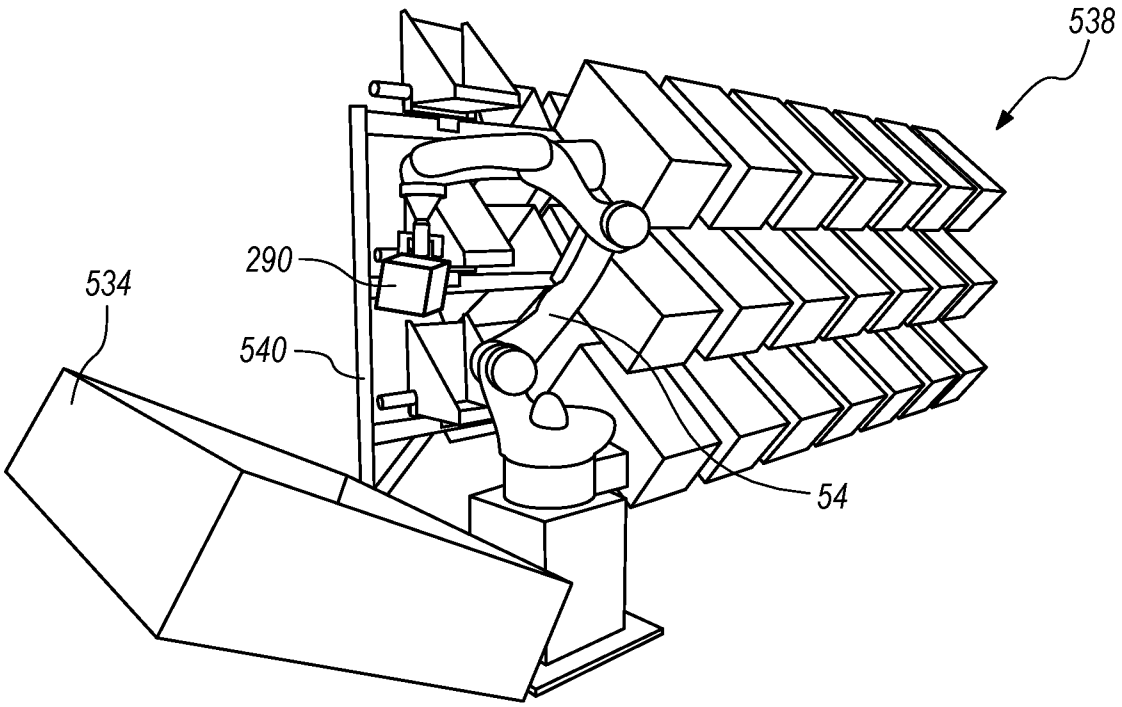


FIG. 34B

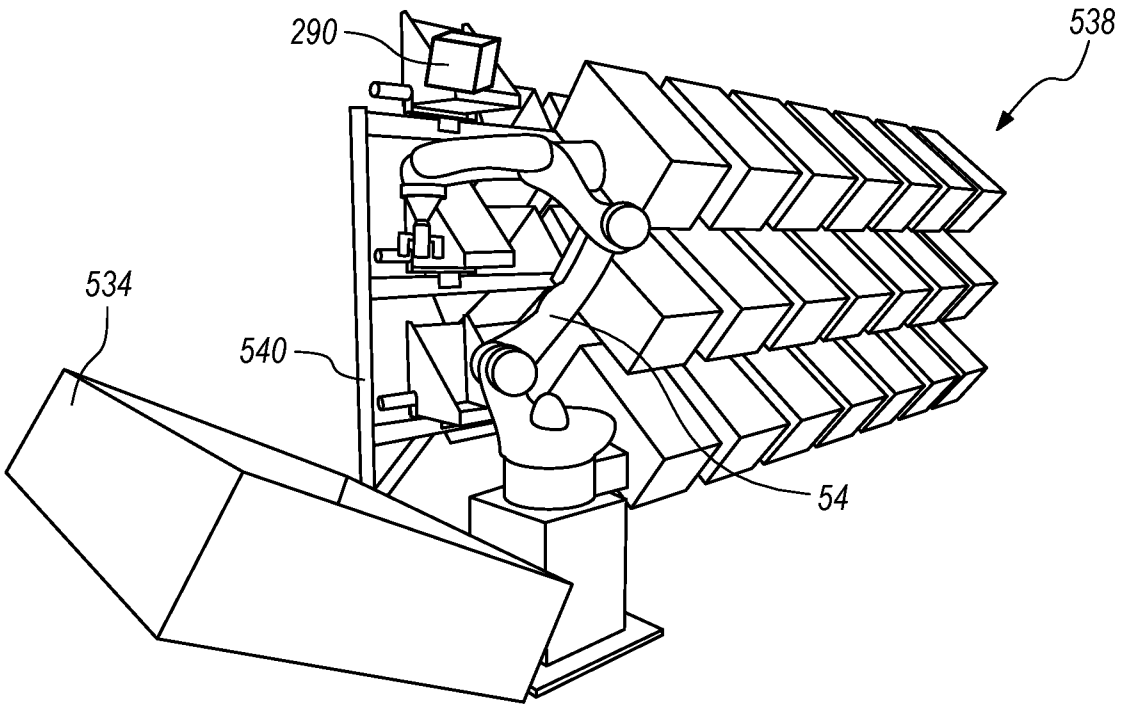


FIG. 34C

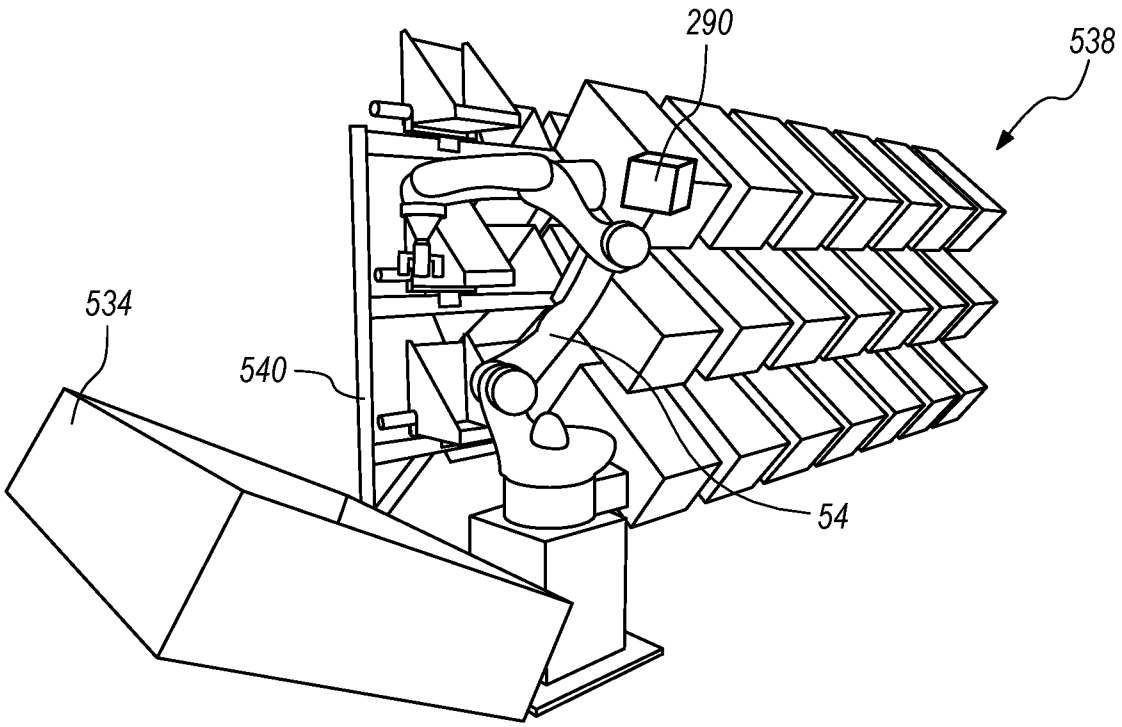


FIG. 34D

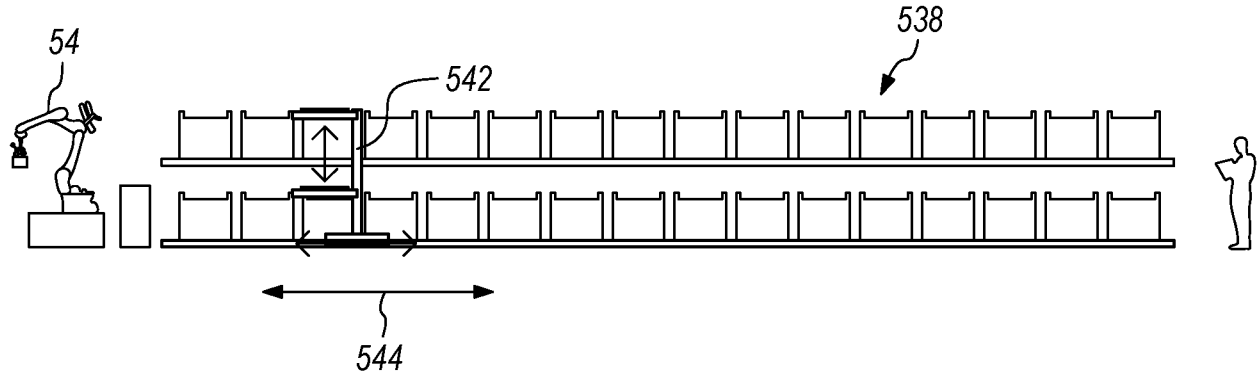


FIG. 34E

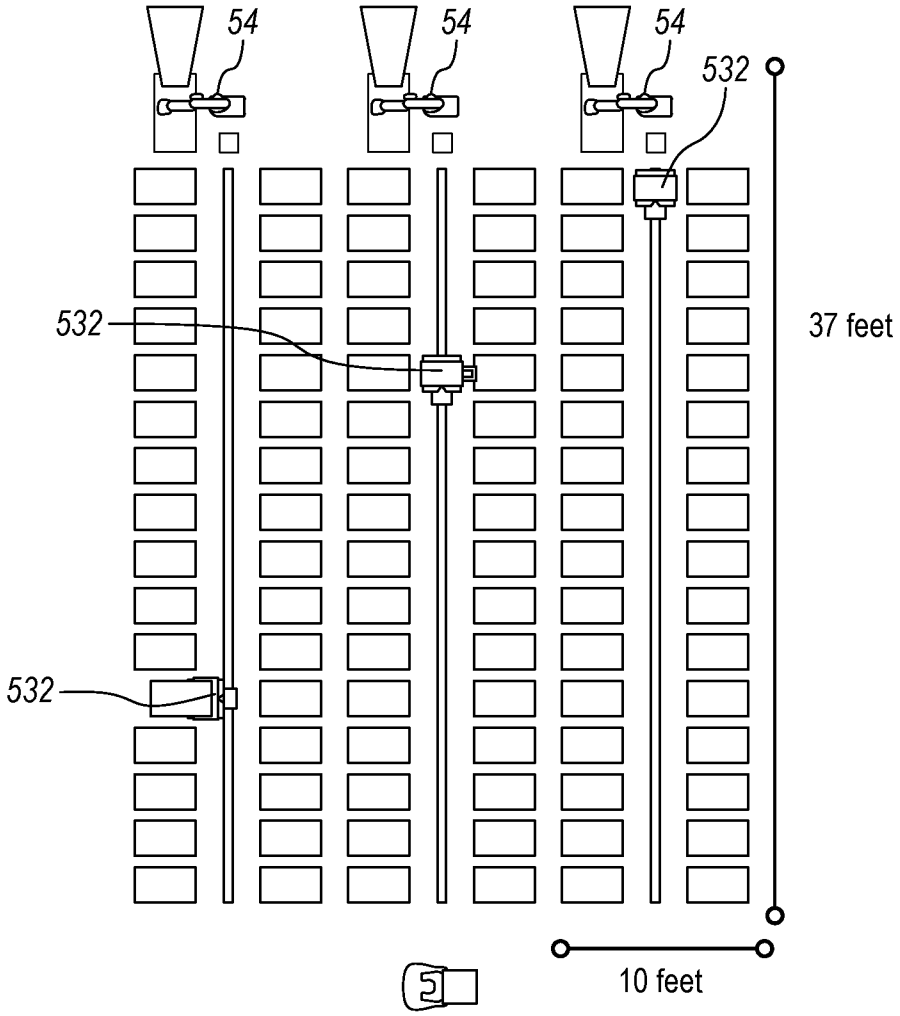


FIG. 34F

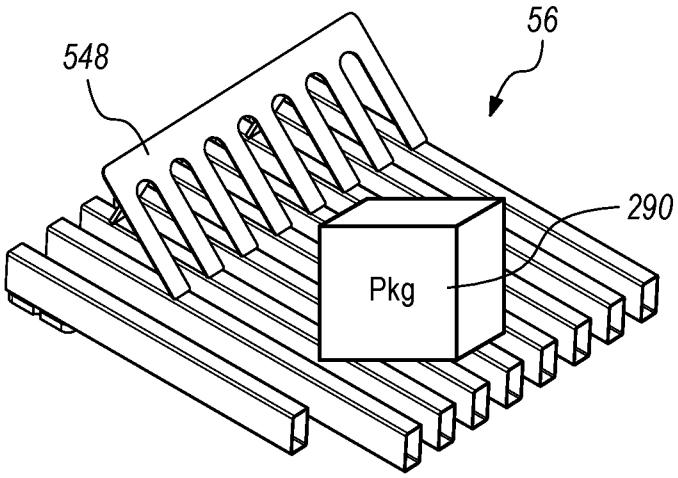


FIG. 35A

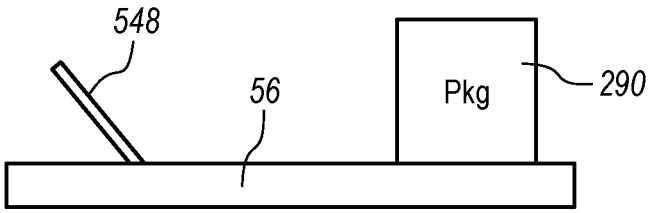


FIG. 35B

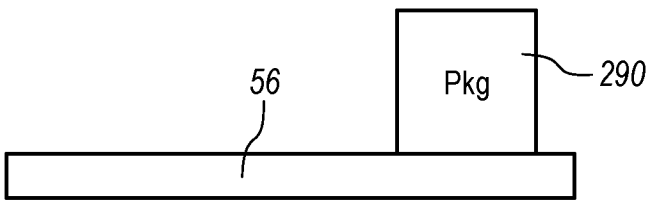


FIG. 35C

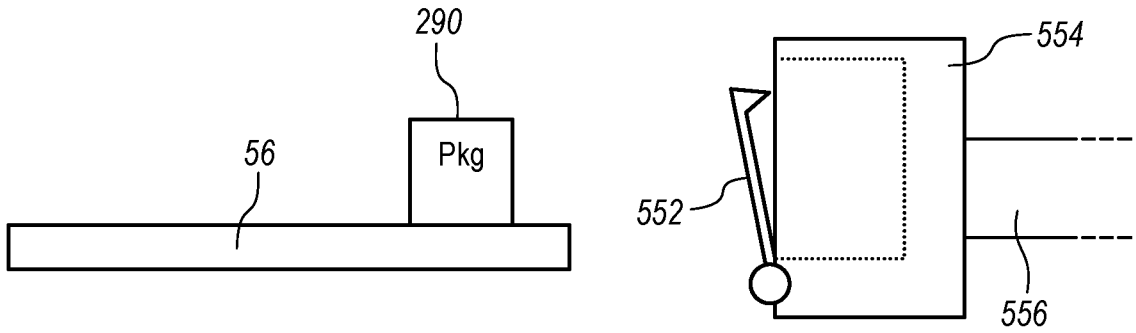


FIG. 35D

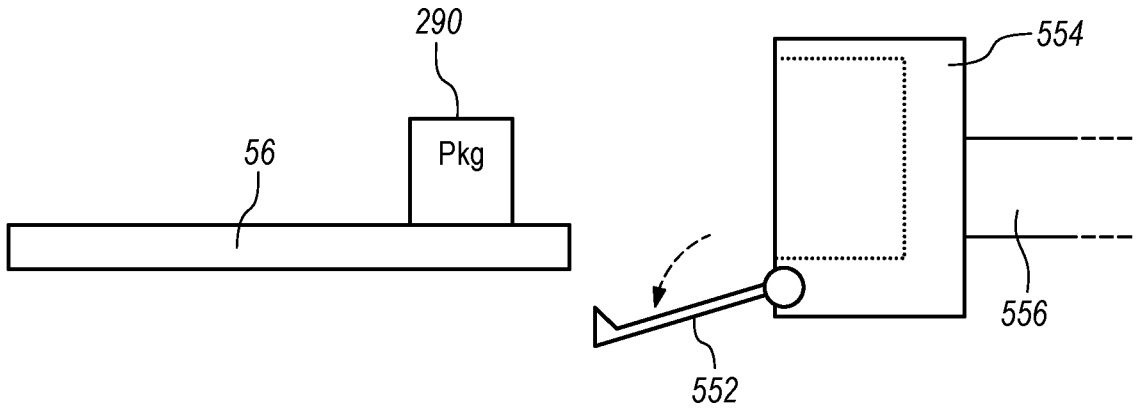


FIG. 35E

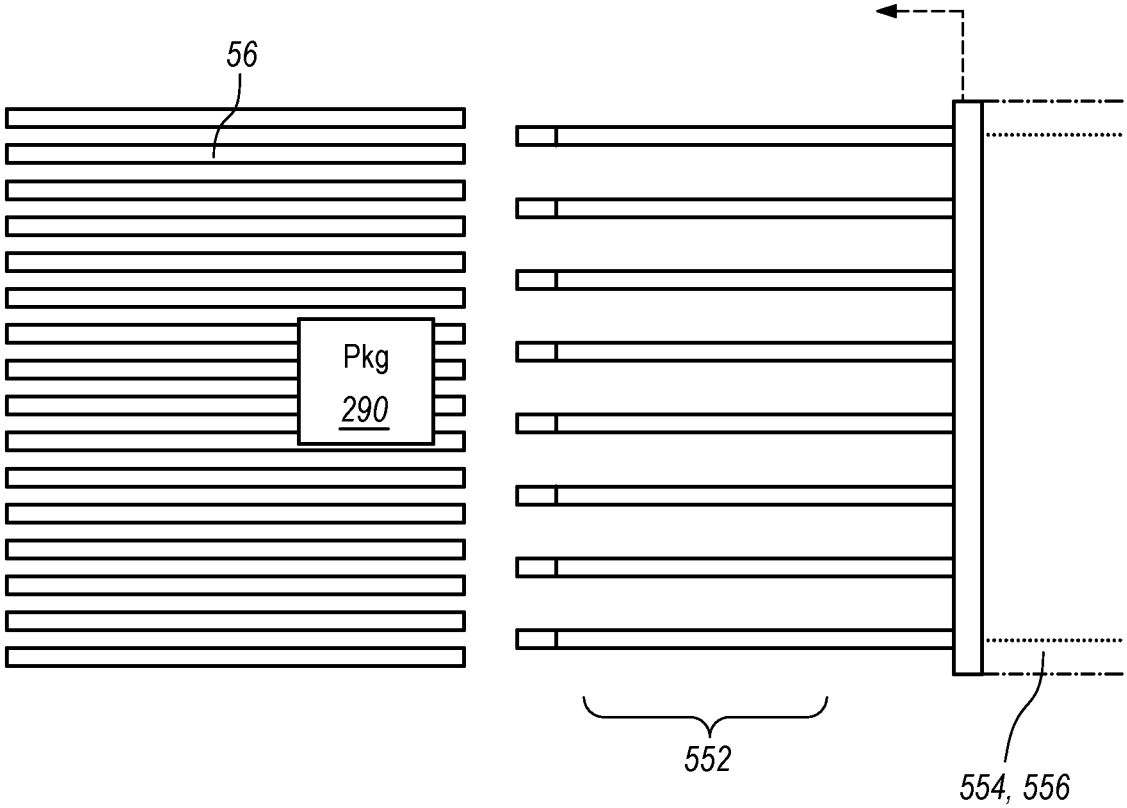


FIG. 37F

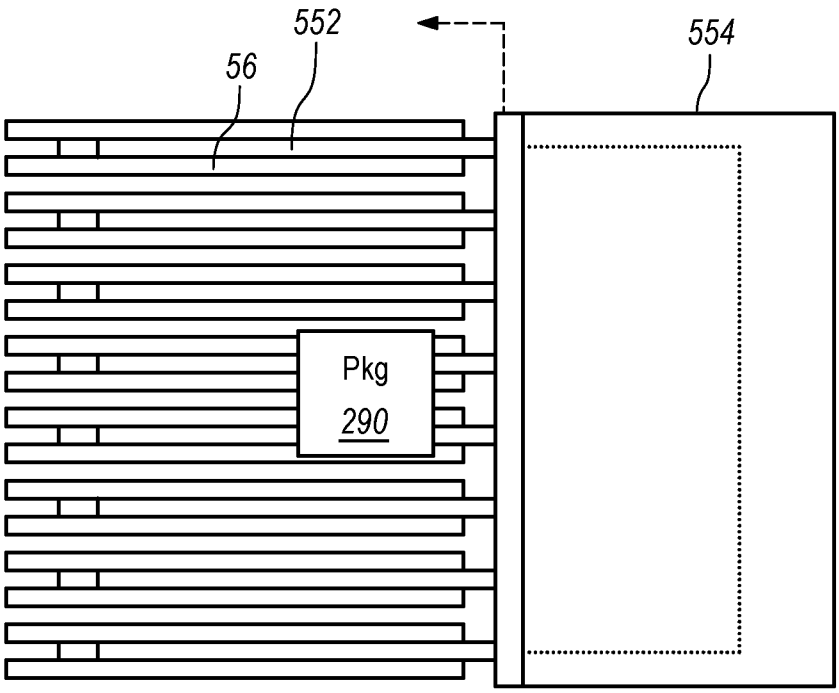


FIG. 37G

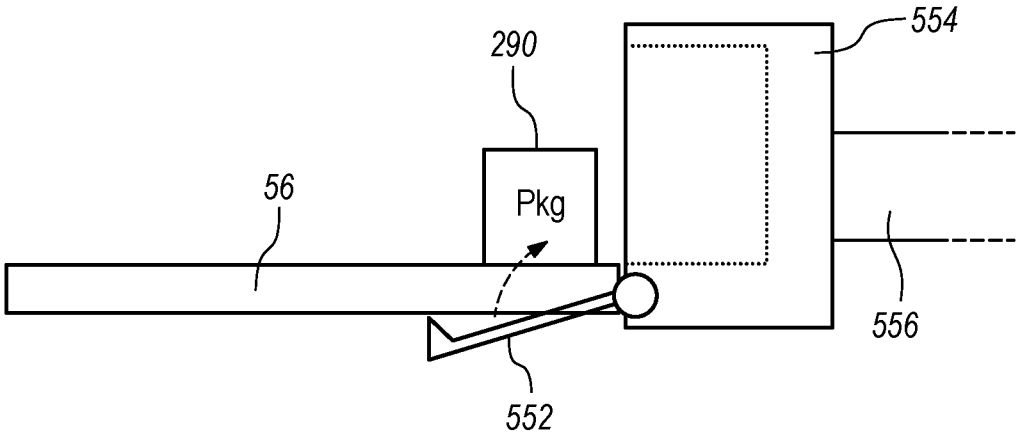


FIG. 37H

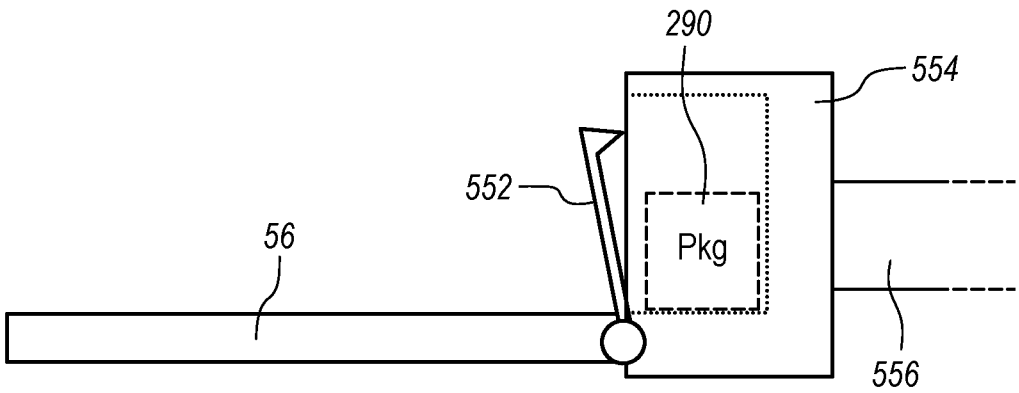


FIG. 37I

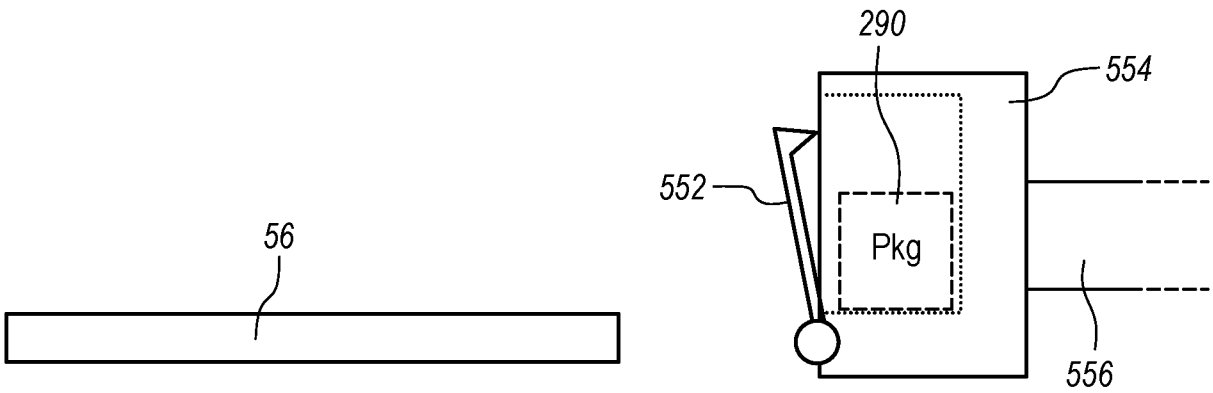
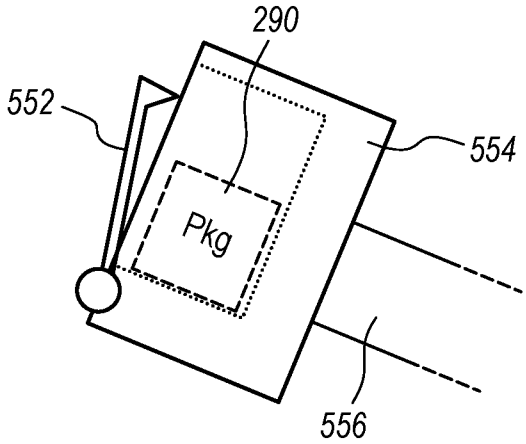


FIG. 37J



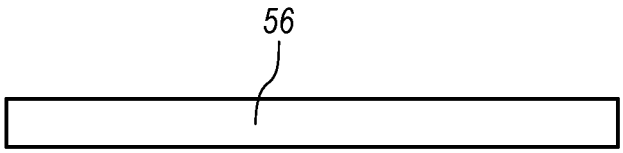


FIG. 37K

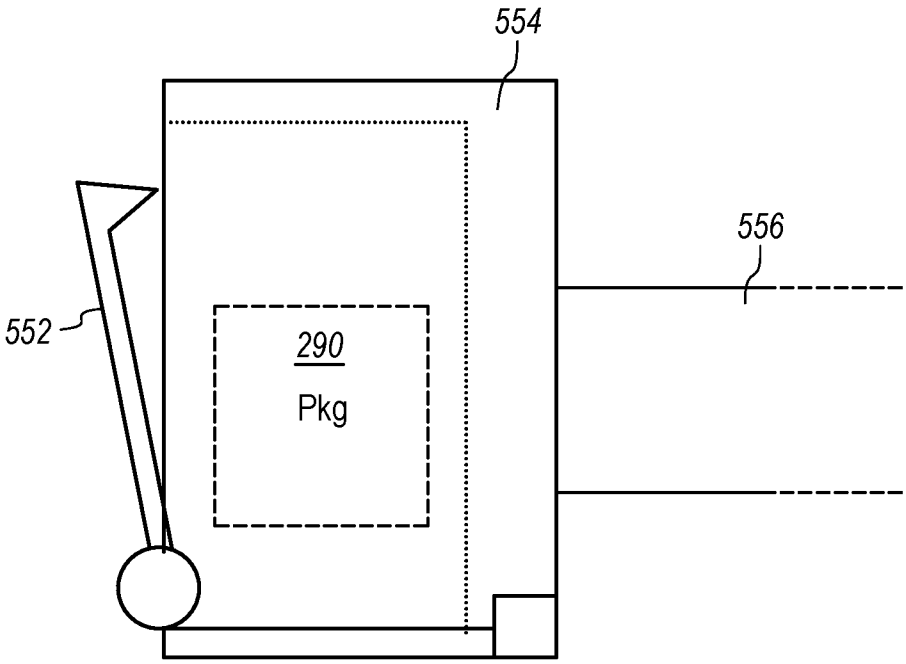


FIG. 38A

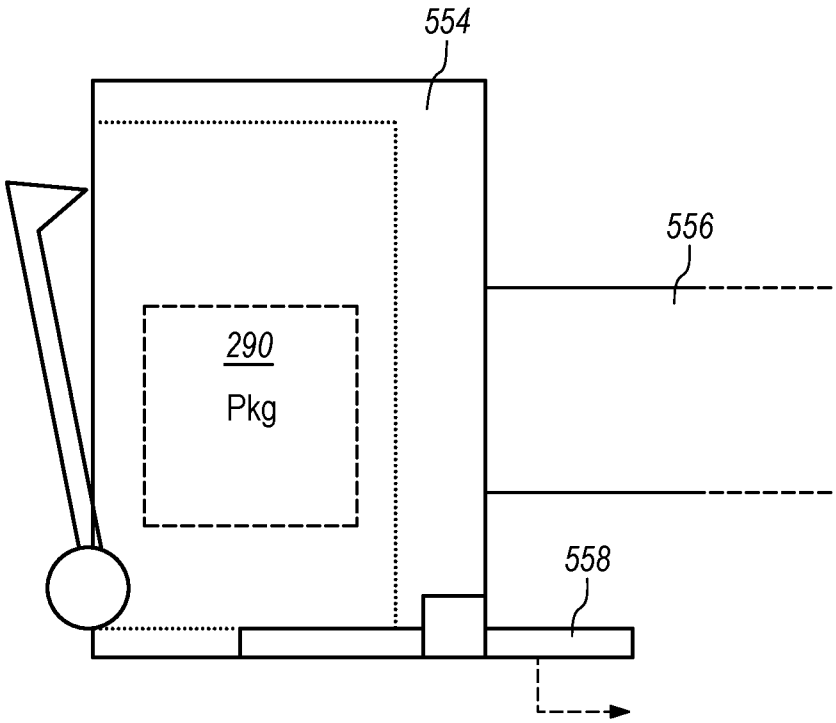


FIG. 38B

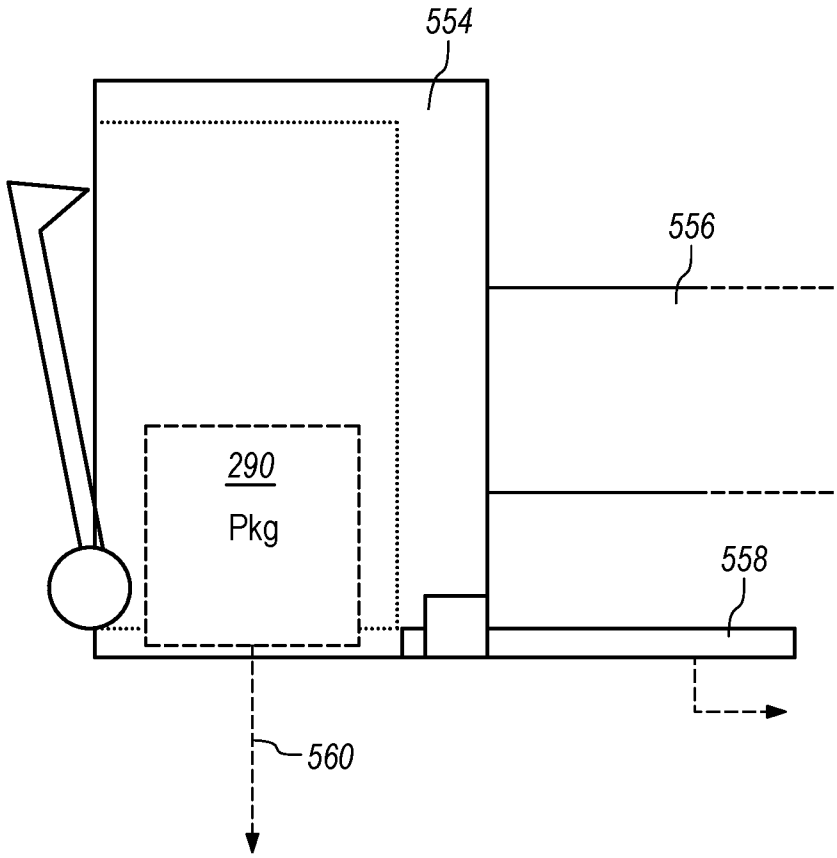


FIG. 38C

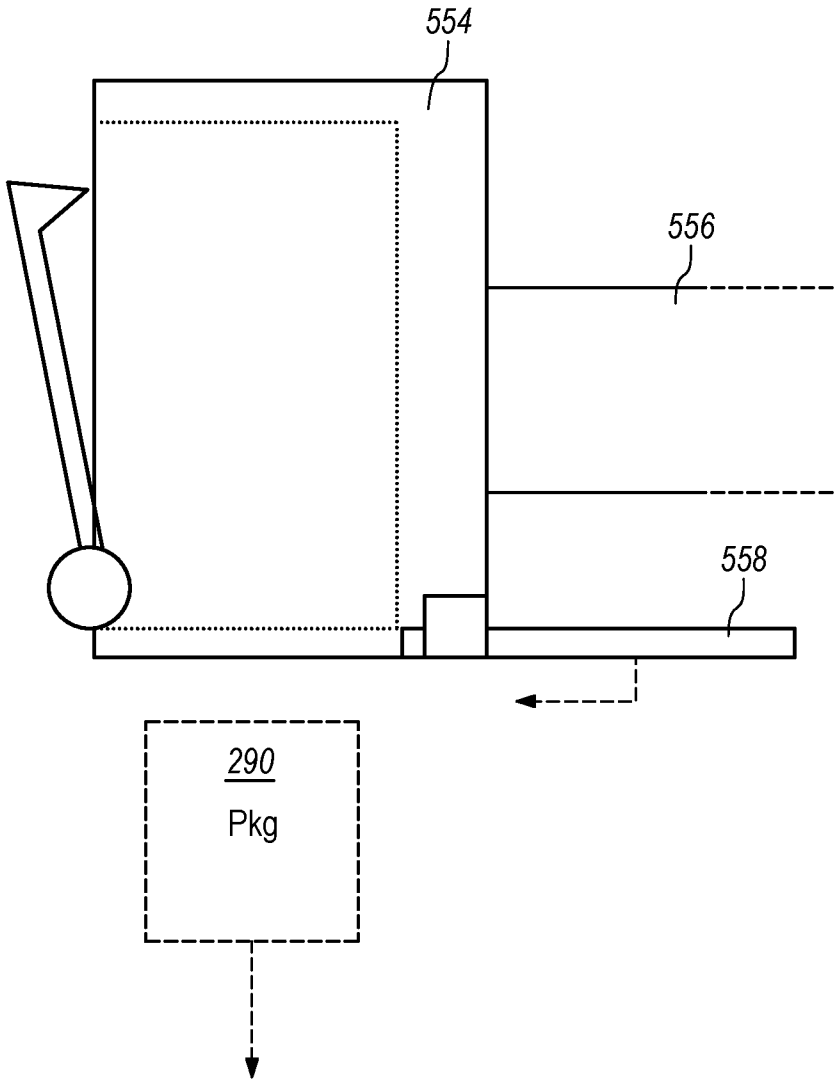


FIG. 38D

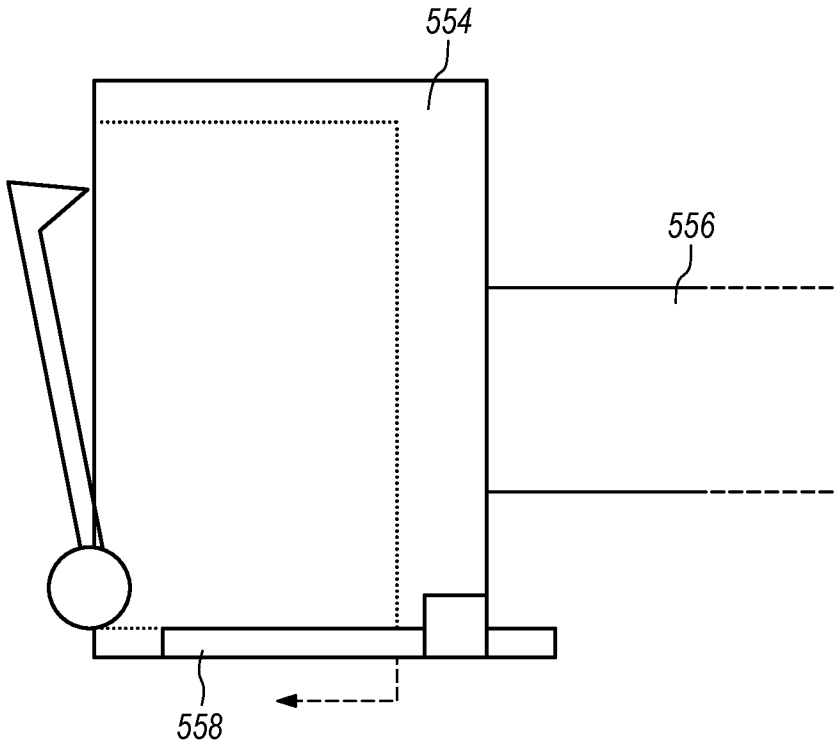


FIG. 38E

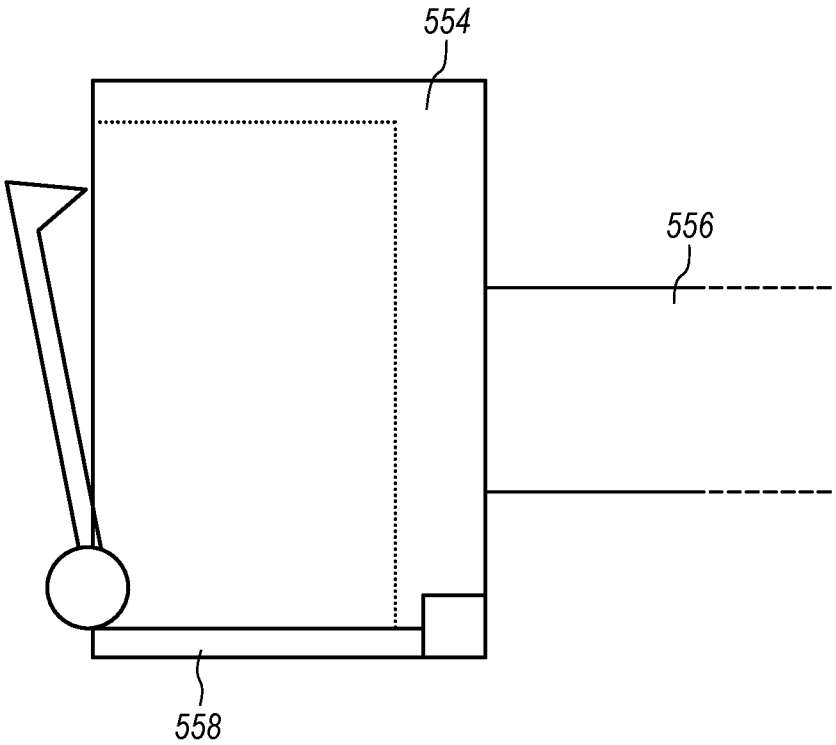


FIG. 38F

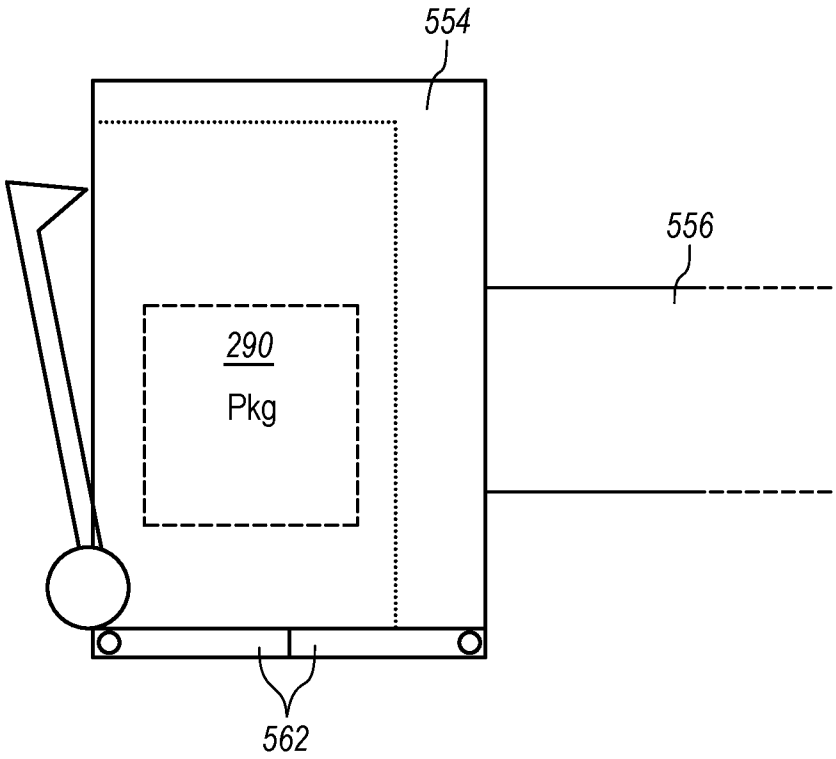


FIG. 39A

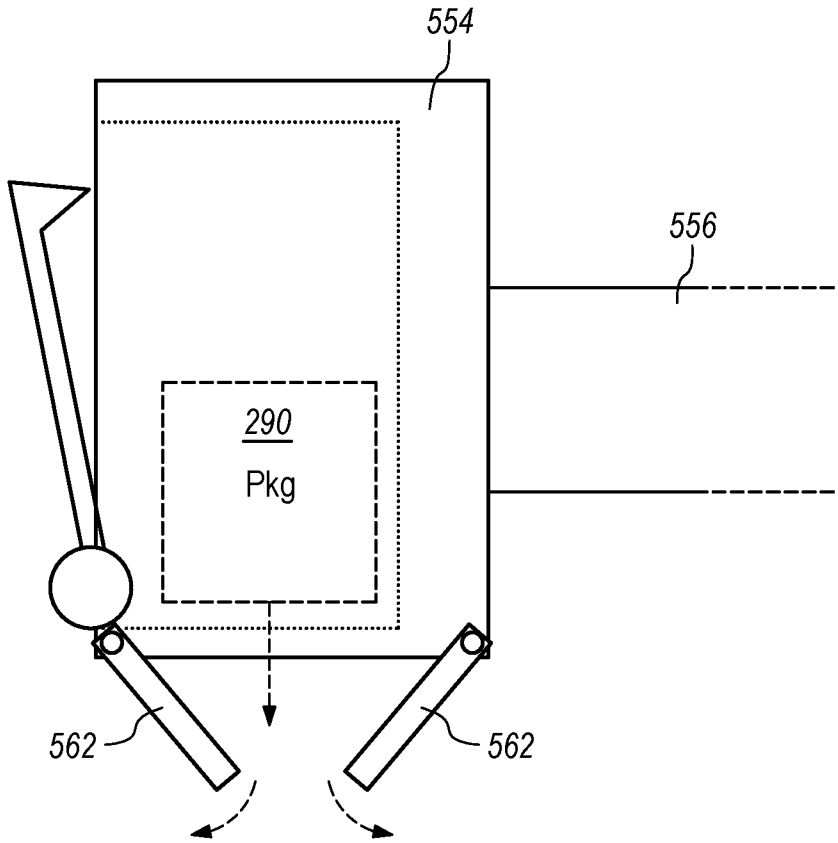


FIG. 39B

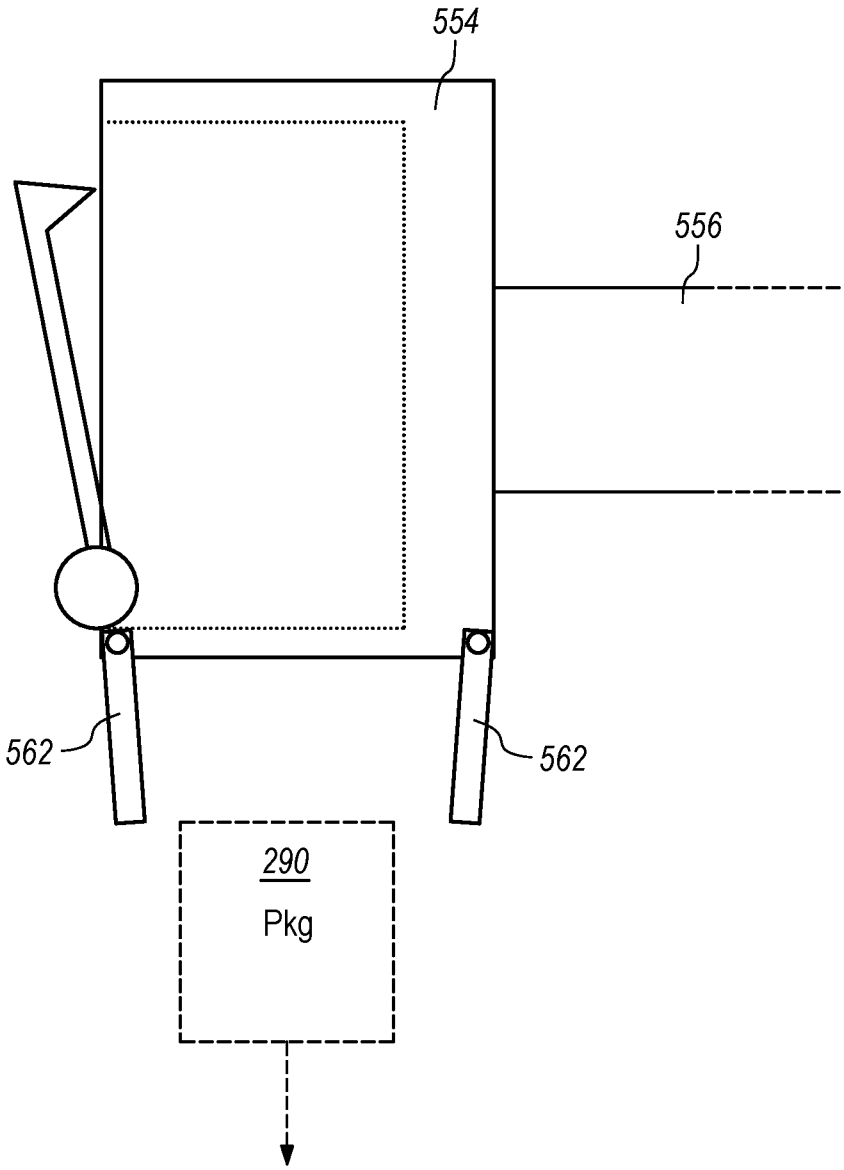


FIG. 39B

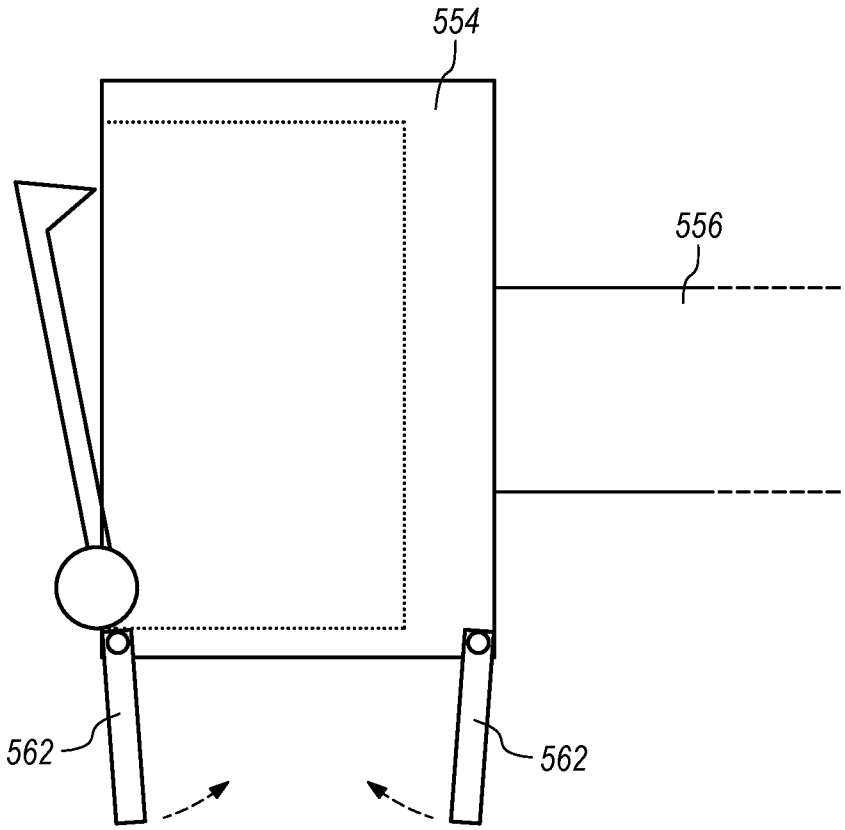


FIG. 39C

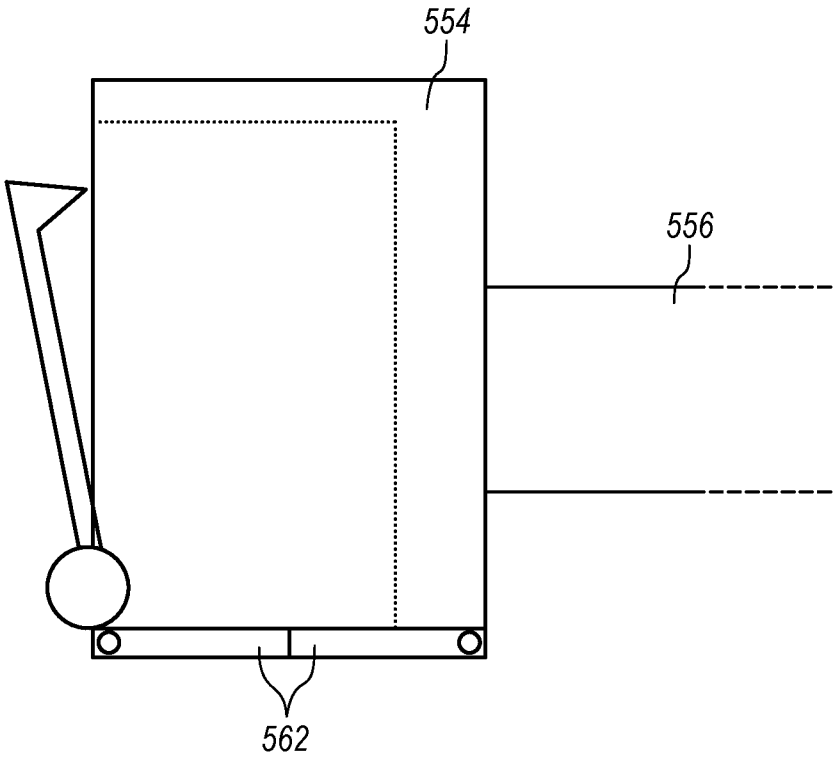


FIG. 39D

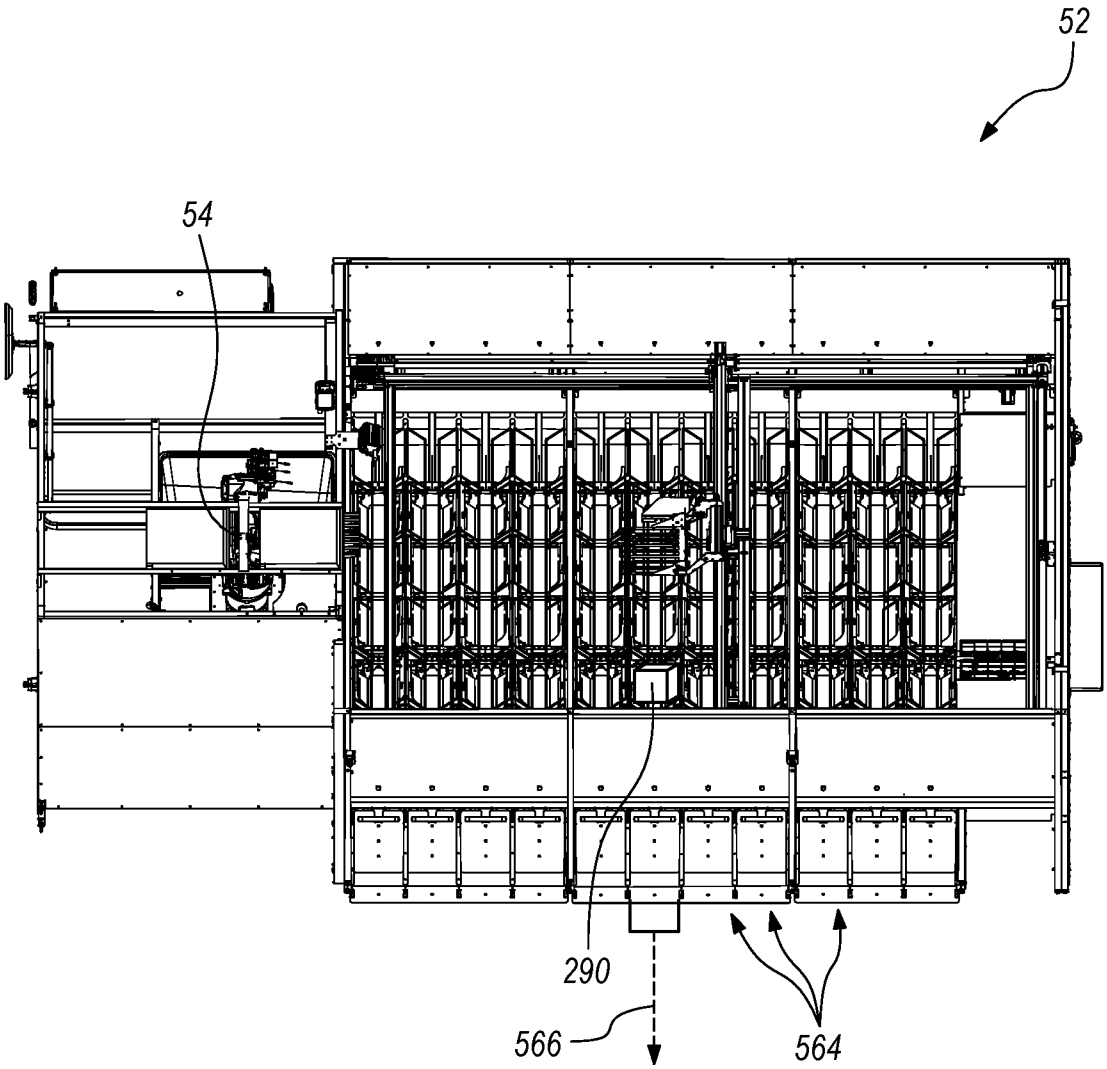


FIG. 40A

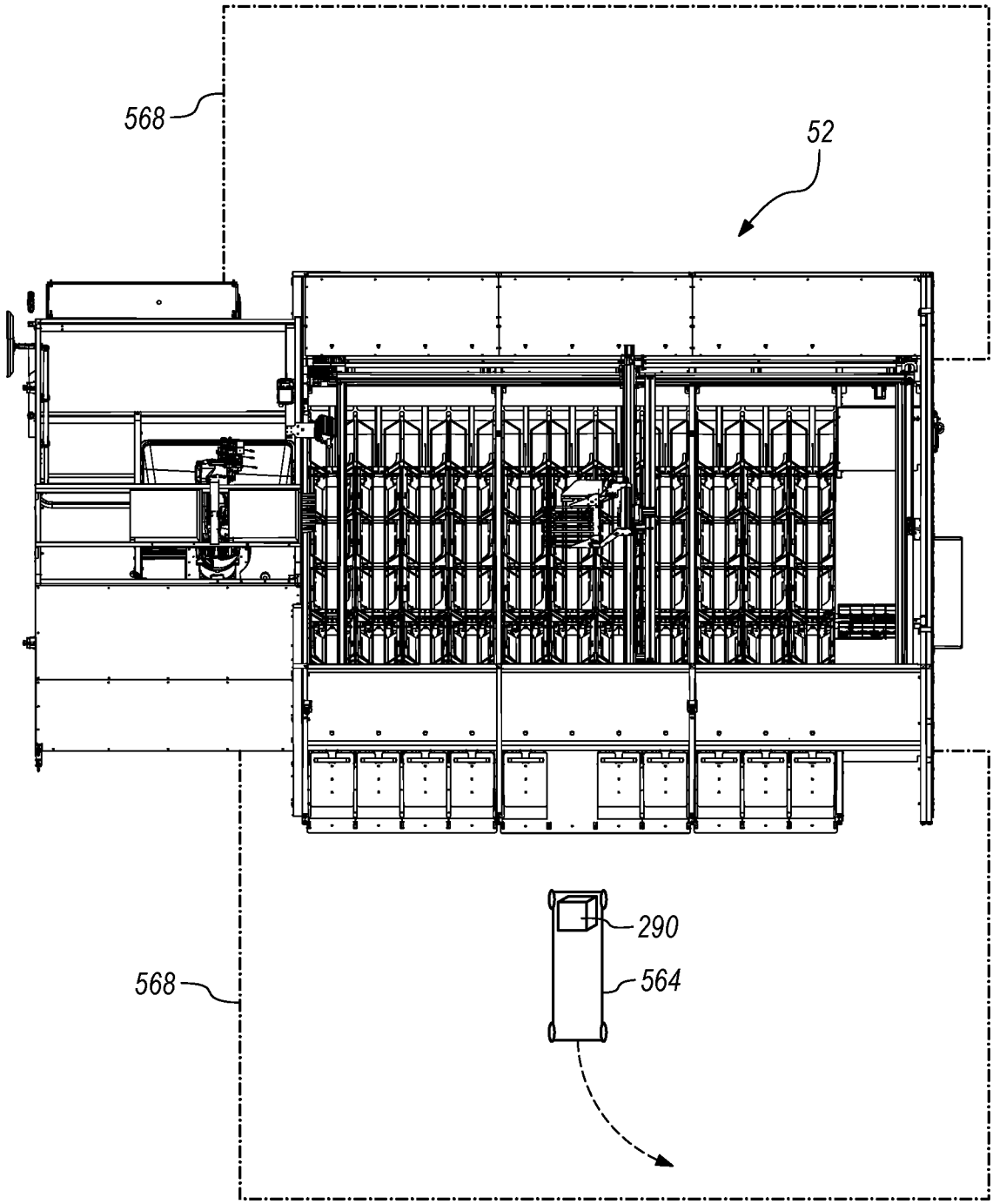


FIG. 40B

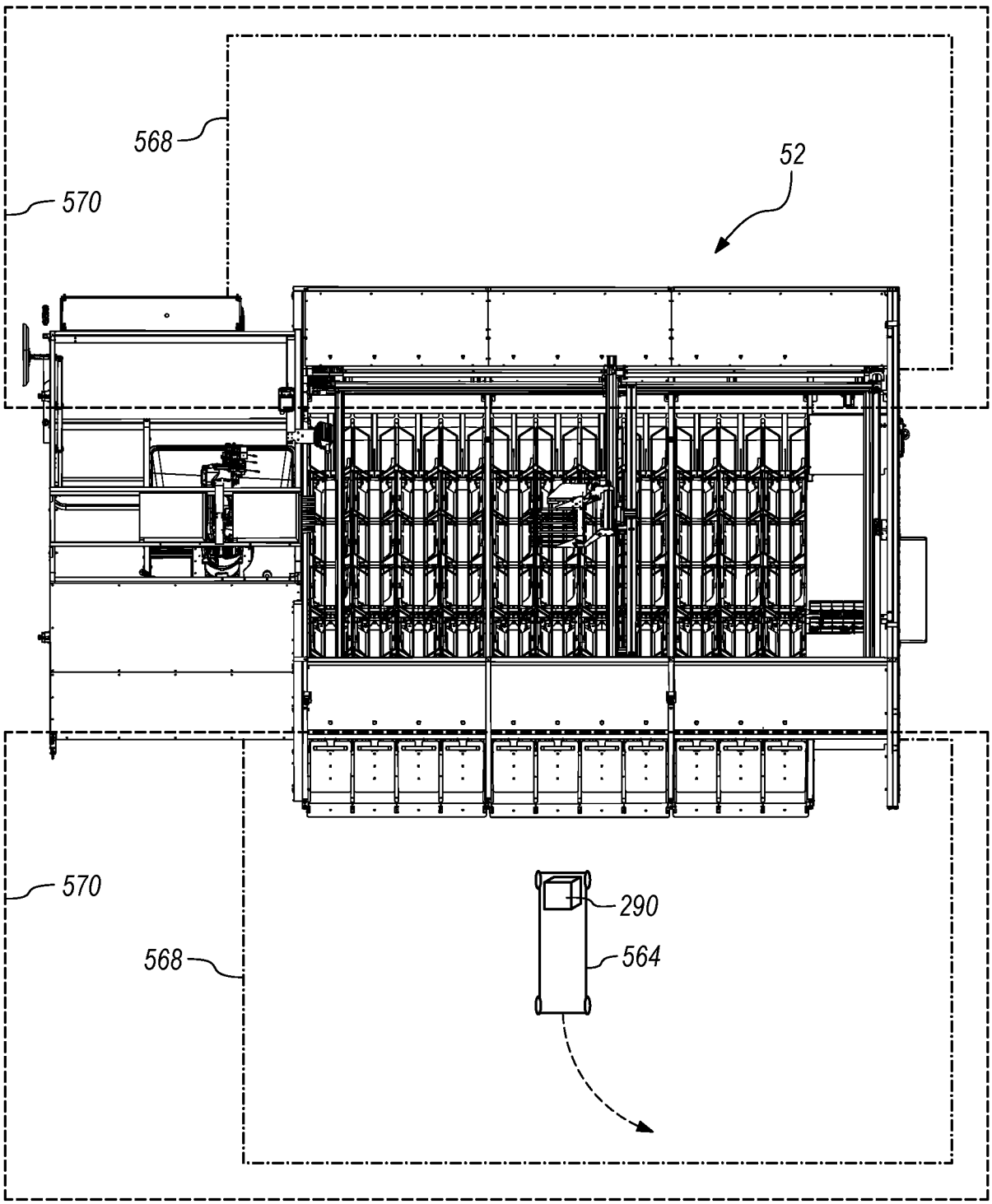


FIG. 40C

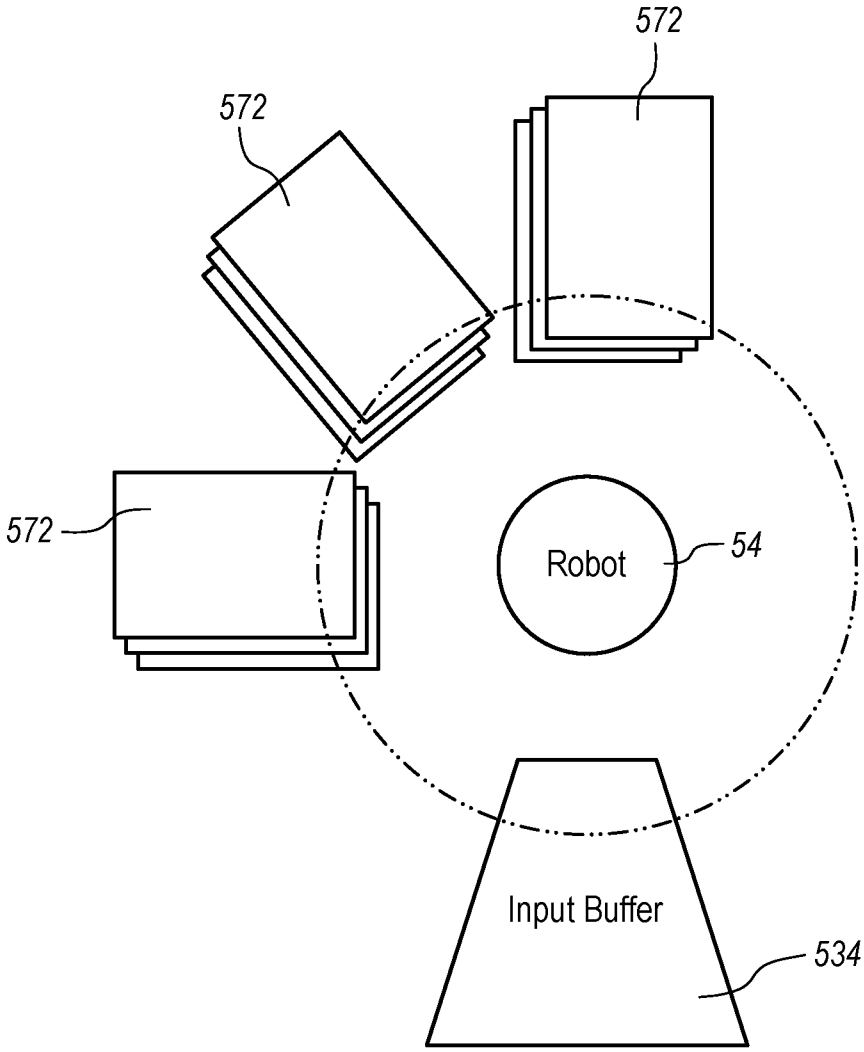


FIG. 41C

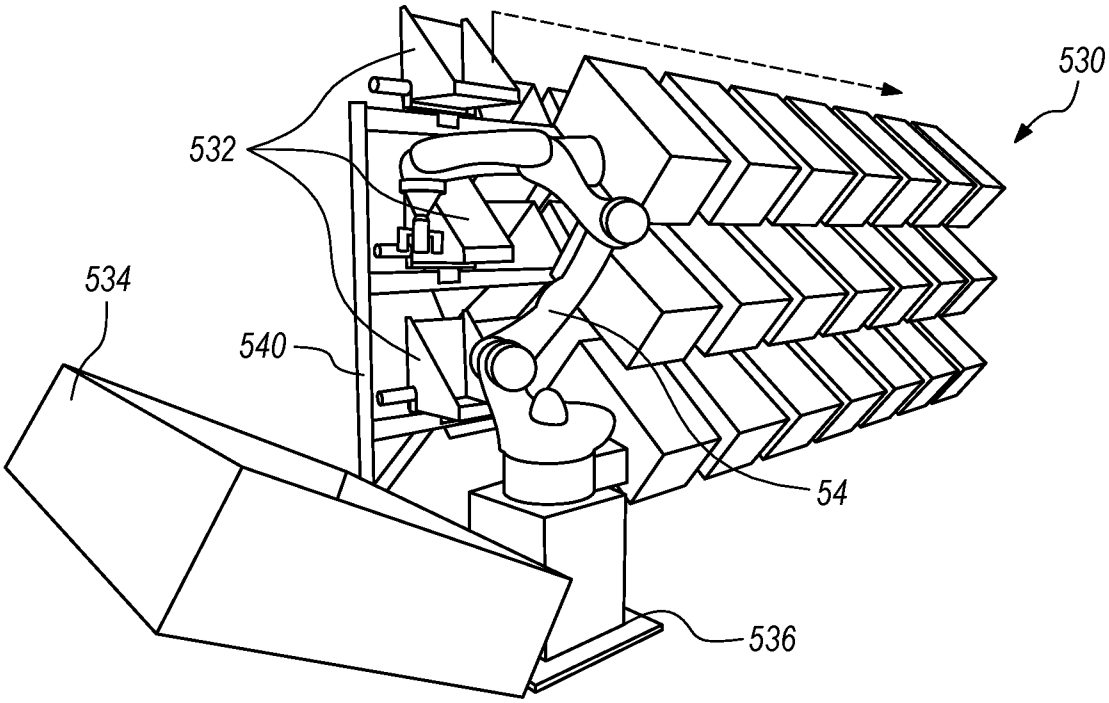


FIG. 41A

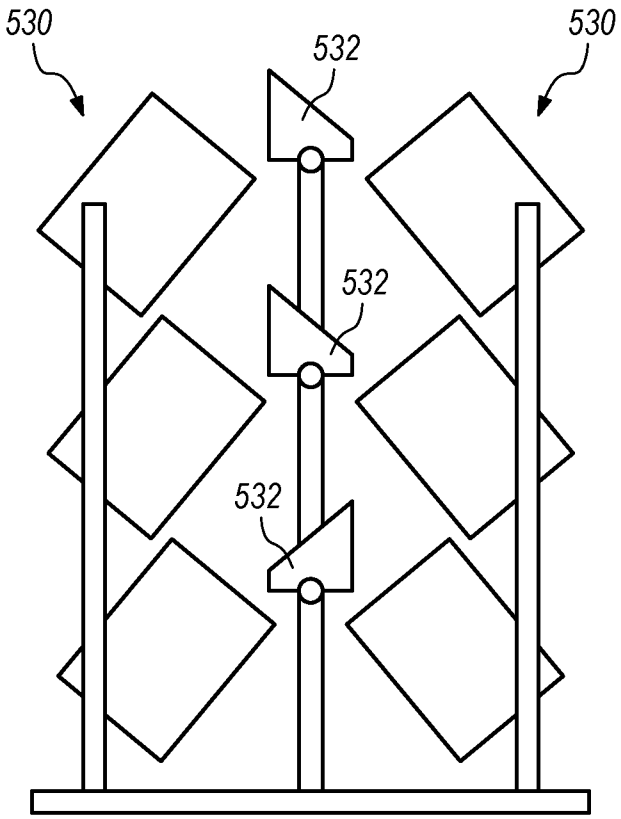


FIG. 41B

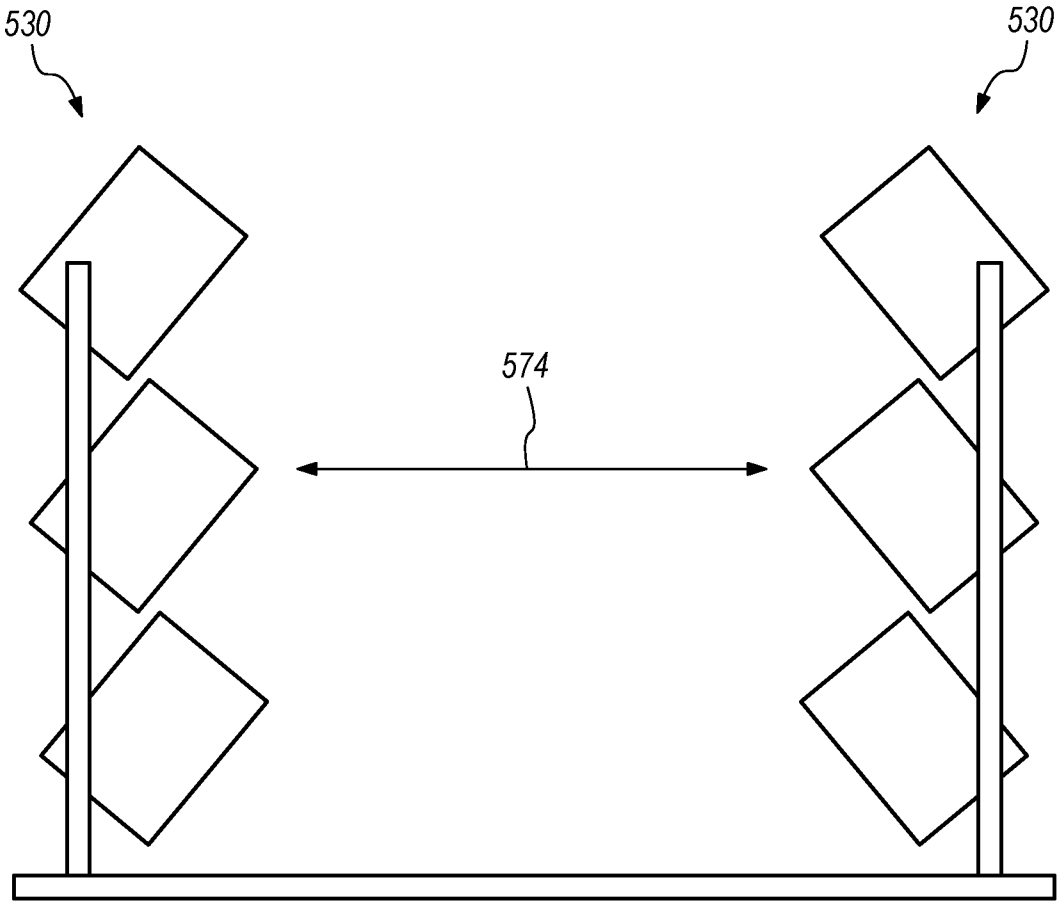


FIG. 41D

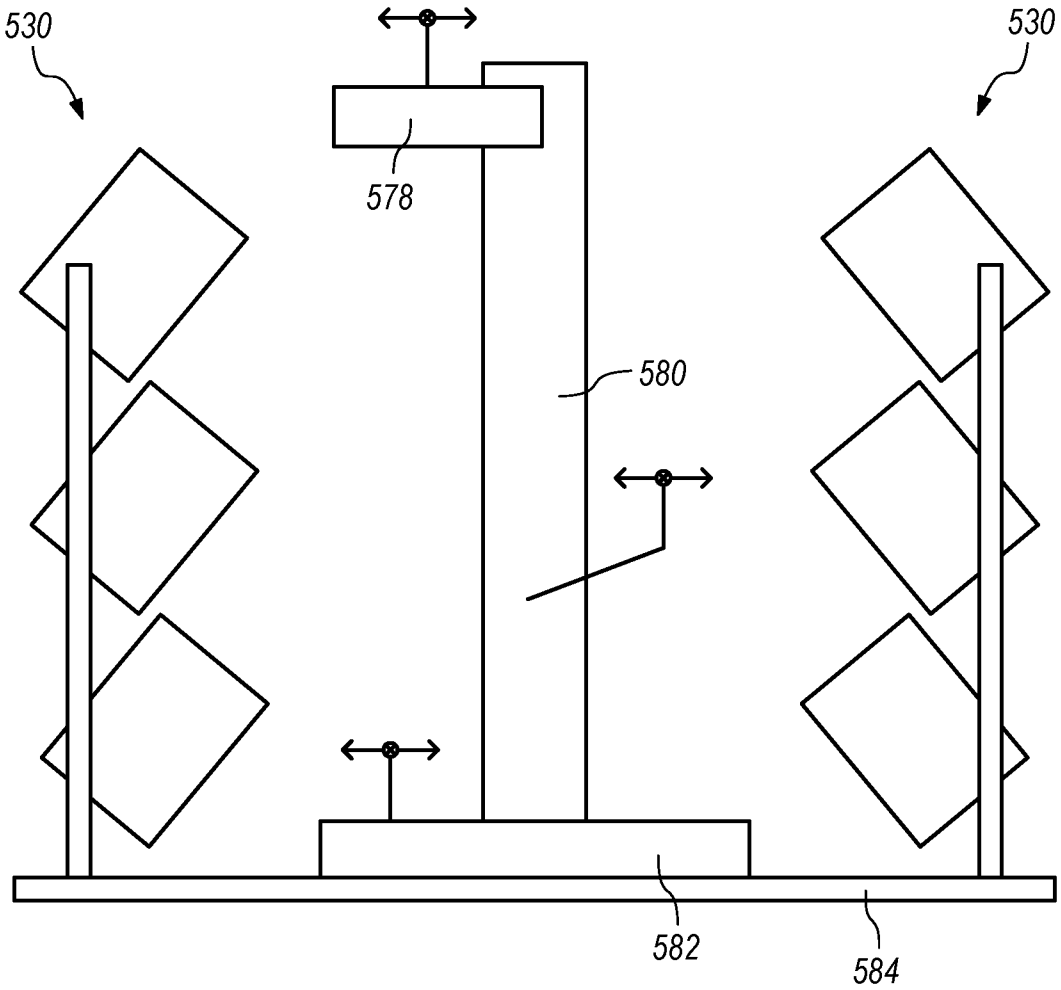


FIG. 41E

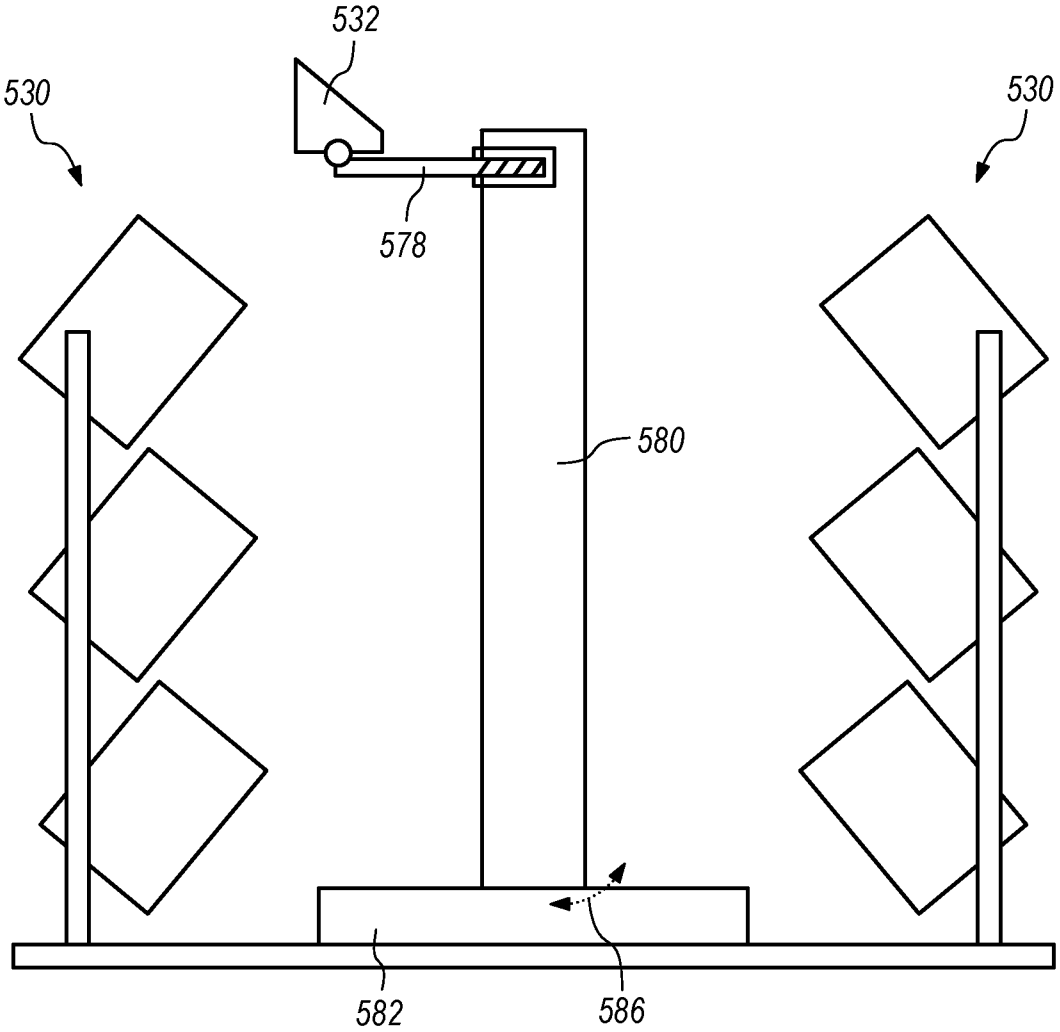


FIG. 41F

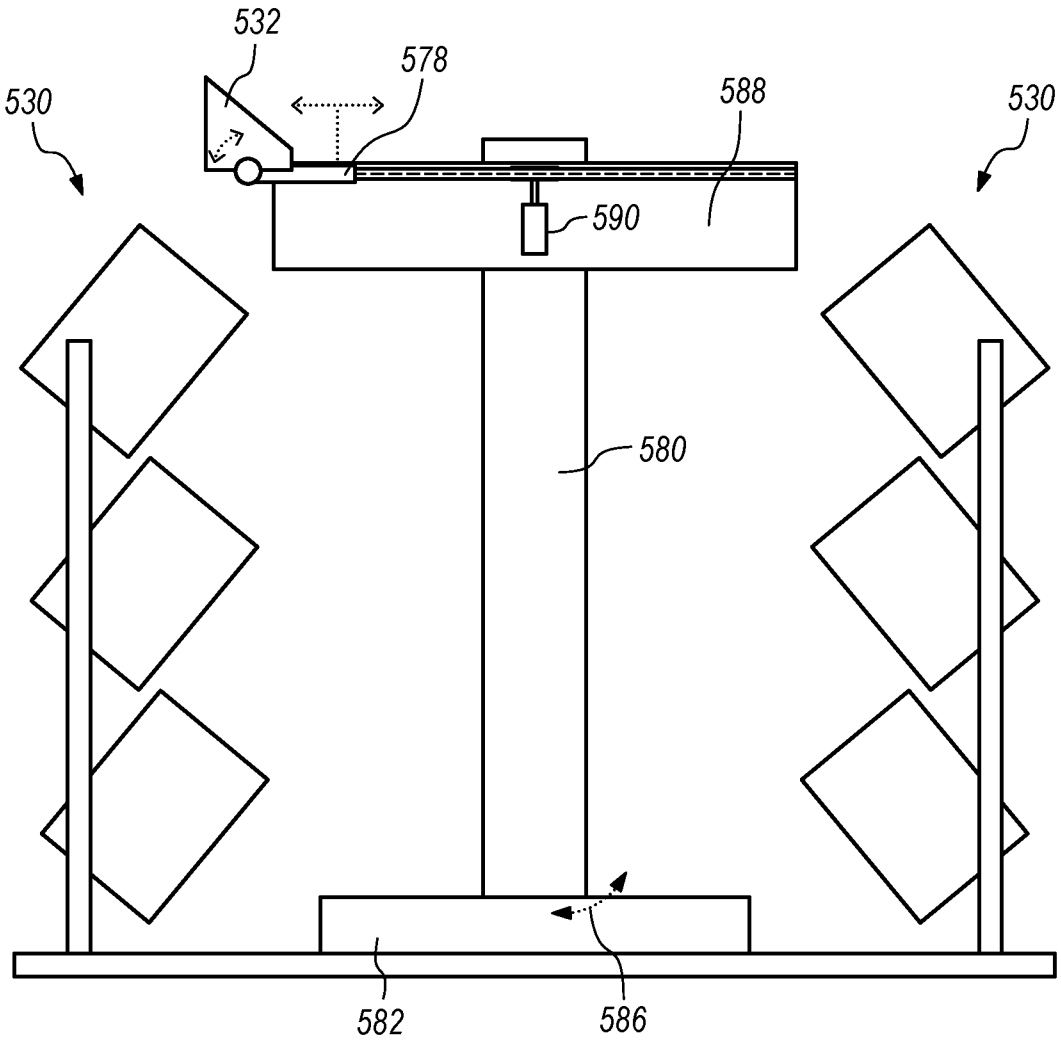


FIG. 41G

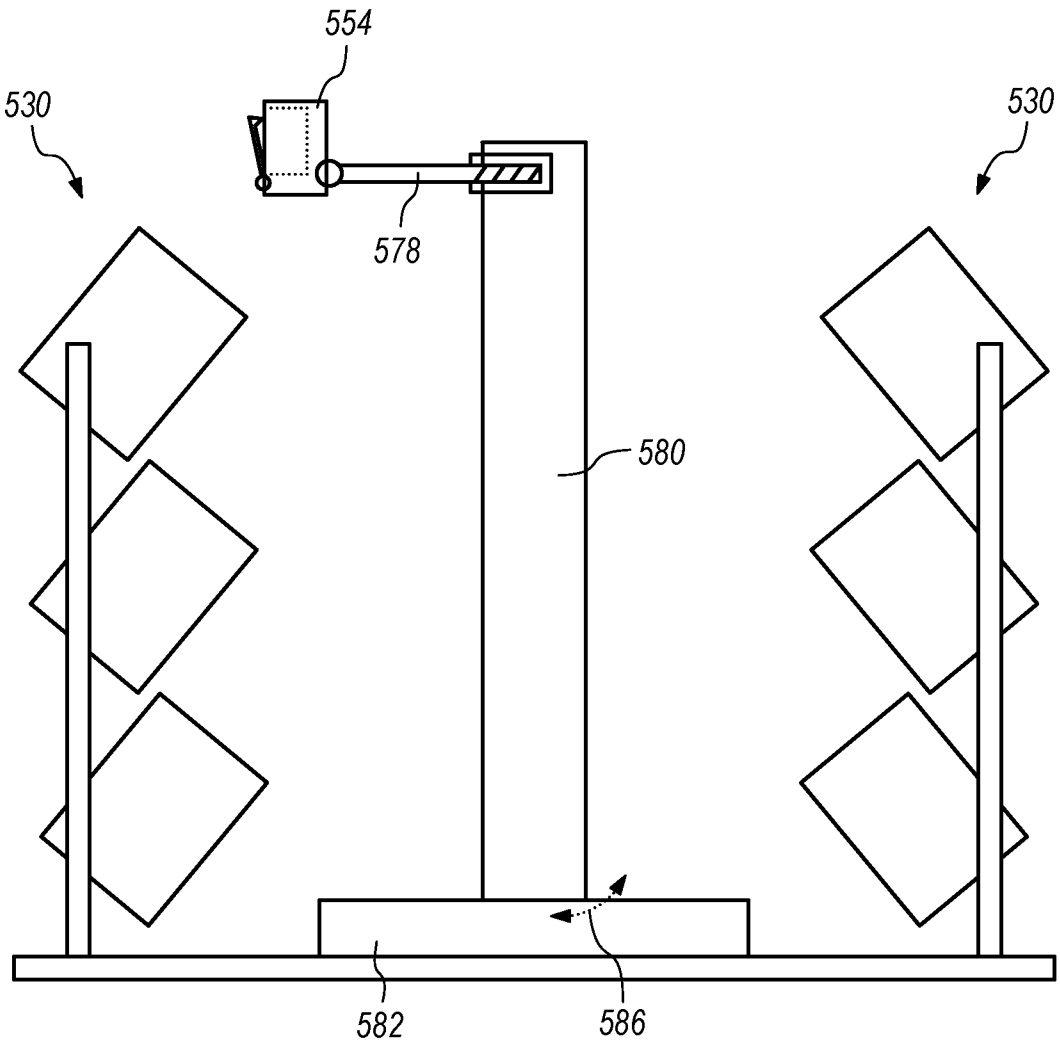


FIG. 41H

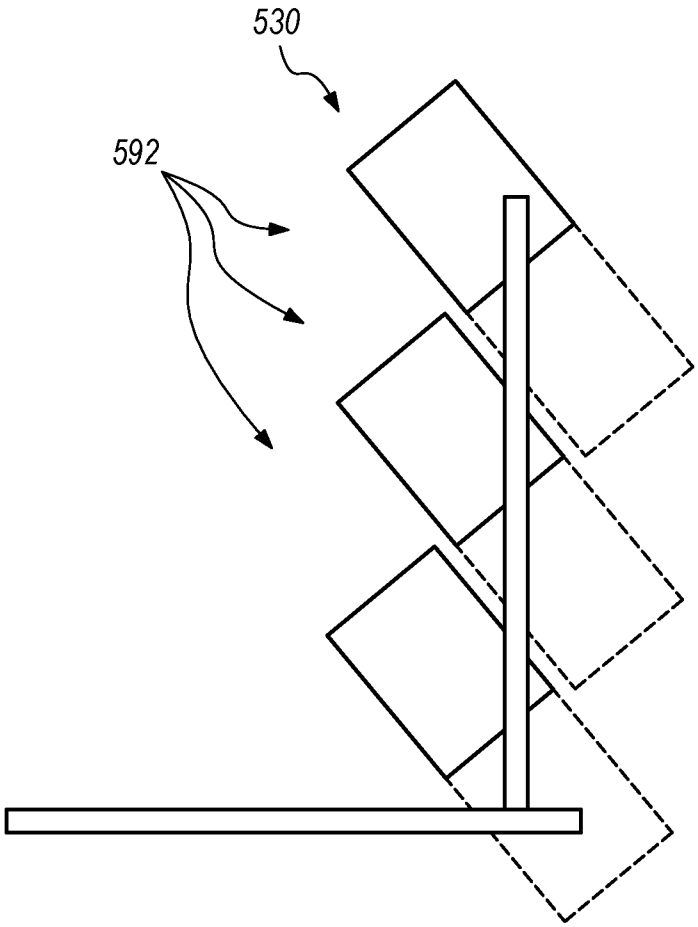


FIG. 42A

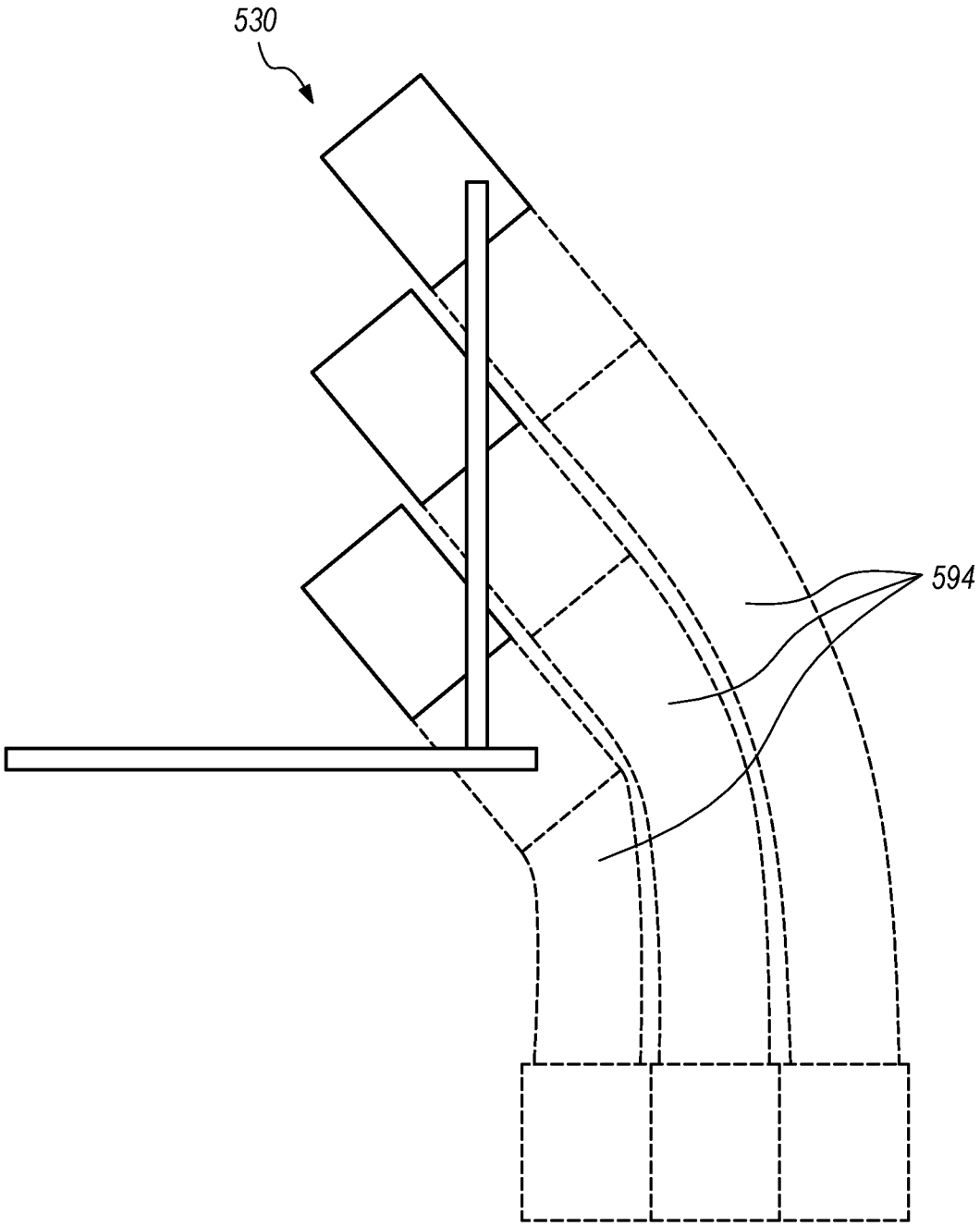


FIG. 42B

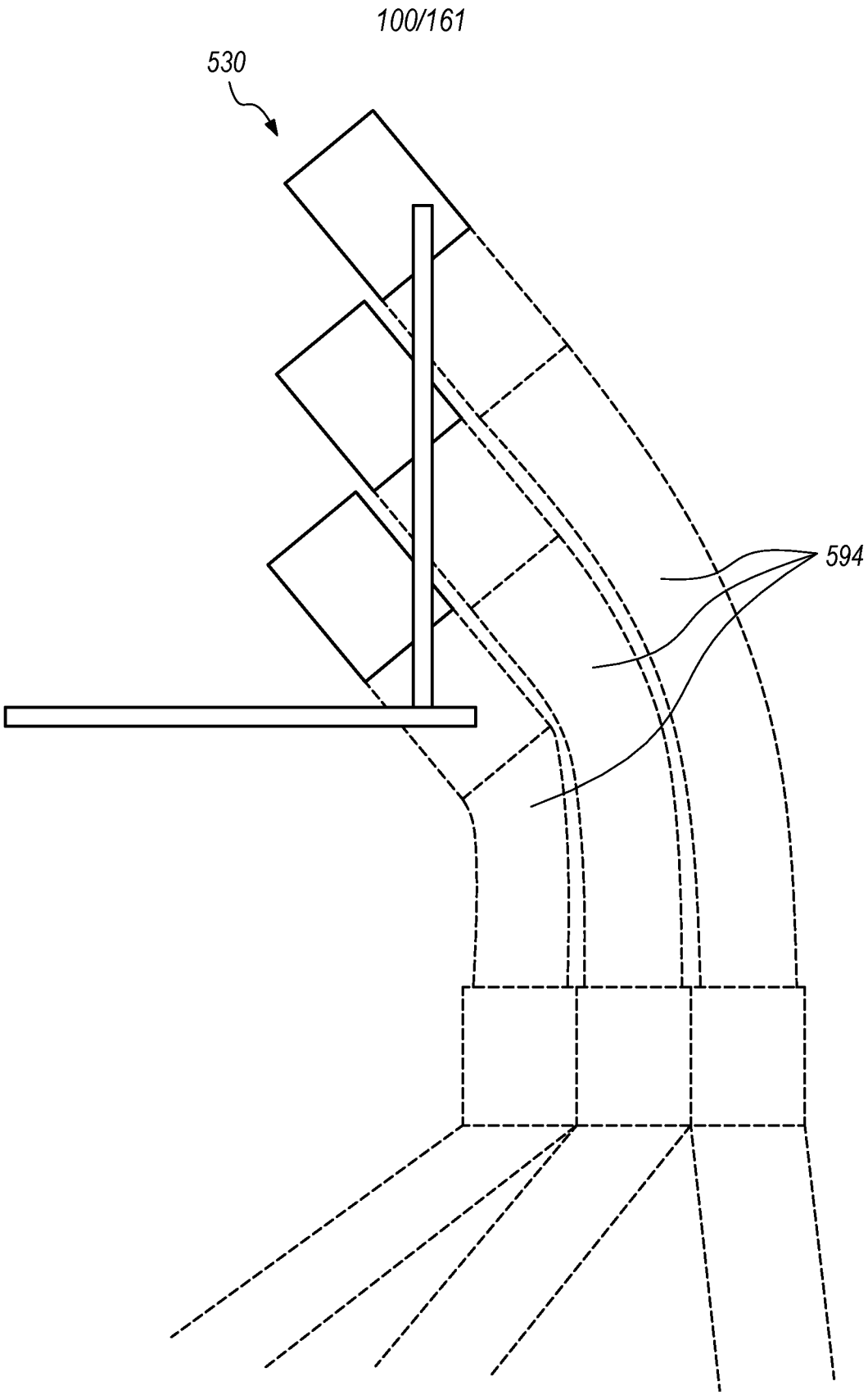


FIG. 42C

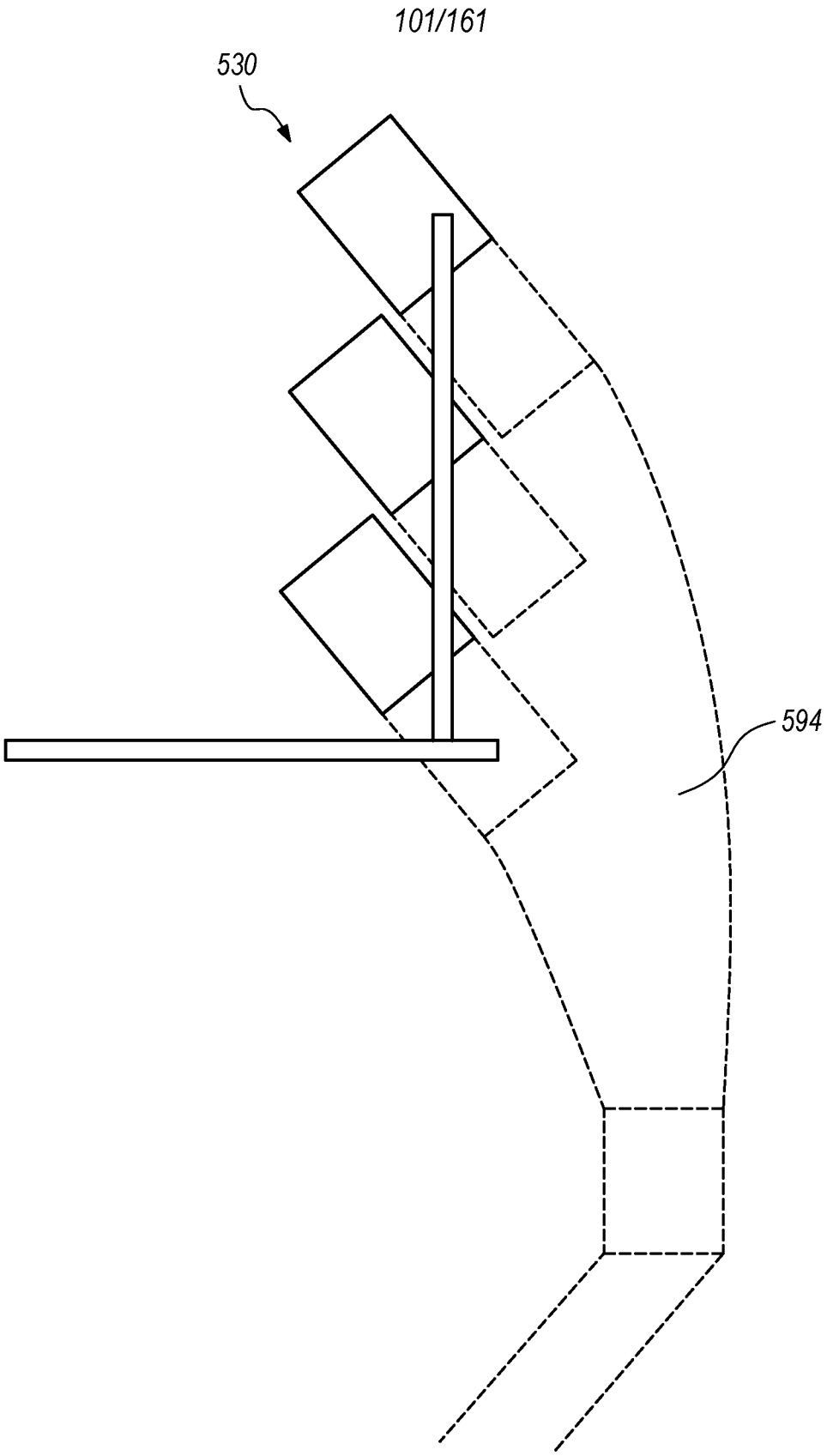


FIG. 42D

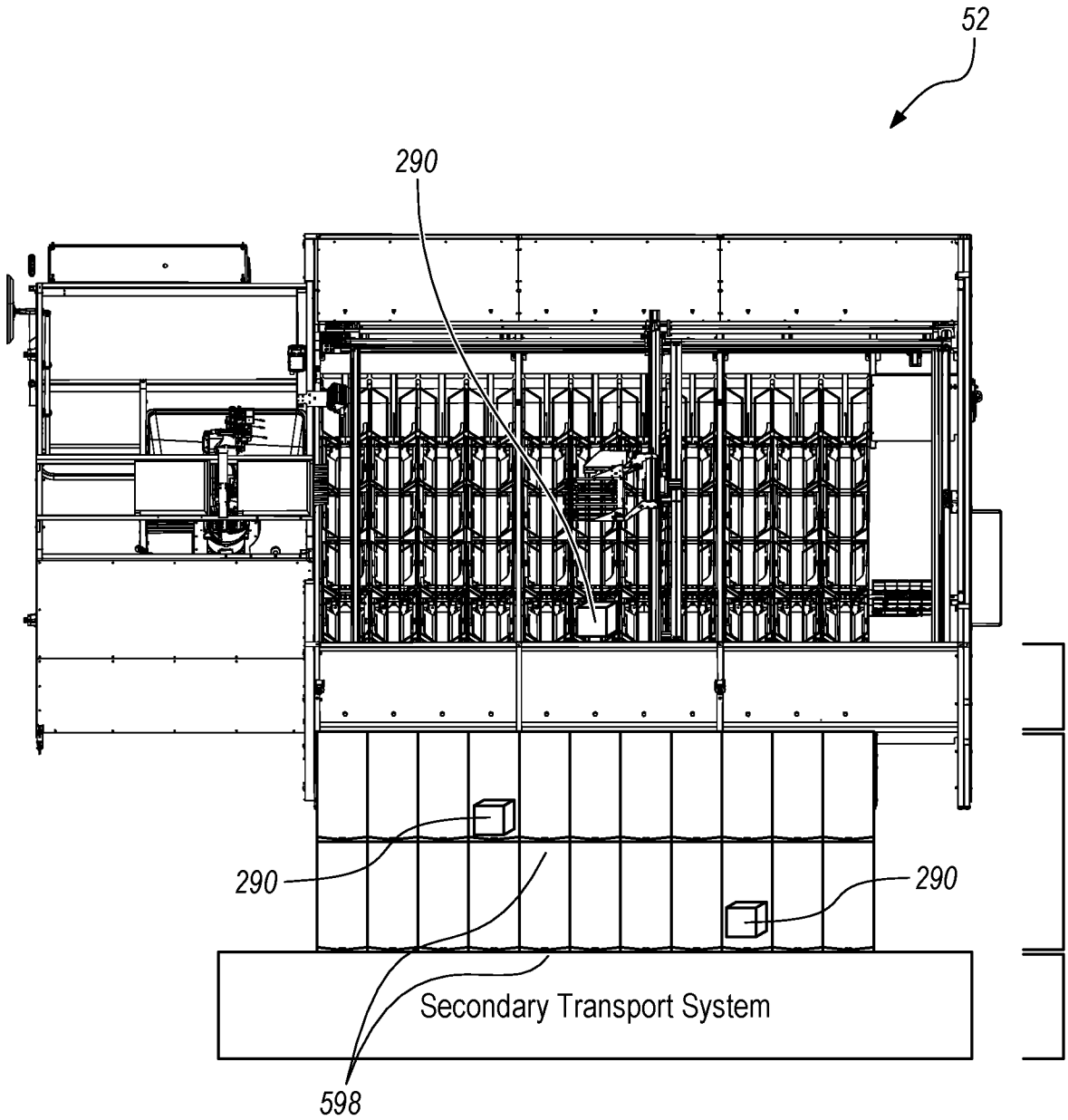


FIG. 43A

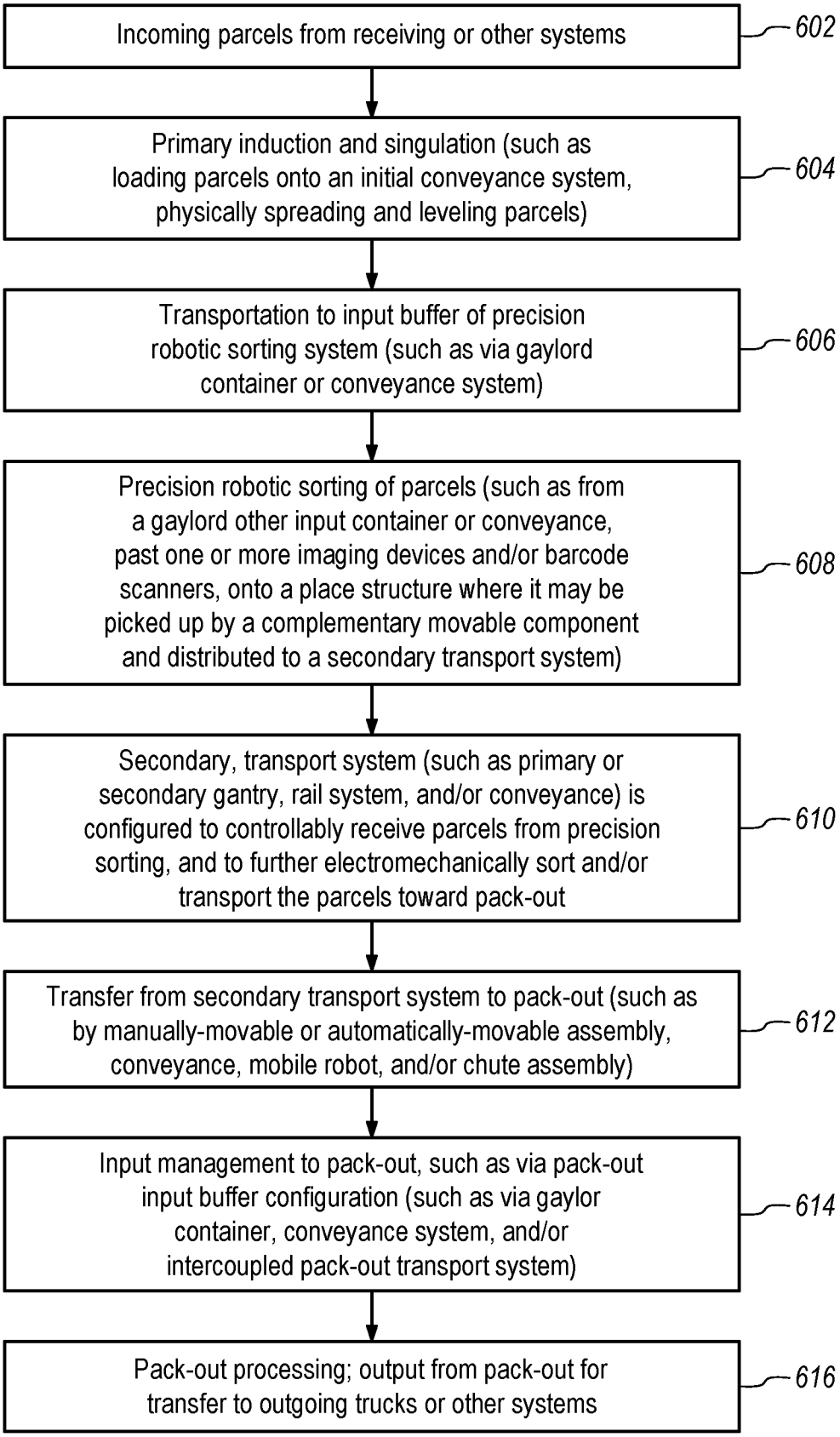

Incoming parcels from receiving or other systems
602
Primary induction and singulation (such as loading parcels onto an initial conveyance system, physically spreading and leveling parcels)
604
Transportation to input buffer of precision robotic sorting system (such as via gaylord container or conveyance system)
606
Precision robotic sorting of parcels (such as from a gaylord other input container or conveyance, past one or more imaging devices and/or barcode scanners, onto a place structure where it may be picked up by a complementary movable component and distributed to a secondary transport system)
608
Secondary, transport system (such as primary or secondary gantry, rail system, and/or conveyance) is configured to controllably receive parcels from precision sorting, and to further electromechanically sort and/or transport the parcels toward pack-out
610
Transfer from secondary transport system to pack-out (such as by manually-movable or automatically-movable assembly, conveyance, mobile robot, and/or chute assembly)
612
Input management to pack-out, such as via pack-out input buffer configuration (such as via gaylor container, conveyance system, and/or intercoupled pack-out transport system)
614
Pack-out processing; output from pack-out for transfer to outgoing trucks or other systems
616

FIG. 43B

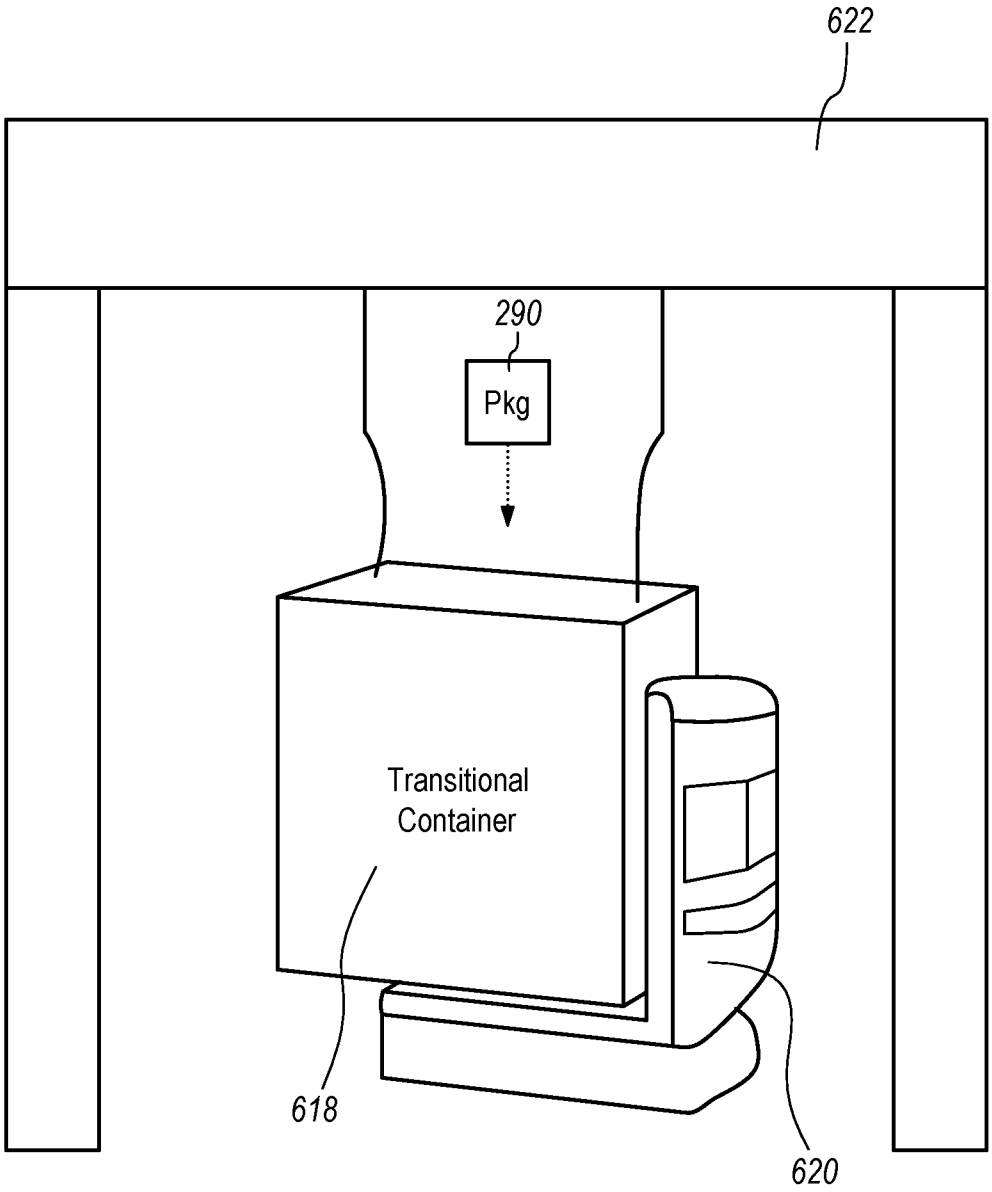


FIG. 43C

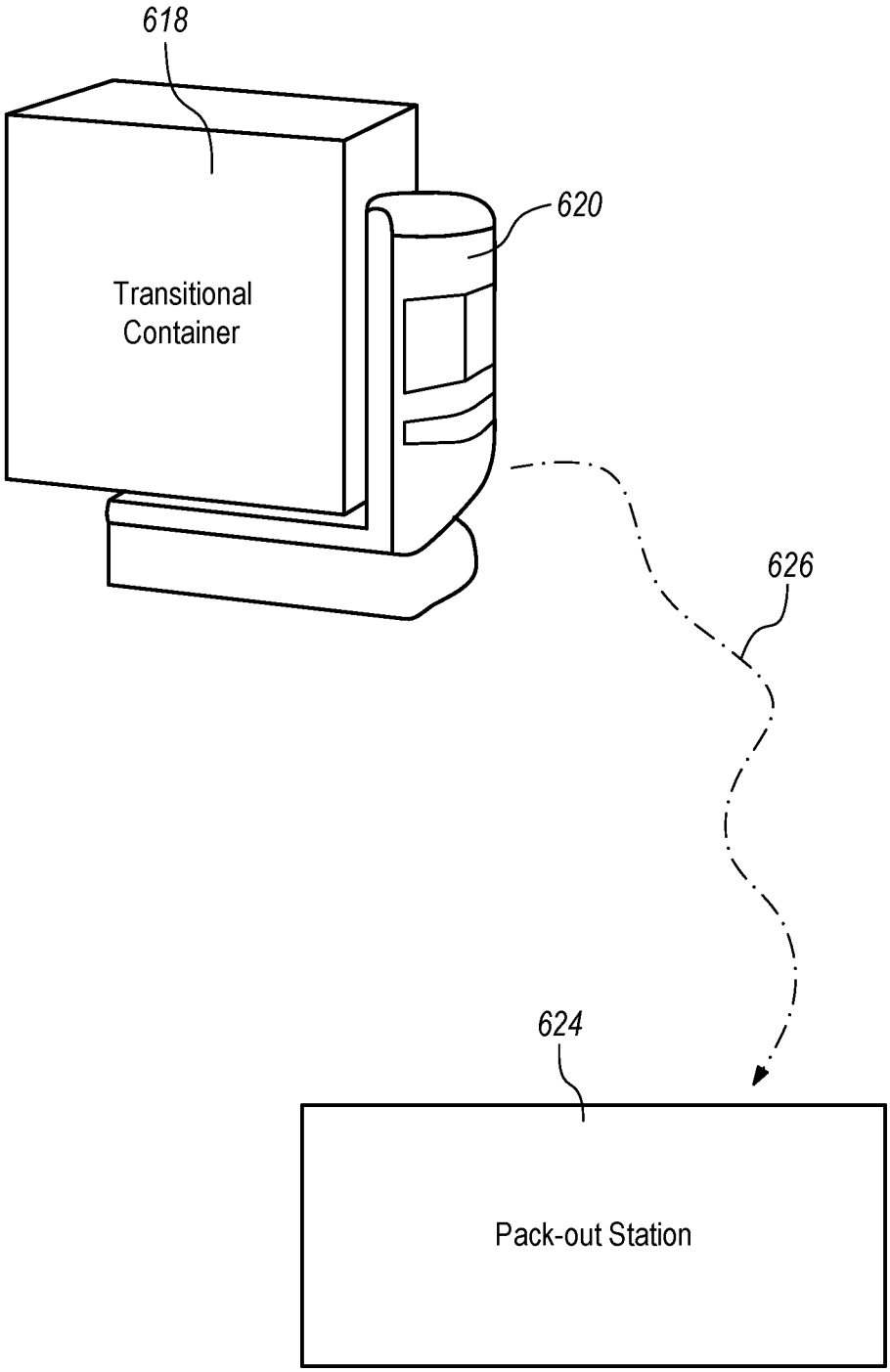


FIG. 43D

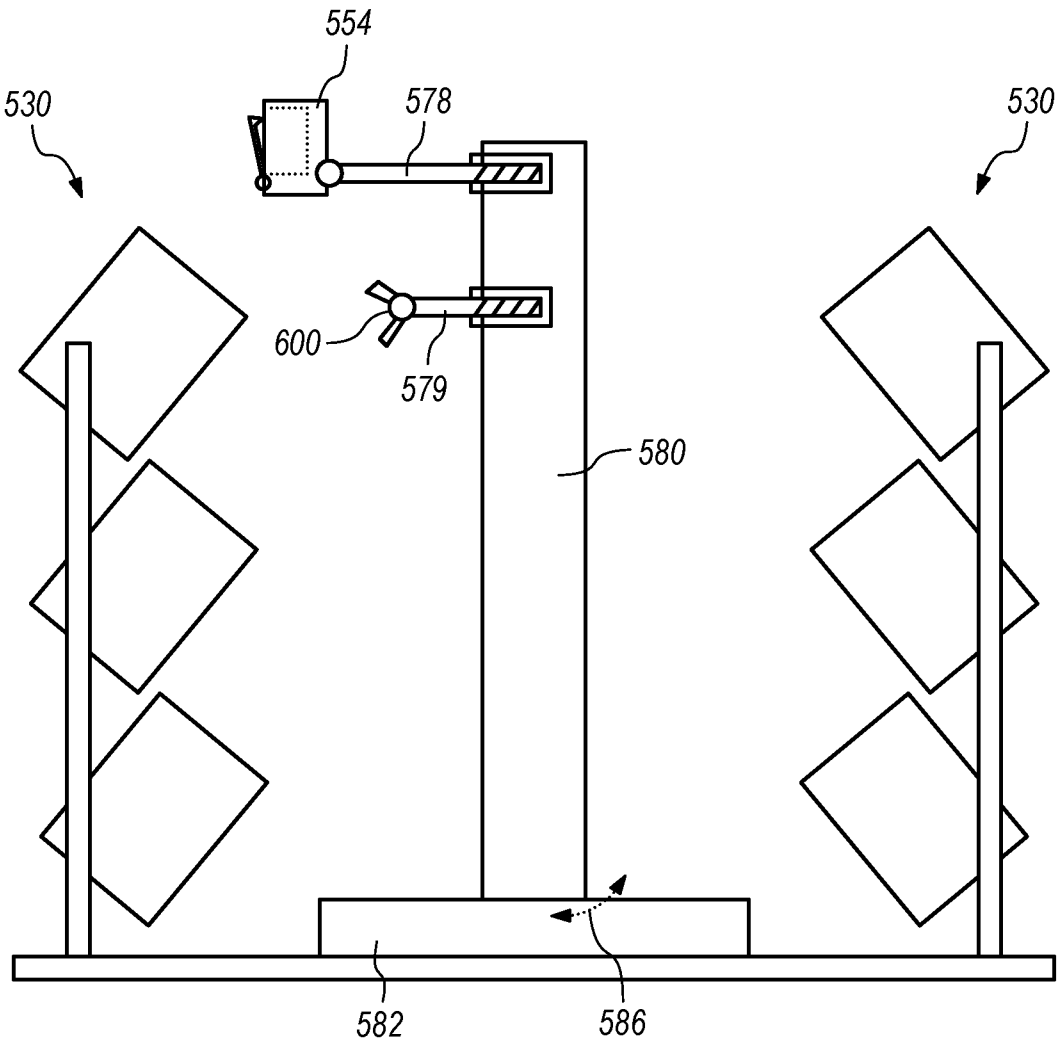


FIG. 44A

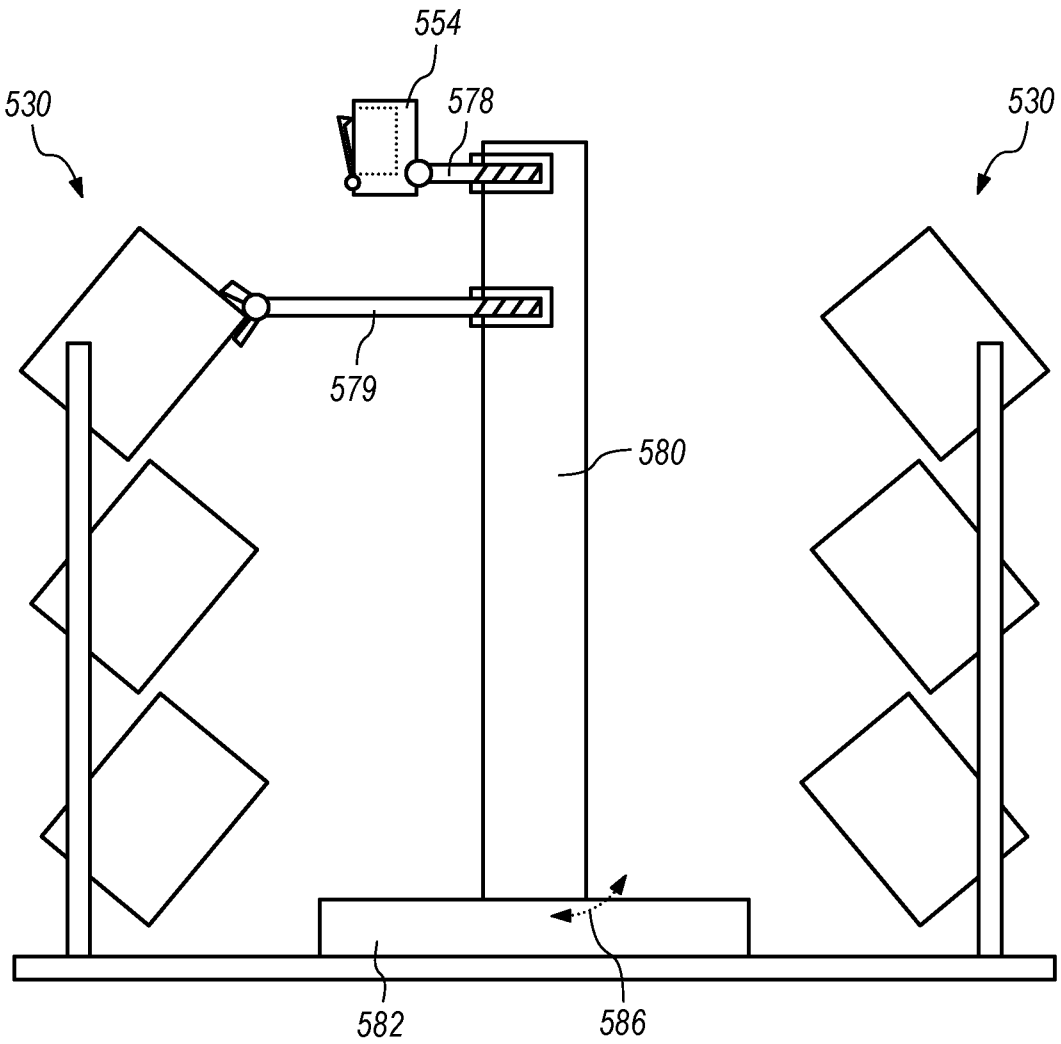


FIG. 44B

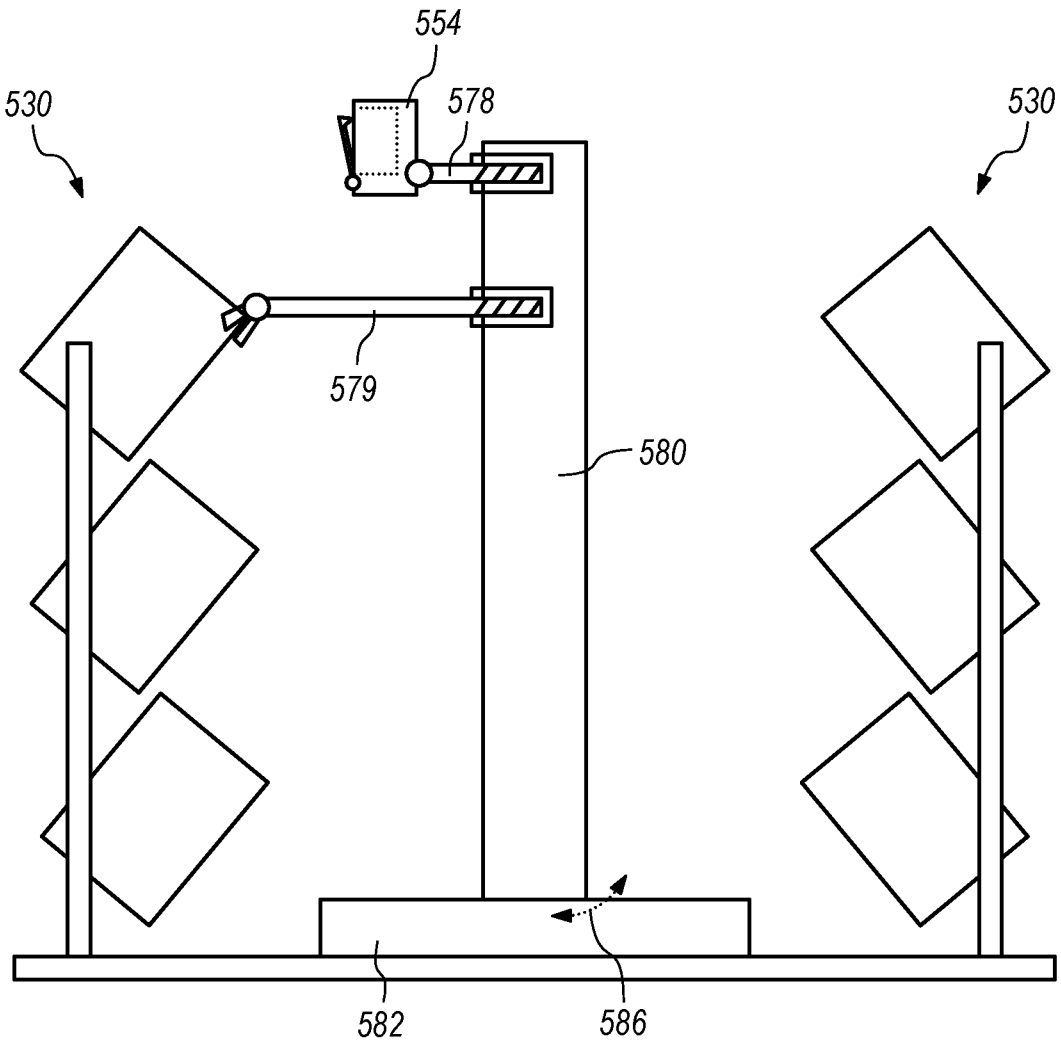


FIG. 44C

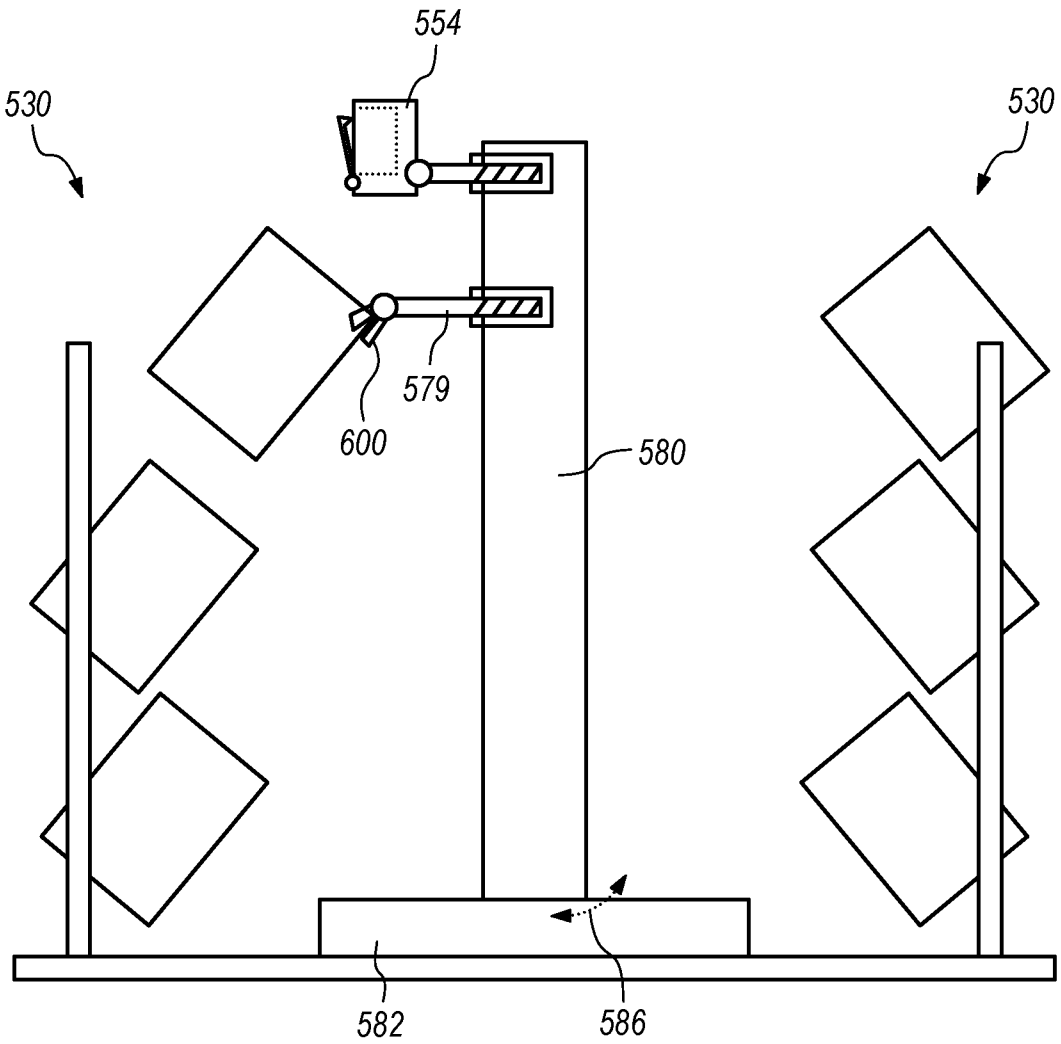


FIG. 44D

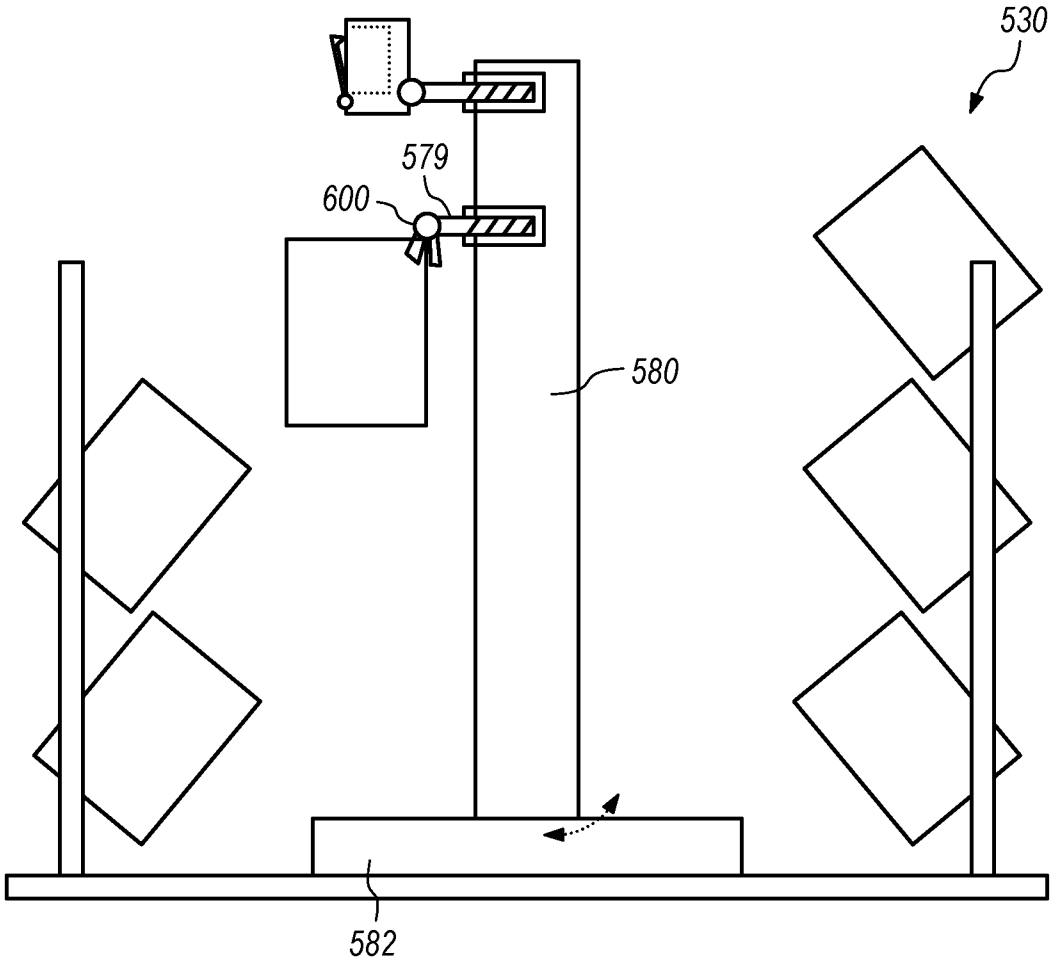


FIG. 44E

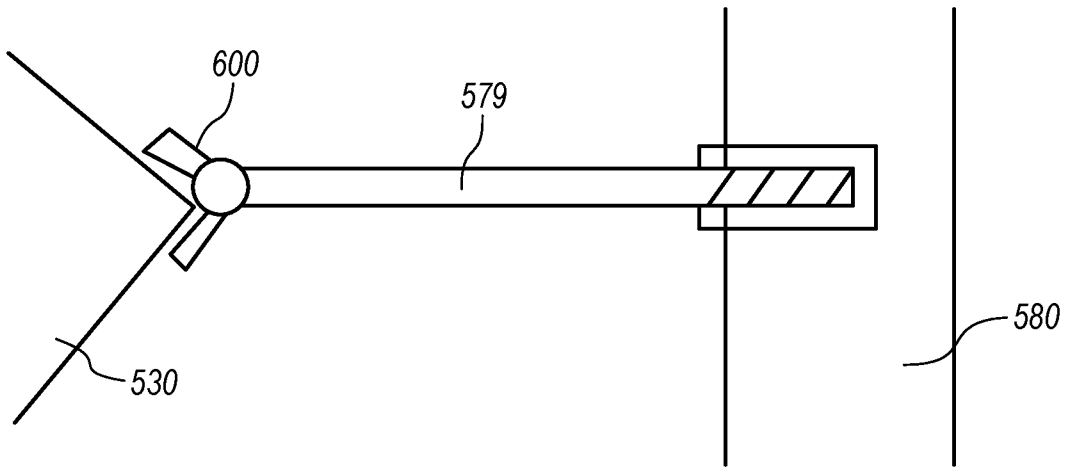


FIG. 44F

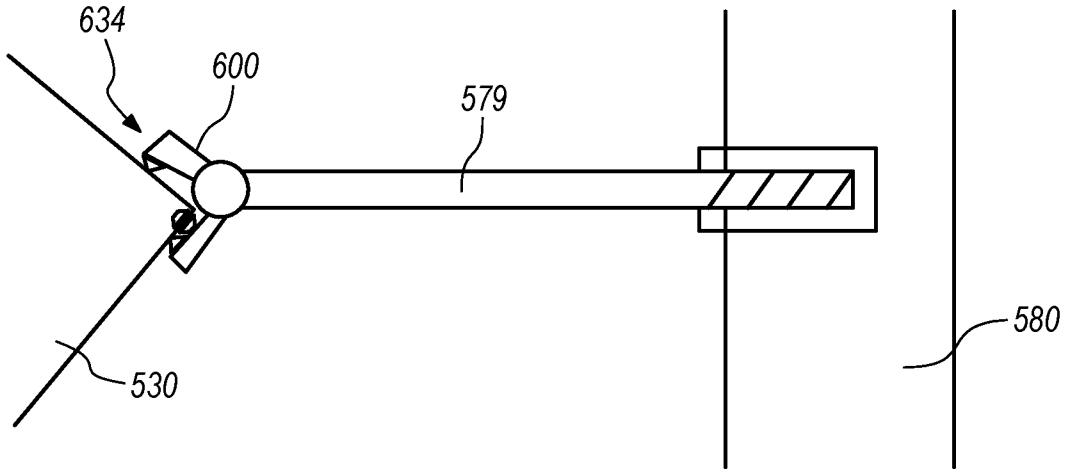


FIG. 44G

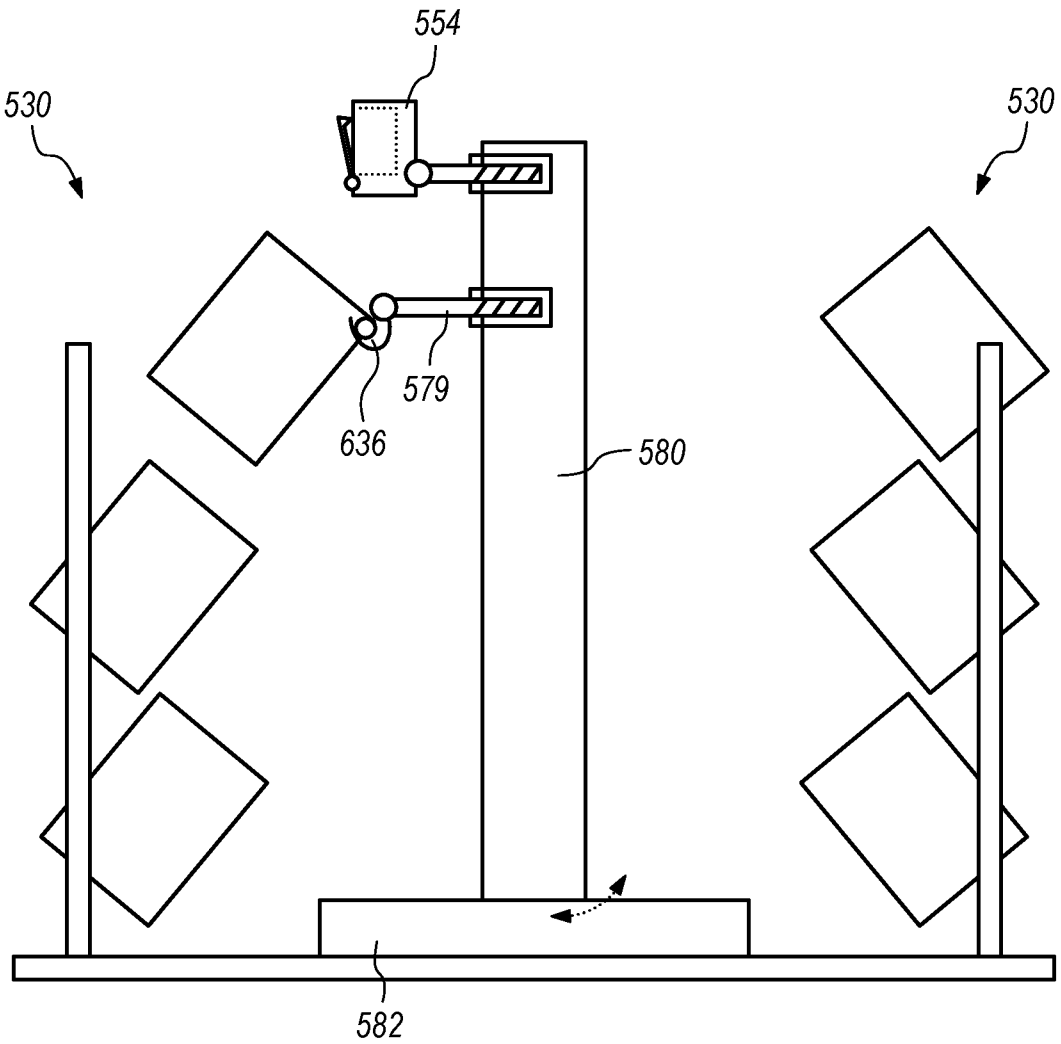


FIG. 44H

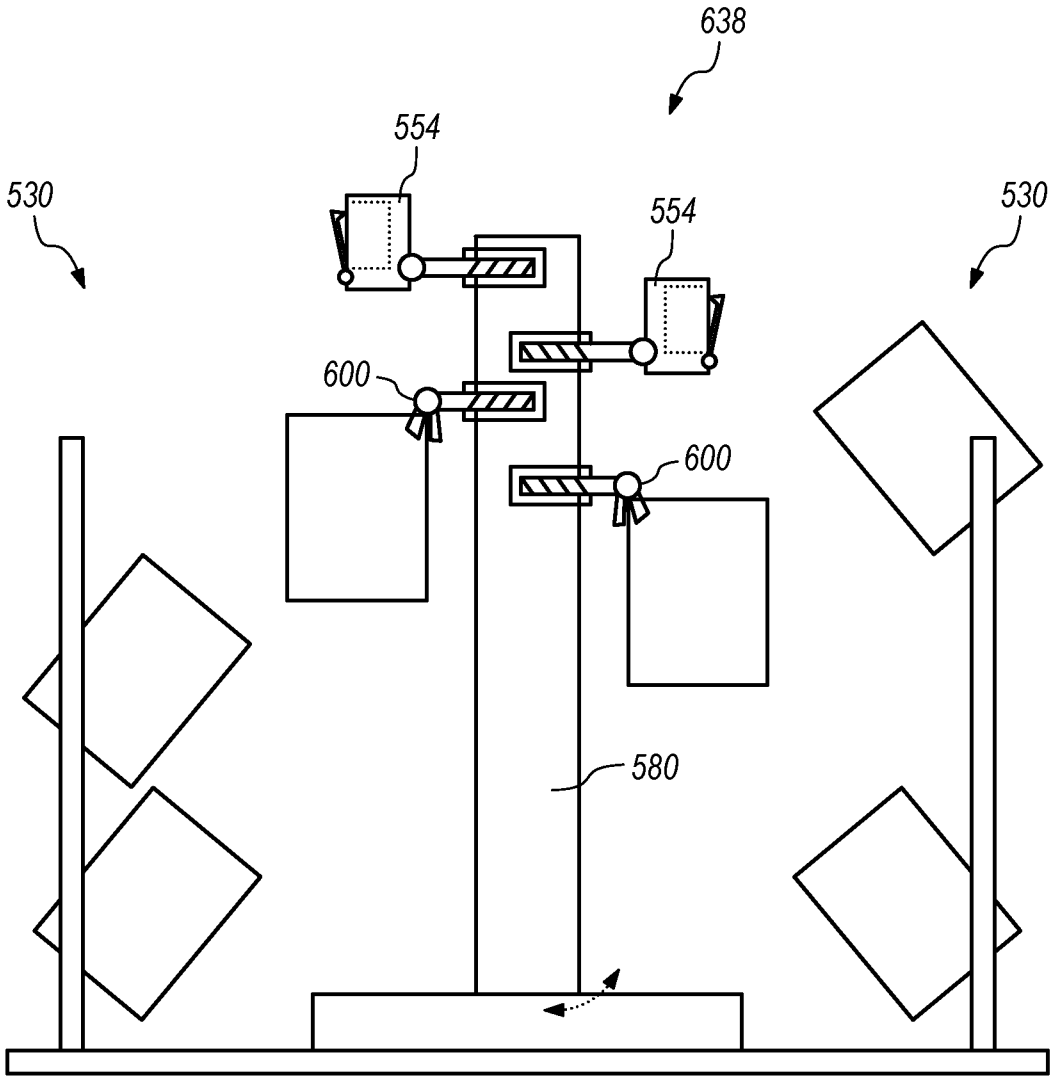


FIG. 44I

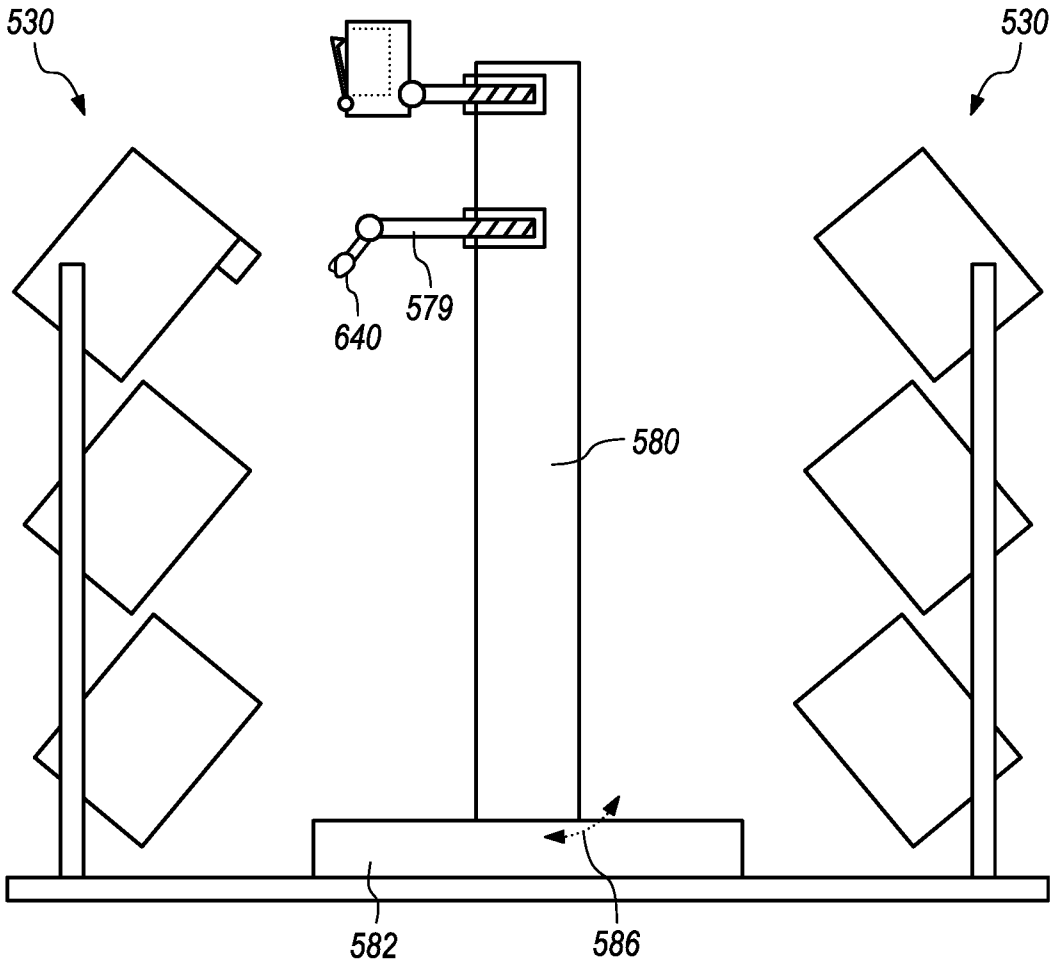


FIG. 44J

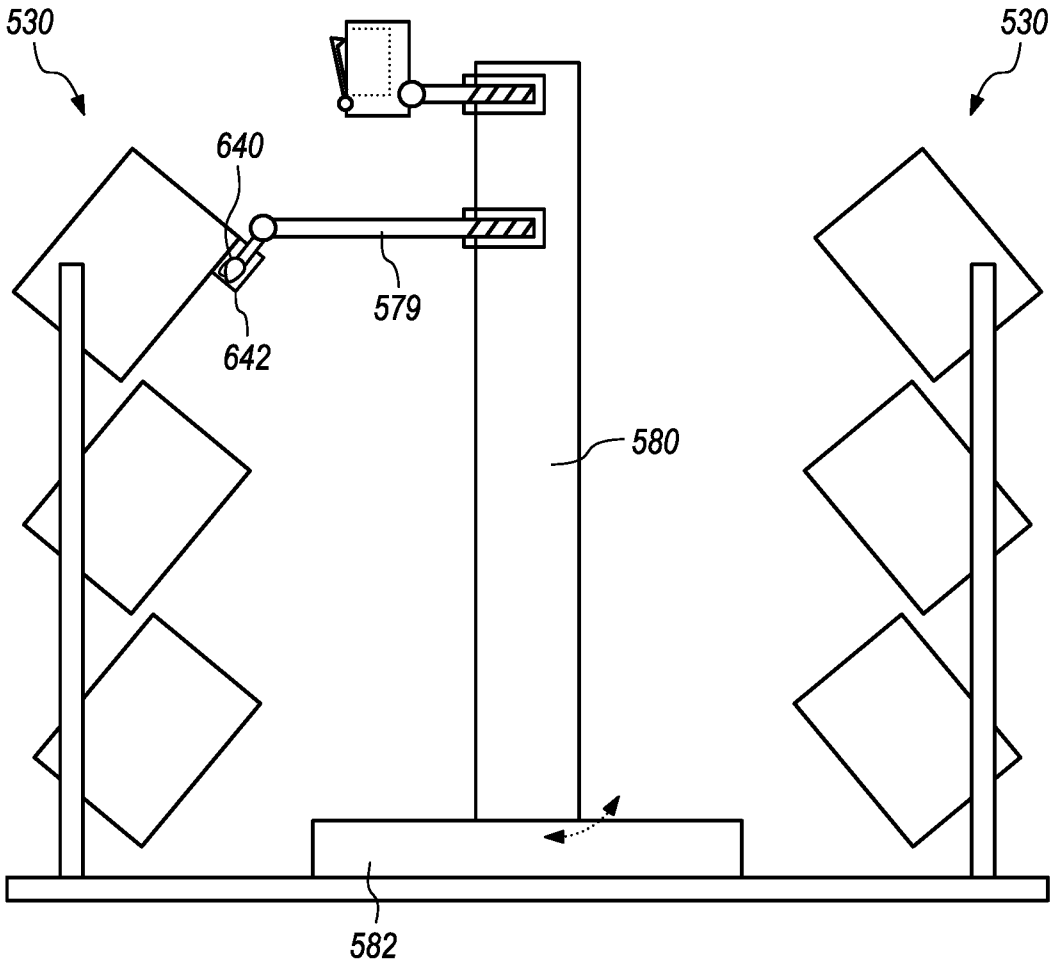


FIG. 44K

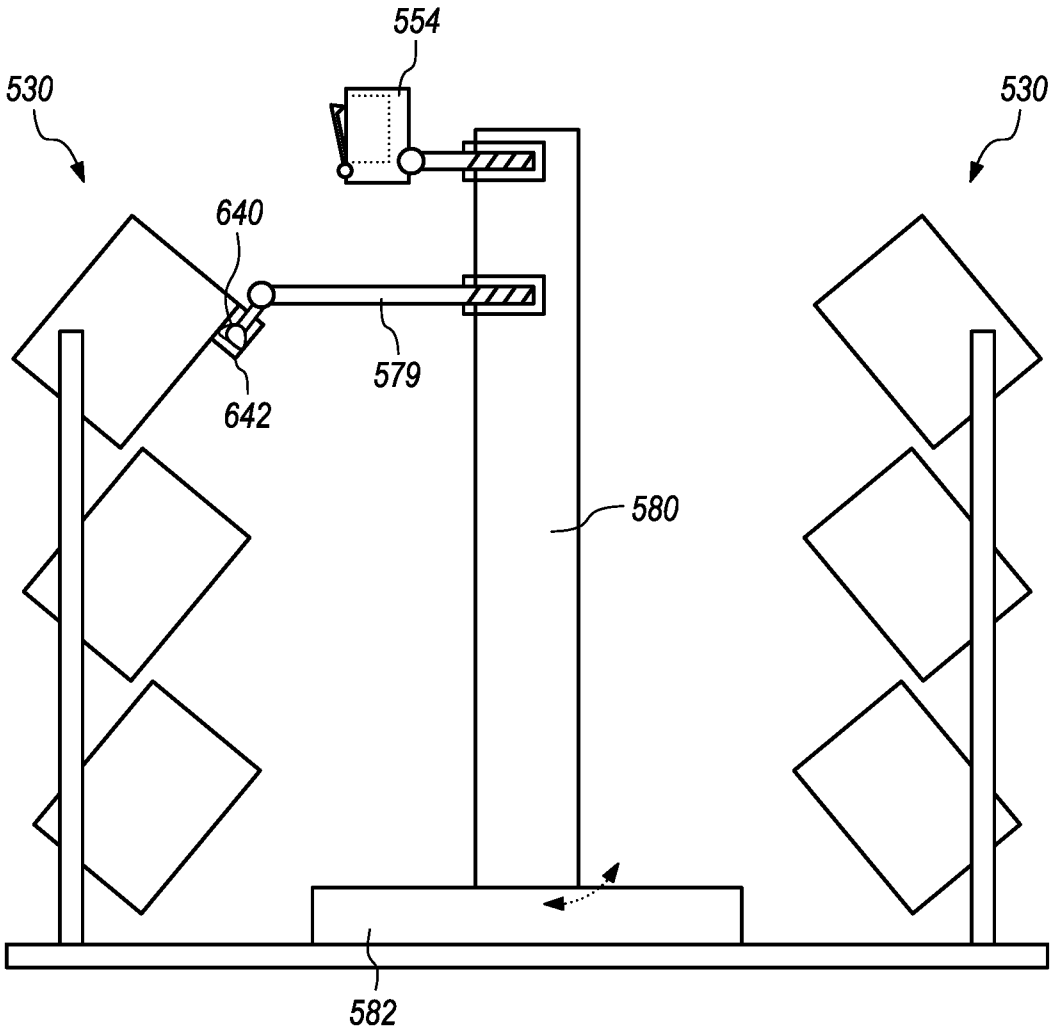


FIG. 44L

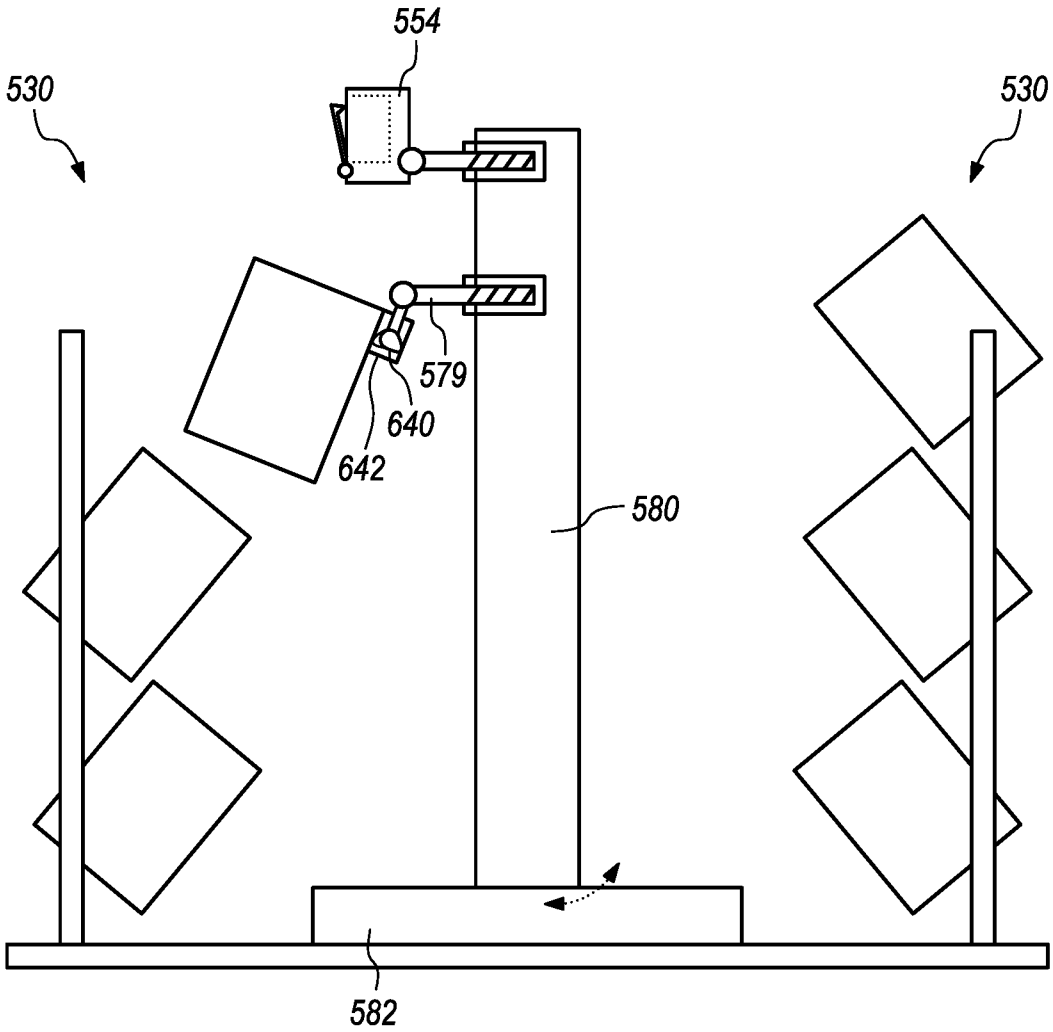


FIG. 44M

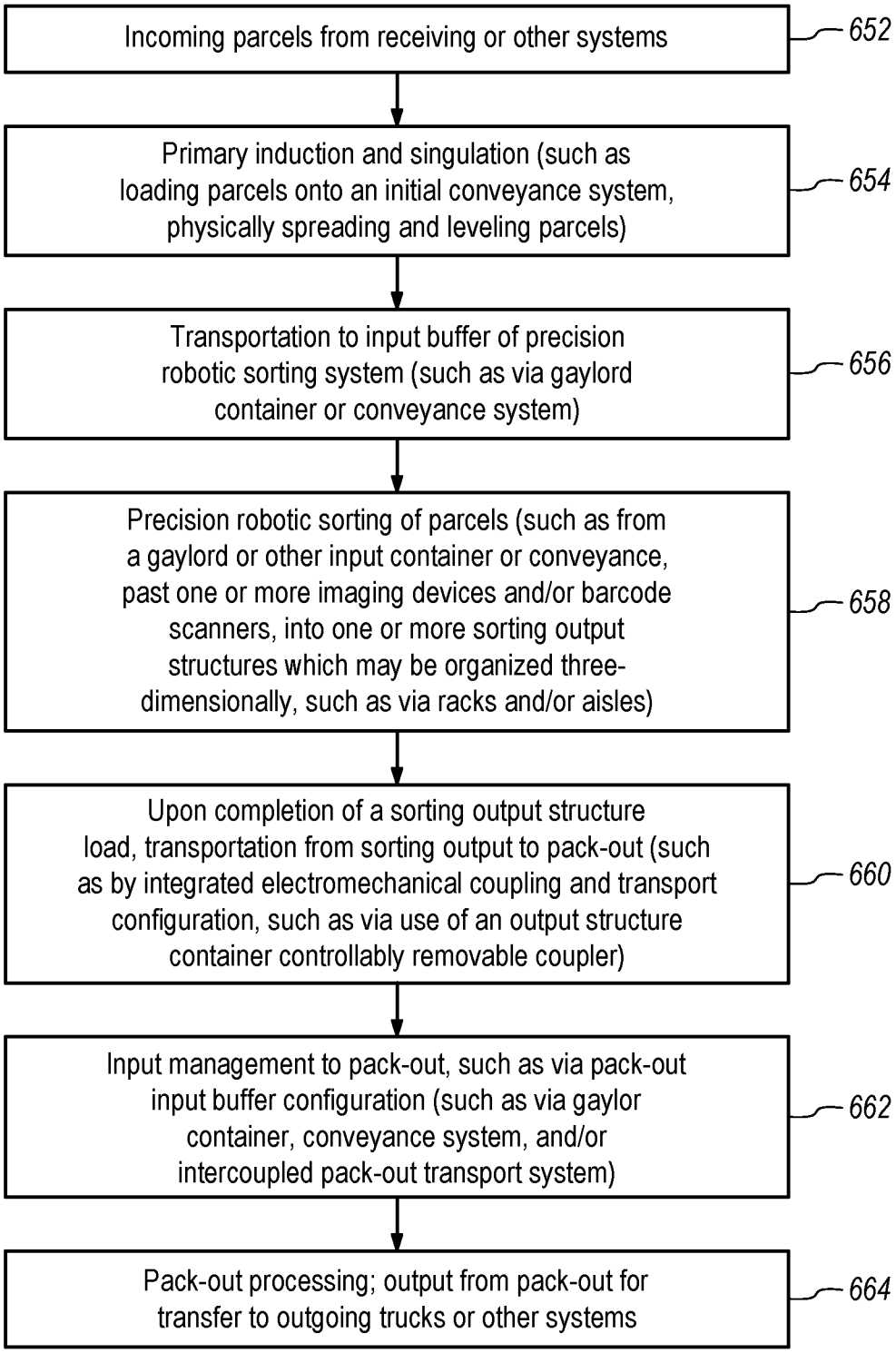

Incoming parcels from receiving or other systems
652
Primary induction and singulation (such as loading parcels onto an initial conveyance system, physically spreading and leveling parcels)
654
Transportation to input buffer of precision robotic sorting system (such as via gaylord container or conveyance system)
656
Precision robotic sorting of parcels (such as from a gaylord or other input container or conveyance, past one or more imaging devices and/or barcode scanners, into one or more sorting output structures which may be organized three-dimensionally, such as via racks and/or aisles)
658
Upon completion of a sorting output structure load, transportation from sorting output to pack-out (such as by integrated electromechanical coupling and transport configuration, such as via use of an output structure container controllably removable coupler)
660
Input management to pack-out, such as via pack-out input buffer configuration (such as via gaylor container, conveyance system, and/or intercoupled pack-out transport system)
662
Pack-out processing; output from pack-out for transfer to outgoing trucks or other systems
664

FIG. 45

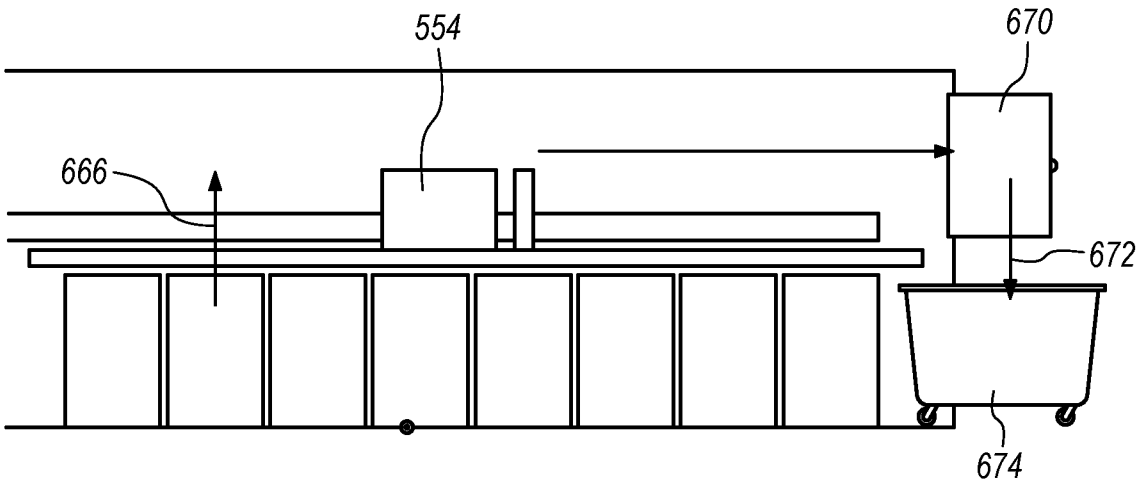


FIG. 46A

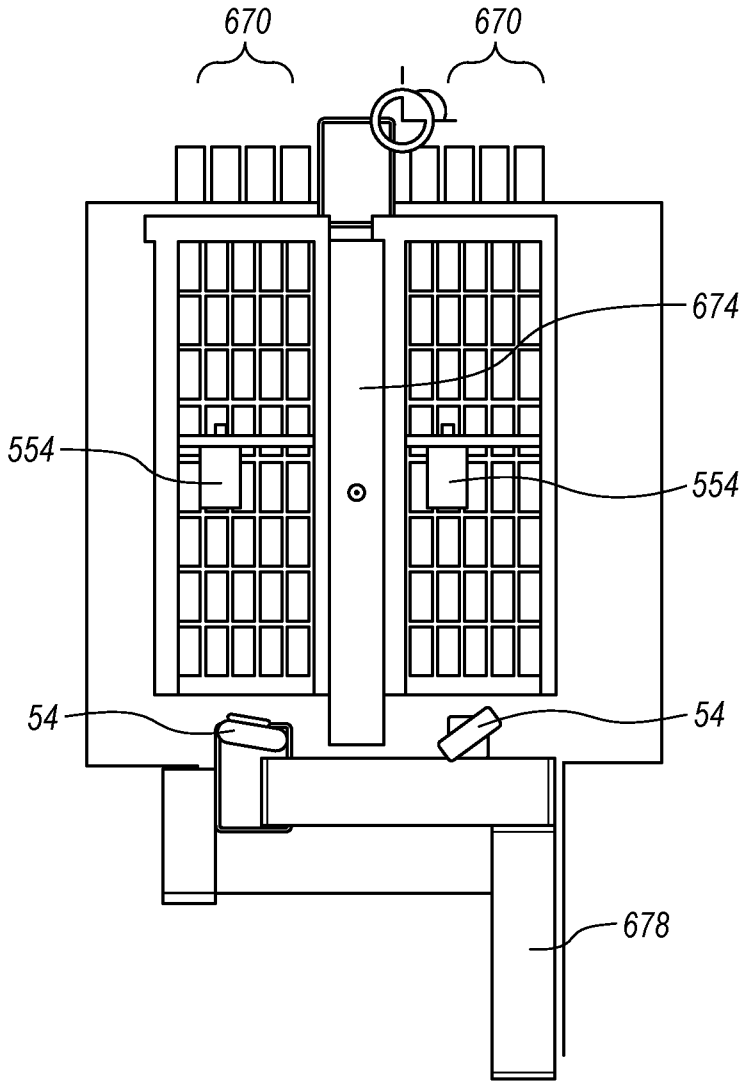


FIG. 46B

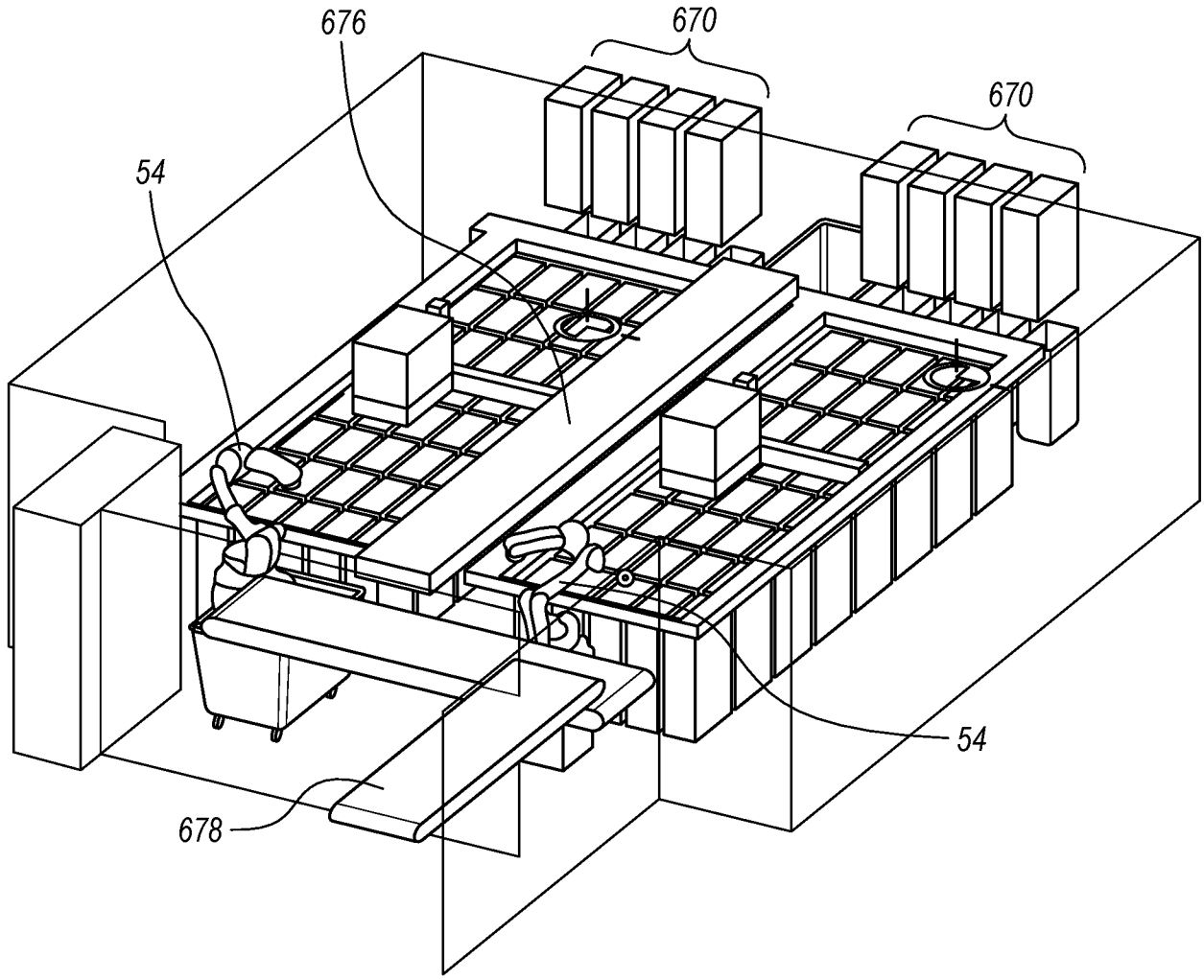


FIG. 46C

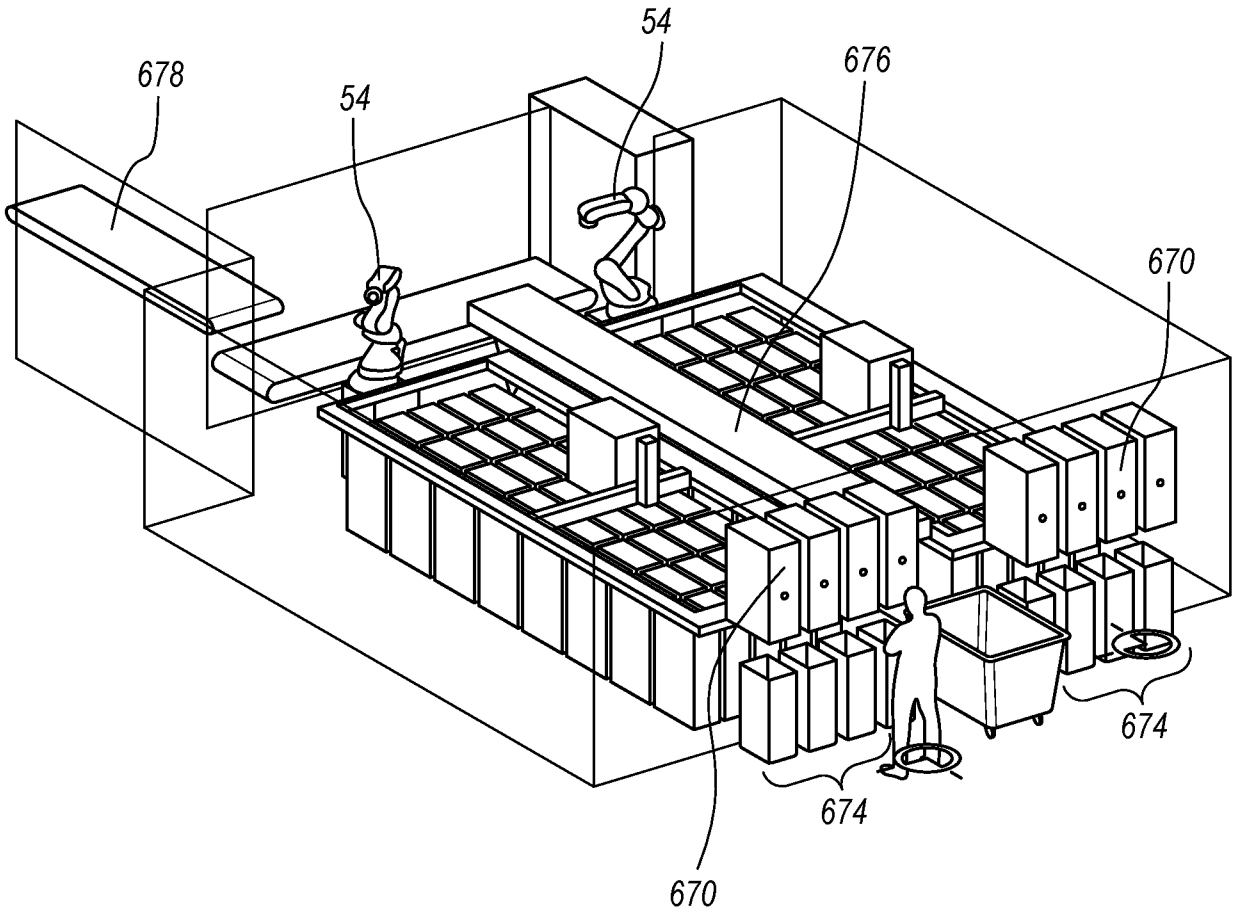


FIG. 46D

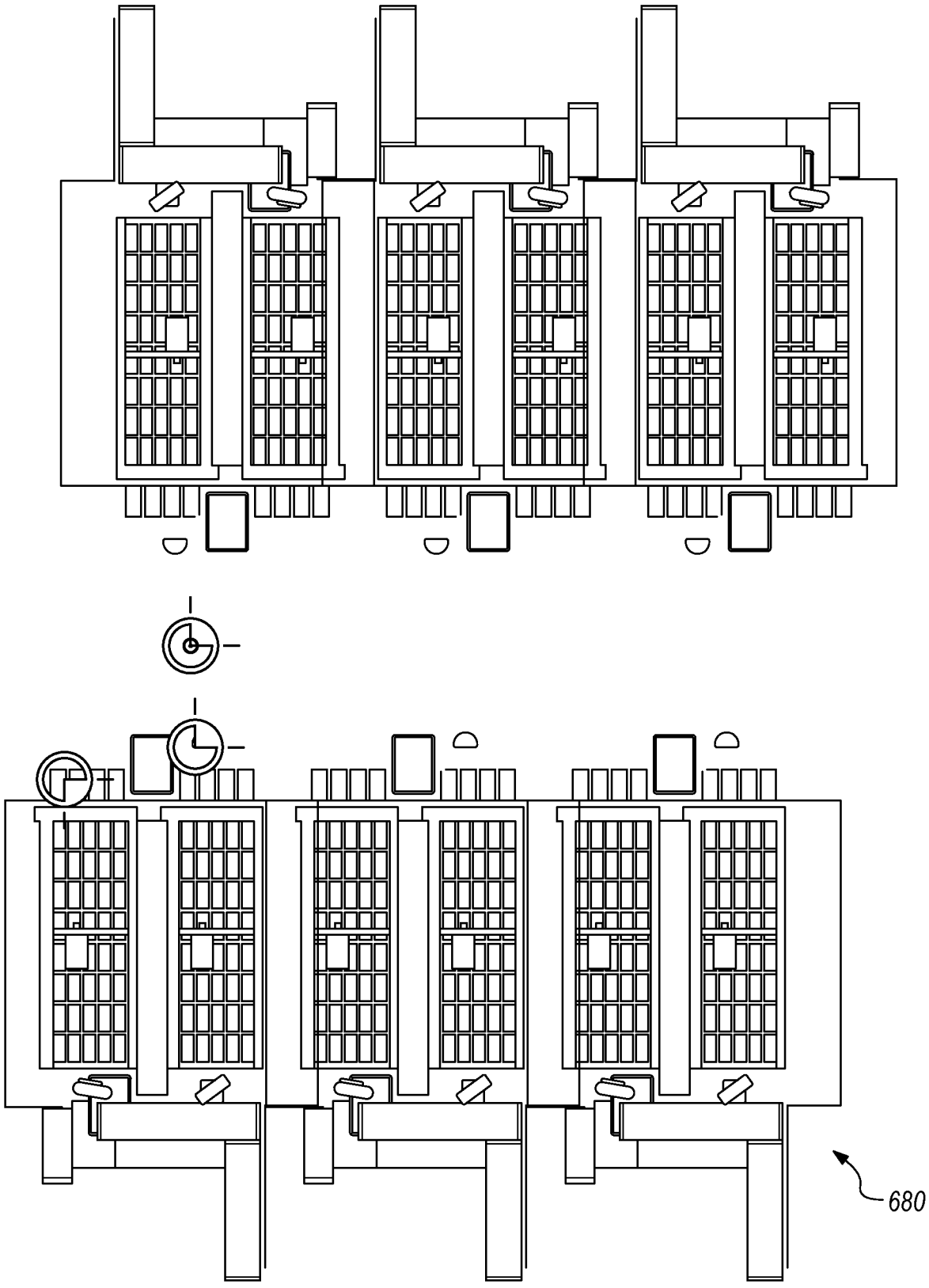


FIG. 46E

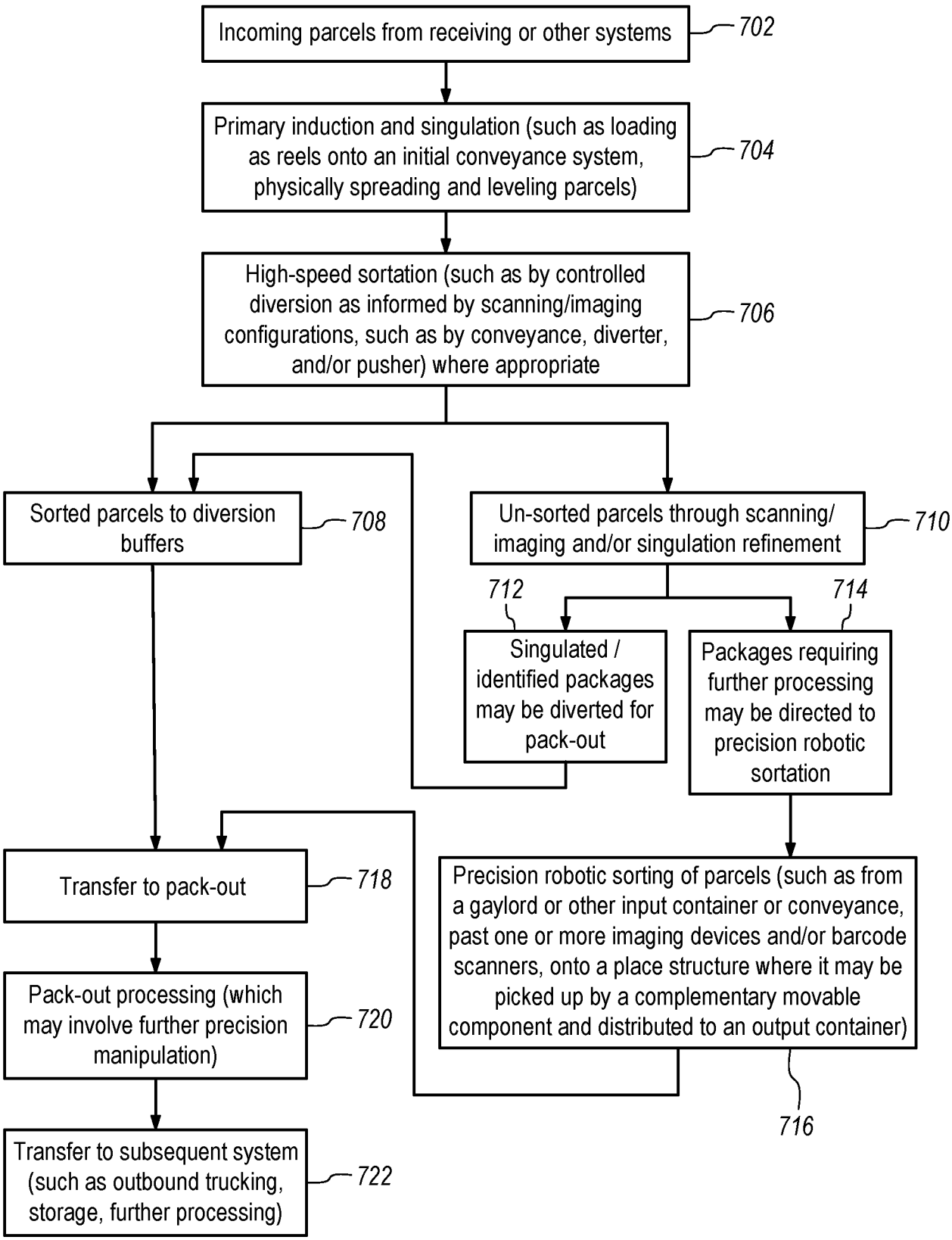

Incoming parcels from receiving or other systems
702
Primary induction and singulation (such as loading as reels onto an initial conveyance system, physically spreading and leveling parcels)
704
High-speed sortation (such as by controlled diversion as informed by scanning/imaging configurations, such as by conveyance, diverter, and/or pusher) where appropriate
706
Sorted parcels to diversion buffers
708
Un-sorted parcels through scanning/ imaging and/or singulation refinement
710
712
714
Singulated / identified packages may be diverted for pack-out
Packages requiring further processing may be directed to precision robotic sortation
Transfer to pack-out
718
Pack-out processing (which may involve further precision manipulation)
720
Transfer to subsequent system (such as outbound trucking, storage, further processing)
722
Precision robotic sorting of parcels (such as from a gaylord or other input container or conveyance, past one or more imaging devices and/or barcode scanners, onto a place structure where it may be picked up by a complementary movable component and distributed to an output container)
716

FIG. 47

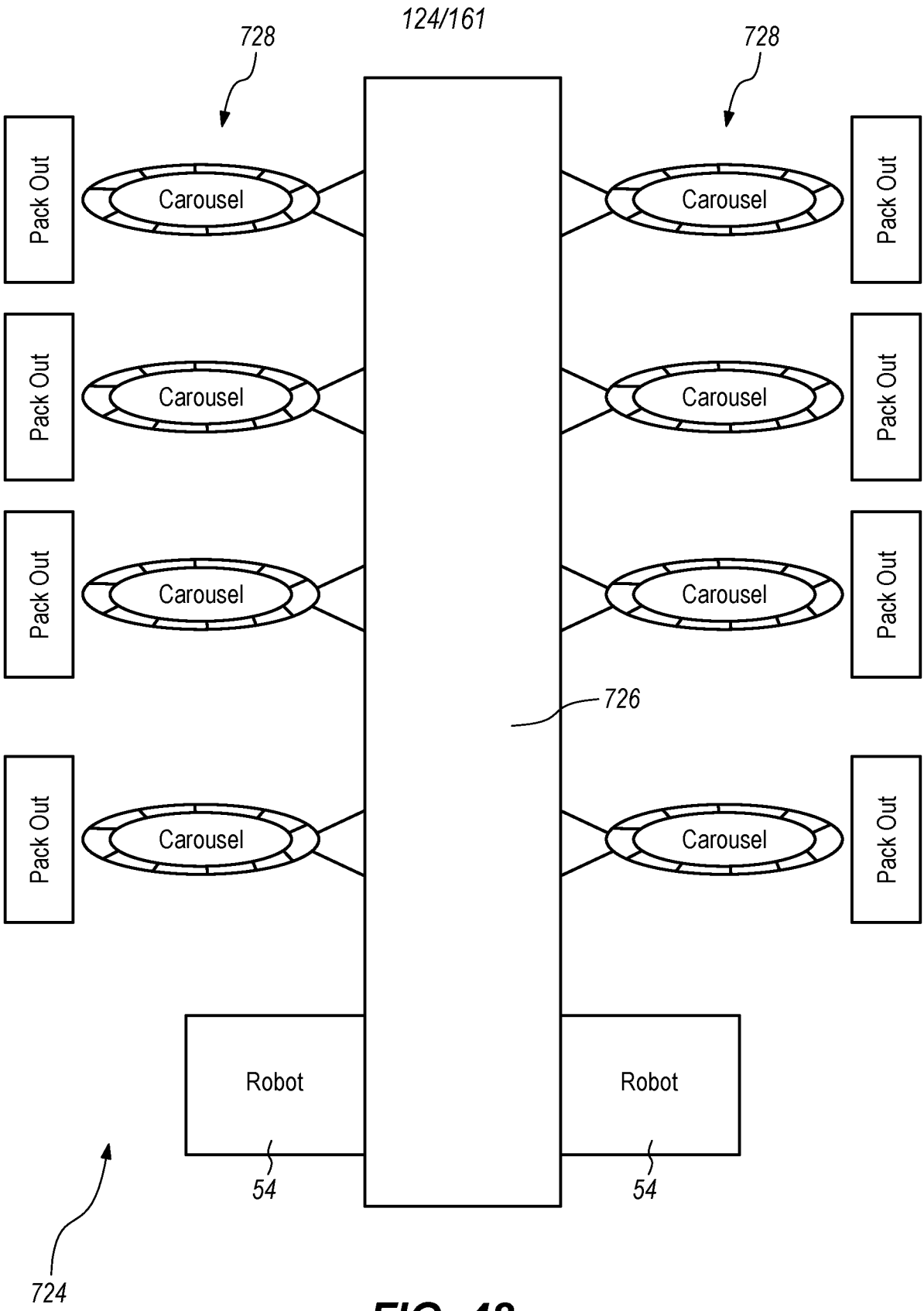

124/161
728
728
Pack Out
Carousel
Carousel
Pack Out
Pack Out
Carousel
Carousel
Pack Out
Pack Out
Carousel
Carousel
Pack Out
726
Pack Out
Carousel
Carousel
Pack Out
Robot
Robot
54
54
724

FIG. 48

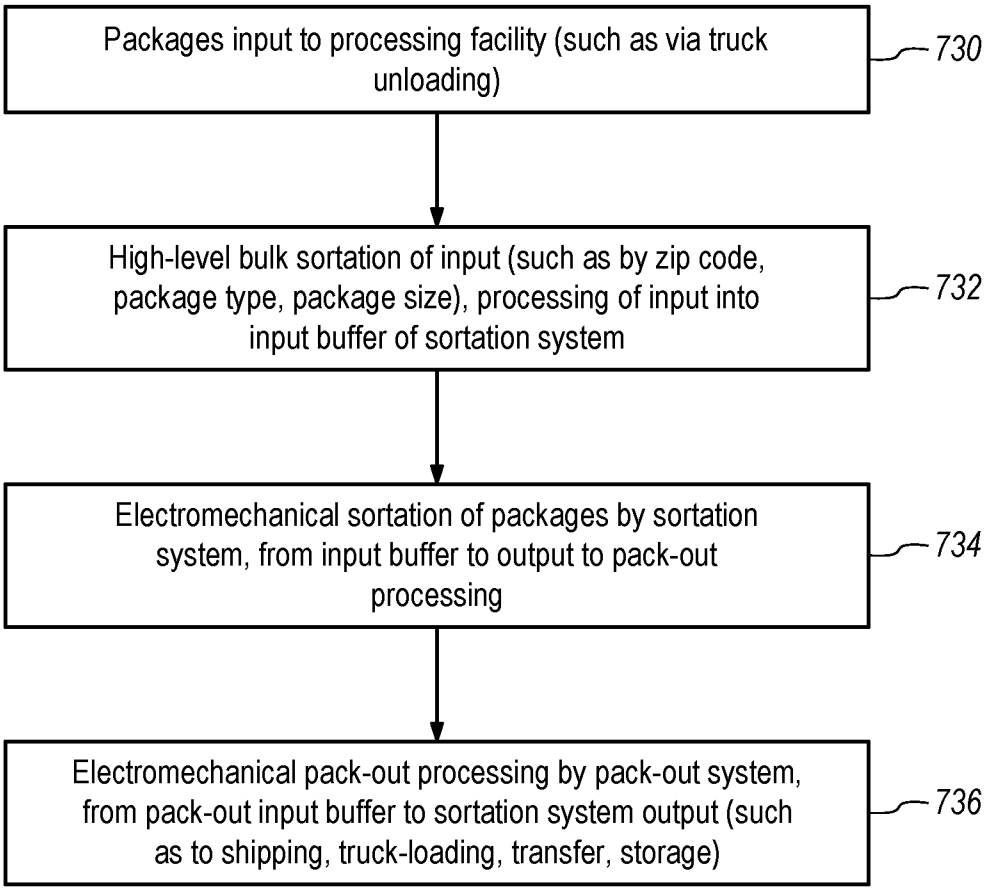

Packages input to processing facility (such as via truck unloading)
730
High-level bulk sortation of input (such as by zip code, package type, package size), processing of input into input buffer of sortation system
732
Electromechanical sortation of packages by sortation system, from input buffer to output to pack-out processing
734
Electromechanical pack-out processing by pack-out system, from pack-out input buffer to sortation system output (such as to shipping, truck-loading, transfer, storage)
736

FIG. 49

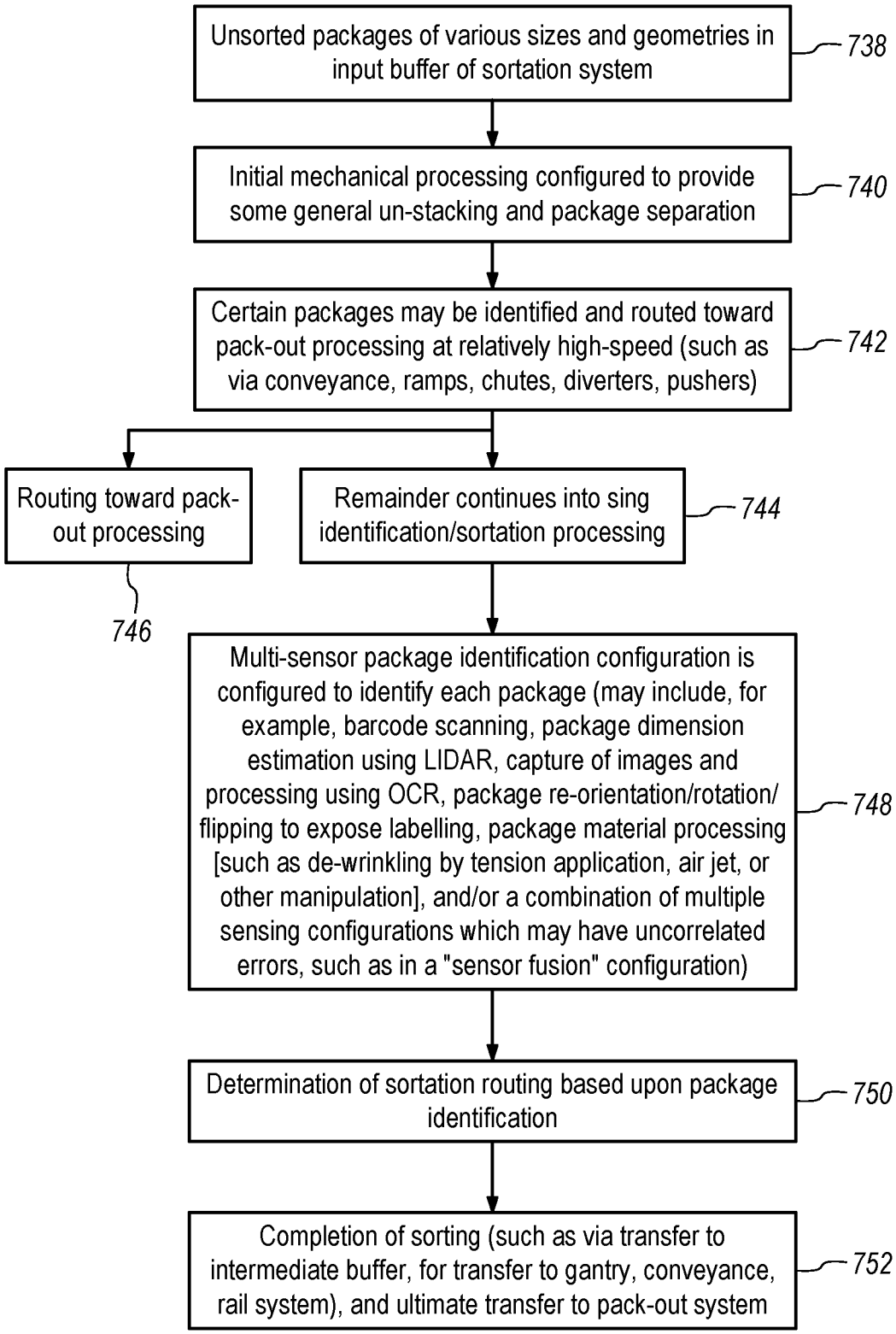

Unsorted packages of various sizes and geometries in input buffer of sortation system
738
Initial mechanical processing configured to provide some general un-stacking and package separation
740
Certain packages may be identified and routed toward pack-out processing at relatively high-speed (such as via conveyance, ramps, chutes, diverters, pushers)
742
Routing toward pack-out processing
746
Remainder continues into sing identification/sortation processing
744
Multi-sensor package identification configuration is configured to identify each package (may include, for example, barcode scanning, package dimension estimation using LIDAR, capture of images and processing using OCR, package re-orientation/rotation/ flipping to expose labelling, package material processing [such as de-wrinkling by tension application, air jet, or other manipulation], and/or a combination of multiple sensing configurations which may have uncorrelated errors, such as in a "sensor fusion" configuration)
748
Determination of sortation routing based upon package identification
750
Completion of sorting (such as via transfer to intermediate buffer, for transfer to gantry, conveyance, rail system), and ultimate transfer to pack-out system
752

FIG. 50

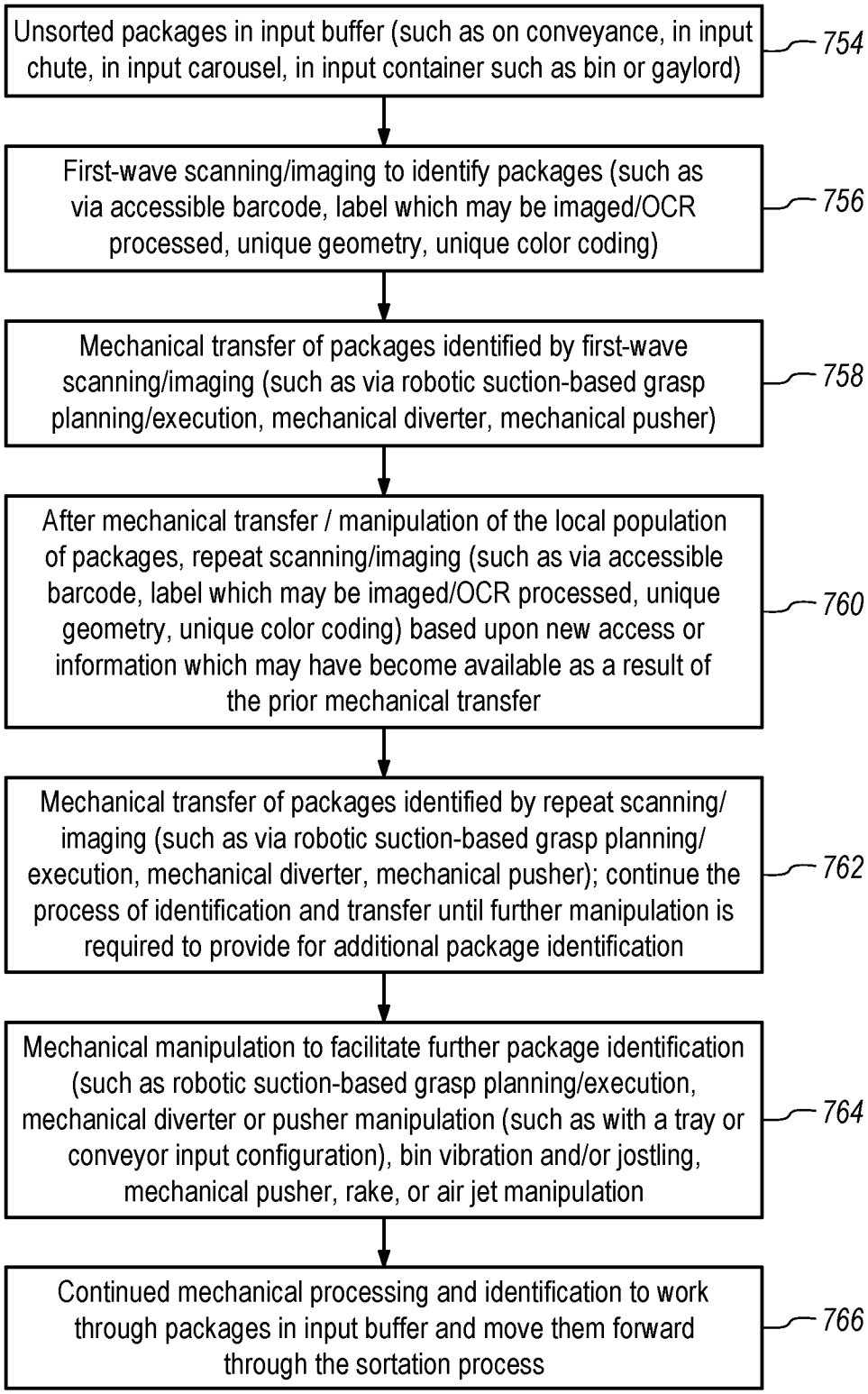

Unsorted packages in input buffer (such as on conveyance, in input chute, in input carousel, in input container such as bin or gaylord)
754
First-wave scanning/imaging to identify packages (such as via accessible barcode, label which may be imaged/OCR processed, unique geometry, unique color coding)
756
Mechanical transfer of packages identified by first-wave scanning/imaging (such as via robotic suction-based grasp planning/execution, mechanical diverter, mechanical pusher)
758
After mechanical transfer / manipulation of the local population of packages, repeat scanning/imaging (such as via accessible barcode, label which may be imaged/OCR processed, unique geometry, unique color coding) based upon new access or information which may have become available as a result of the prior mechanical transfer
760
Mechanical transfer of packages identified by repeat scanning/ imaging (such as via robotic suction-based grasp planning/ execution, mechanical diverter, mechanical pusher); continue the process of identification and transfer until further manipulation is required to provide for additional package identification
762
Mechanical manipulation to facilitate further package identification (such as robotic suction-based grasp planning/execution, mechanical diverter or pusher manipulation (such as with a tray or conveyor input configuration), bin vibration and/or jostling, mechanical pusher, rake, or air jet manipulation
764
Continued mechanical processing and identification to work through packages in input buffer and move them forward through the sortation process
766

FIG. 51

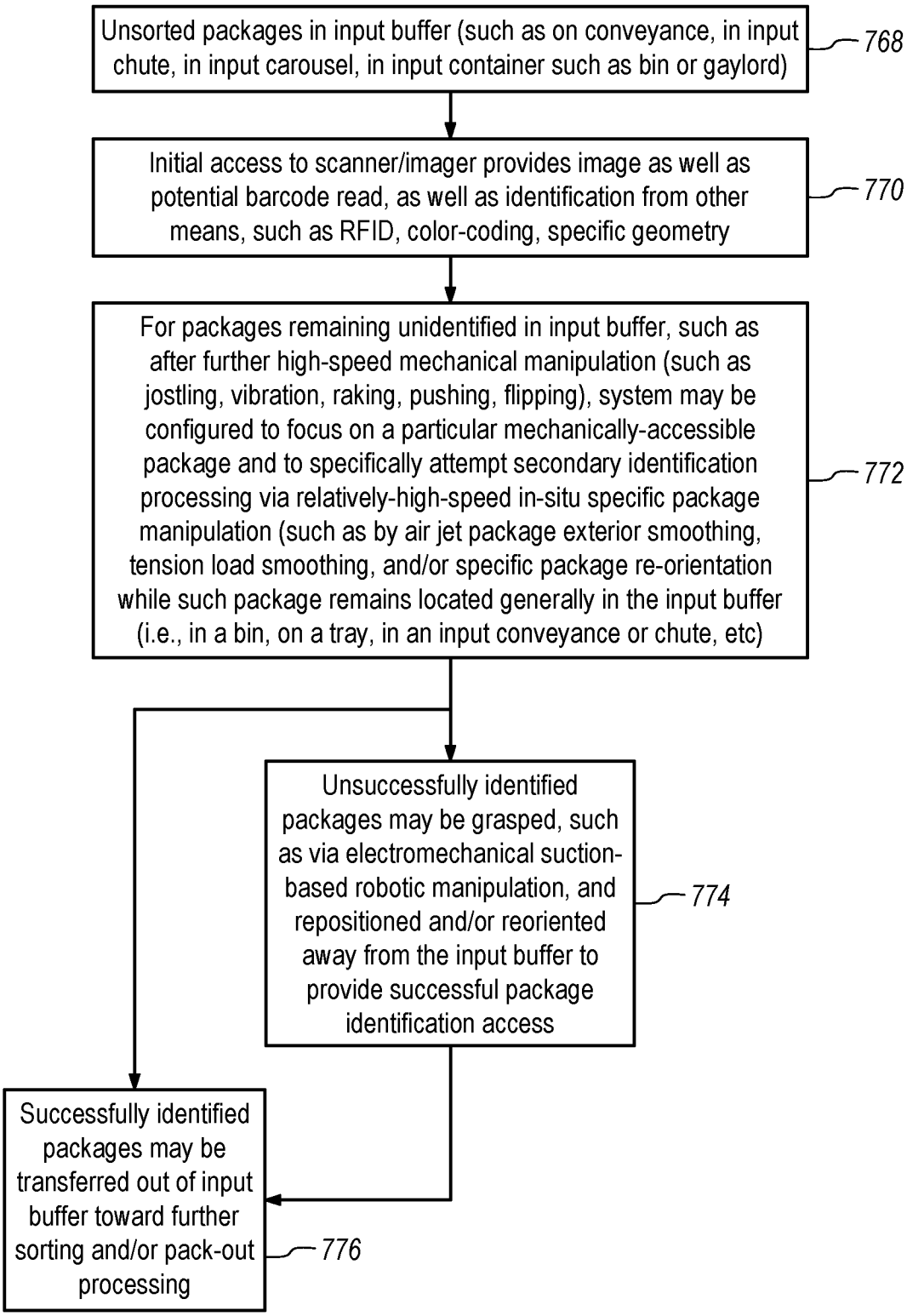

Unsorted packages in input buffer (such as on conveyance, in input chute, in input carousel, in input container such as bin or gaylord)
768
Initial access to scanner/imager provides image as well as potential barcode read, as well as identification from other means, such as RFID, color-coding, specific geometry
770
For packages remaining unidentified in input buffer, such as after further high-speed mechanical manipulation (such as jostling, vibration, raking, pushing, flipping), system may be configured to focus on a particular mechanically-accessible package and to specifically attempt secondary identification processing via relatively-high-speed in-situ specific package manipulation (such as by air jet package exterior smoothing, tension load smoothing, and/or specific package re-orientation while such package remains located generally in the input buffer (i.e., in a bin, on a tray, in an input conveyance or chute, etc)
772
Unsuccessfully identified packages may be grasped, such as via electromechanical suction-based robotic manipulation, and repositioned and/or reoriented away from the input buffer to provide successful package identification access
774
Successfully identified packages may be transferred out of input buffer toward further sorting and/or pack-out processing
776

FIG. 52

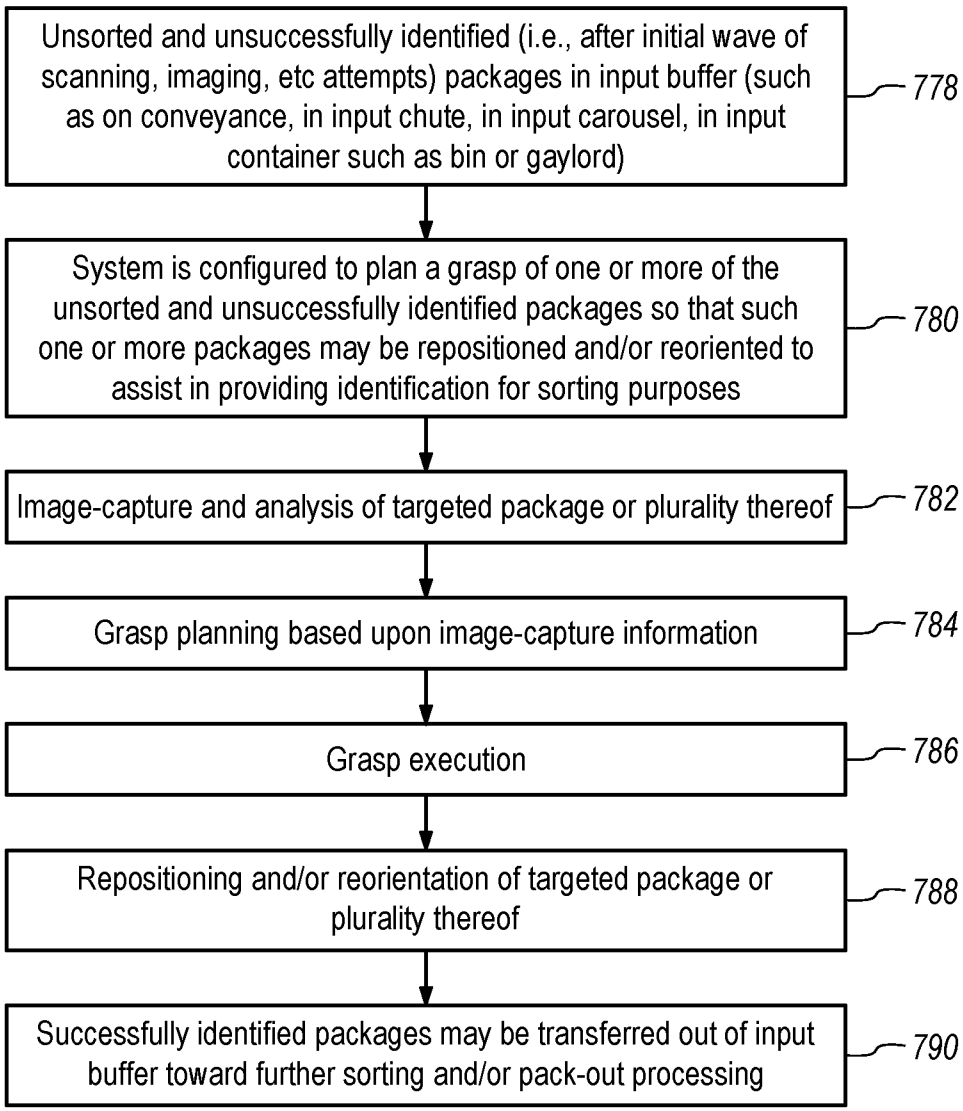

Unsorted and unsuccessfully identified (i.e., after initial wave of scanning, imaging, etc attempts) packages in input buffer (such as on conveyance, in input chute, in input carousel, in input container such as bin or gaylord)
778
System is configured to plan a grasp of one or more of the unsorted and unsuccessfully identified packages so that such one or more packages may be repositioned and/or reoriented to assist in providing identification for sorting purposes
780
Image-capture and analysis of targeted package or plurality thereof
782
Grasp planning based upon image-capture information
784
Grasp execution
786
Repositioning and/or reorientation of targeted package or plurality thereof
788
Successfully identified packages may be transferred out of input buffer toward further sorting and/or pack-out processing
790

FIG. 53

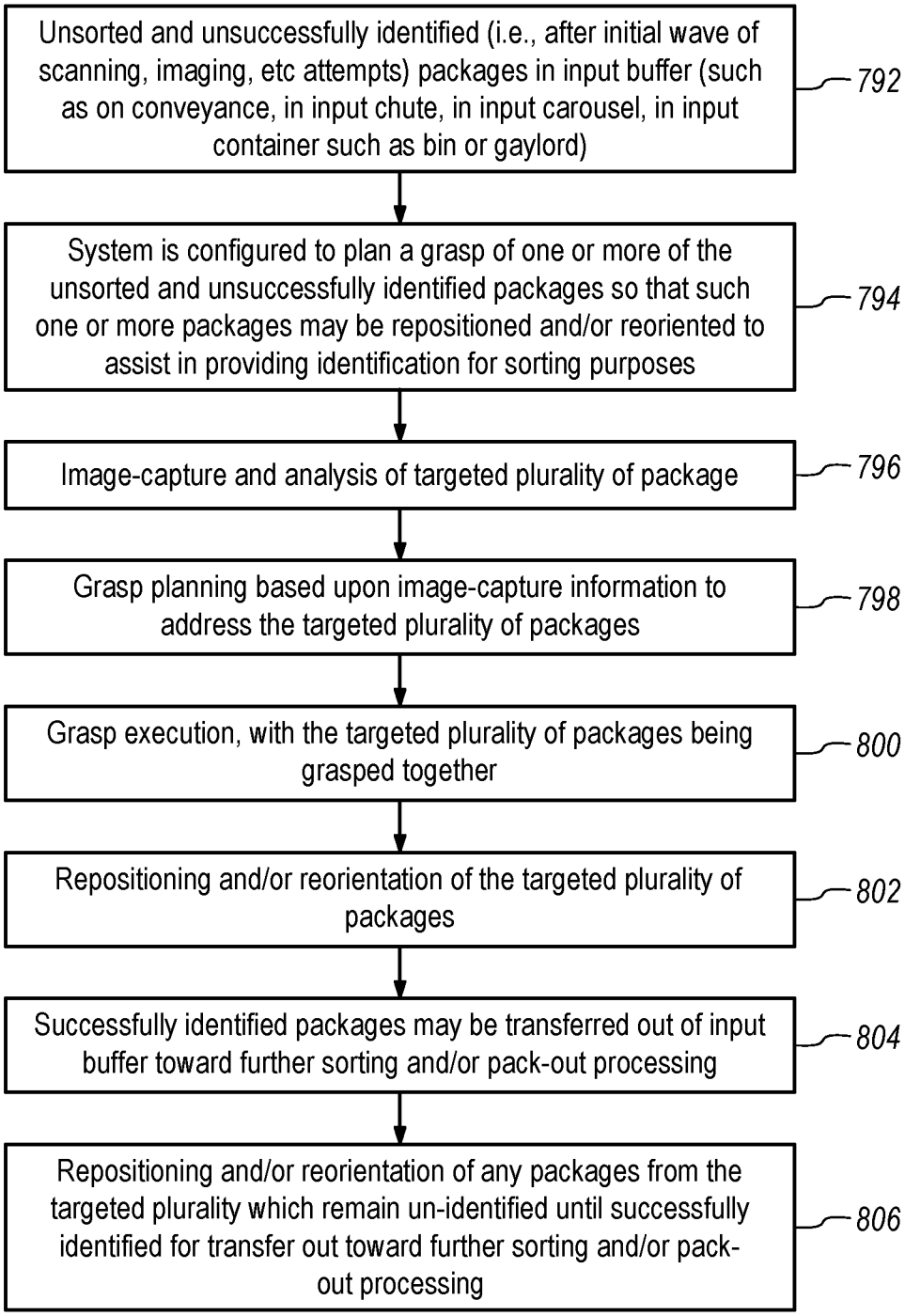

Unsorted and unsuccessfully identified (i.e., after initial wave of scanning, imaging, etc attempts) packages in input buffer (such as on conveyance, in input chute, in input carousel, in input container such as bin or gaylord)
792
System is configured to plan a grasp of one or more of the unsorted and unsuccessfully identified packages so that such one or more packages may be repositioned and/or reoriented to assist in providing identification for sorting purposes
794
Image-capture and analysis of targeted plurality of package
796
Grasp planning based upon image-capture information to address the targeted plurality of packages
798
Grasp execution, with the targeted plurality of packages being grasped together
800
Repositioning and/or reorientation of the targeted plurality of packages
802
Successfully identified packages may be transferred out of input buffer toward further sorting and/or pack-out processing
804
Repositioning and/or reorientation of any packages from the targeted plurality which remain un-identified until successfully identified for transfer out toward further sorting and/or pack-out processing
806

FIG. 54

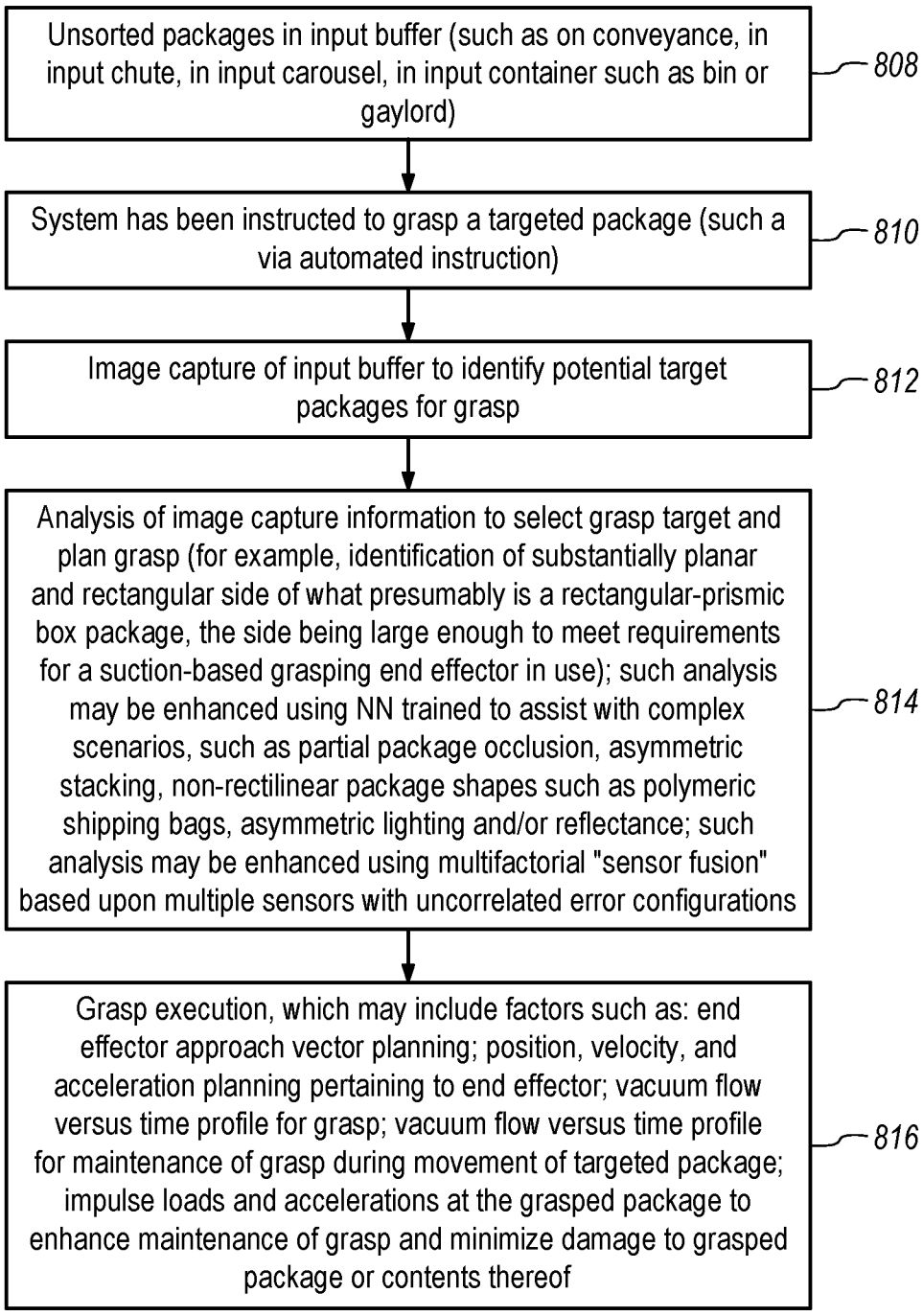

Unsorted packages in input buffer (such as on conveyance, in input chute, in input carousel, in input container such as bin or gaylord)
808
System has been instructed to grasp a targeted package (such a via automated instruction)
810
Image capture of input buffer to identify potential target packages for grasp
812
Analysis of image capture information to select grasp target and plan grasp (for example, identification of substantially planar and rectangular side of what presumably is a rectangular-prismic box package, the side being large enough to meet requirements for a suction-based grasping end effector in use); such analysis may be enhanced using NN trained to assist with complex scenarios, such as partial package occlusion, asymmetric stacking, non-rectilinear package shapes such as polymeric shipping bags, asymmetric lighting and/or reflectance; such analysis may be enhanced using multifactorial "sensor fusion" based upon multiple sensors with uncorrelated error configurations
814
Grasp execution, which may include factors such as: end effector approach vector planning; position, velocity, and acceleration planning pertaining to end effector; vacuum flow versus time profile for grasp; vacuum flow versus time profile for maintenance of grasp during movement of targeted package; impulse loads and accelerations at the grasped package to enhance maintenance of grasp and minimize damage to grasped package or contents thereof
816

FIG. 55

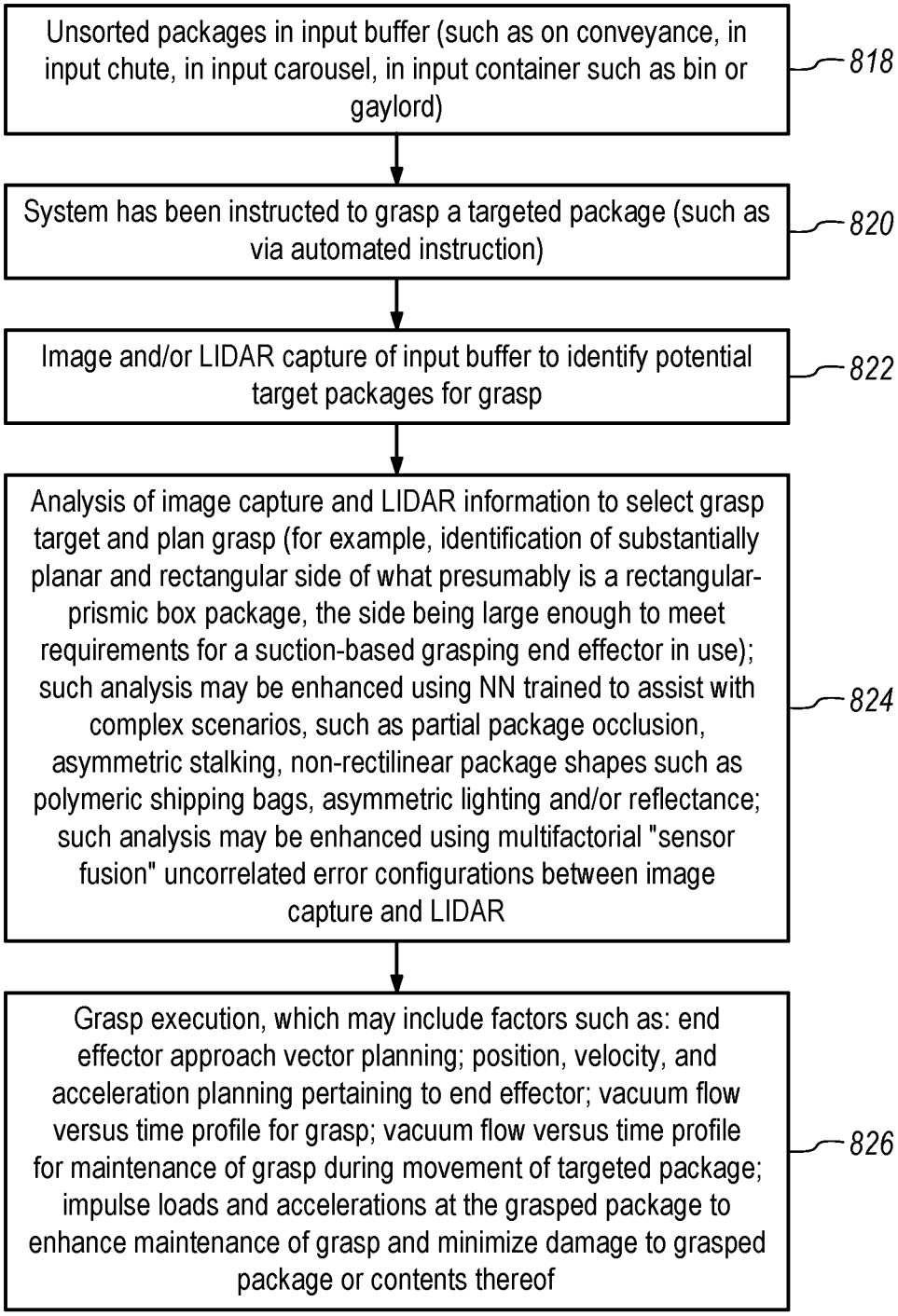

Unsorted packages in input buffer (such as on conveyance, in input chute, in input carousel, in input container such as bin or gaylord)
818
System has been instructed to grasp a targeted package (such as via automated instruction)
820
Image and/or LIDAR capture of input buffer to identify potential target packages for grasp
822
Analysis of image capture and LIDAR information to select grasp target and plan grasp (for example, identification of substantially planar and rectangular side of what presumably is a rectangular-prismic box package, the side being large enough to meet requirements for a suction-based grasping end effector in use); such analysis may be enhanced using NN trained to assist with complex scenarios, such as partial package occlusion, asymmetric stalking, non-rectilinear package shapes such as polymeric shipping bags, asymmetric lighting and/or reflectance; such analysis may be enhanced using multifactorial "sensor fusion" uncorrelated error configurations between image capture and LIDAR
824
Grasp execution, which may include factors such as: end effector approach vector planning; position, velocity, and acceleration planning pertaining to end effector; vacuum flow versus time profile for grasp; vacuum flow versus time profile for maintenance of grasp during movement of targeted package; impulse loads and accelerations at the grasped package to enhance maintenance of grasp and minimize damage to grasped package or contents thereof
826

FIG. 56

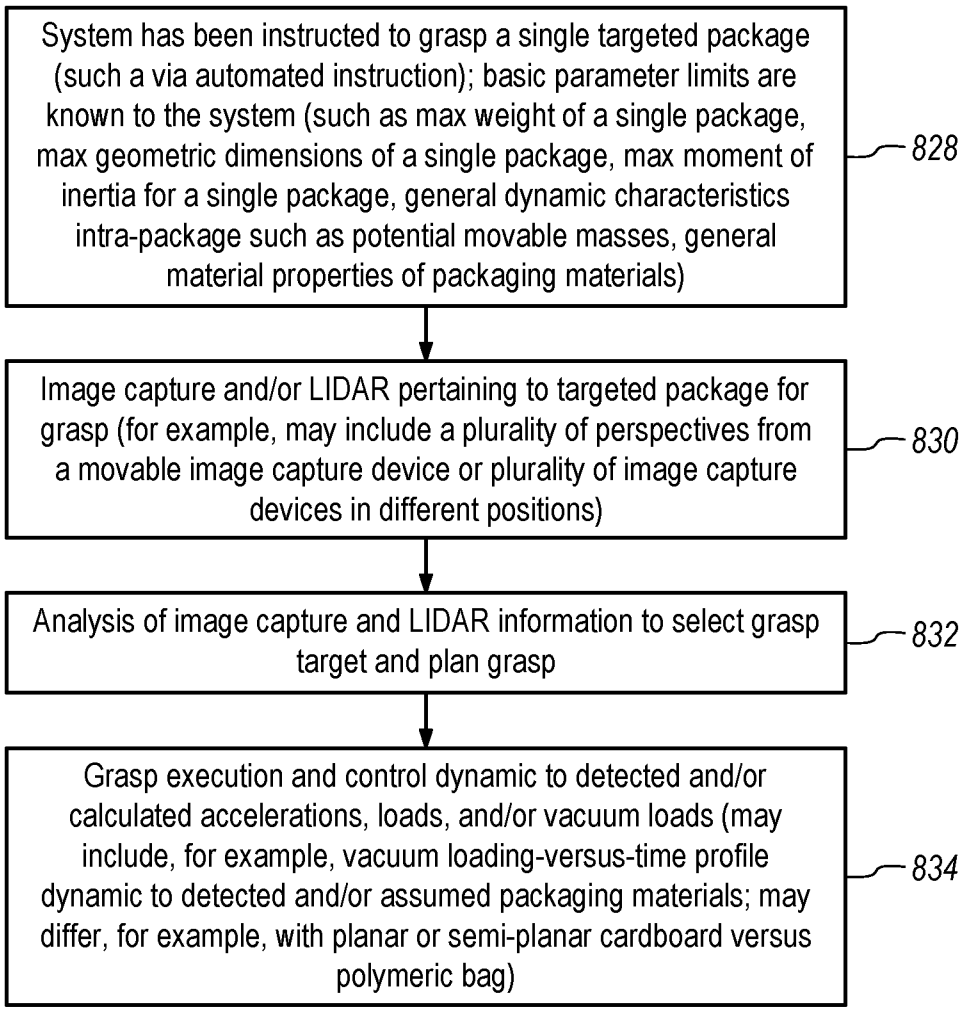

System has been instructed to grasp a single targeted package (such a via automated instruction); basic parameter limits are known to the system (such as max weight of a single package, max geometric dimensions of a single package, max moment of inertia for a single package, general dynamic characteristics intra-package such as potential movable masses, general material properties of packaging materials)
828
Image capture and/or LIDAR pertaining to targeted package for grasp (for example, may include a plurality of perspectives from a movable image capture device or plurality of image capture devices in different positions)
830
Analysis of image capture and LIDAR information to select grasp target and plan grasp
832
Grasp execution and control dynamic to detected and/or calculated accelerations, loads, and/or vacuum loads (may include, for example, vacuum loading-versus-time profile dynamic to detected and/or assumed packaging materials; may differ, for example, with planar or semi-planar cardboard versus polymeric bag)
834

FIG. 57

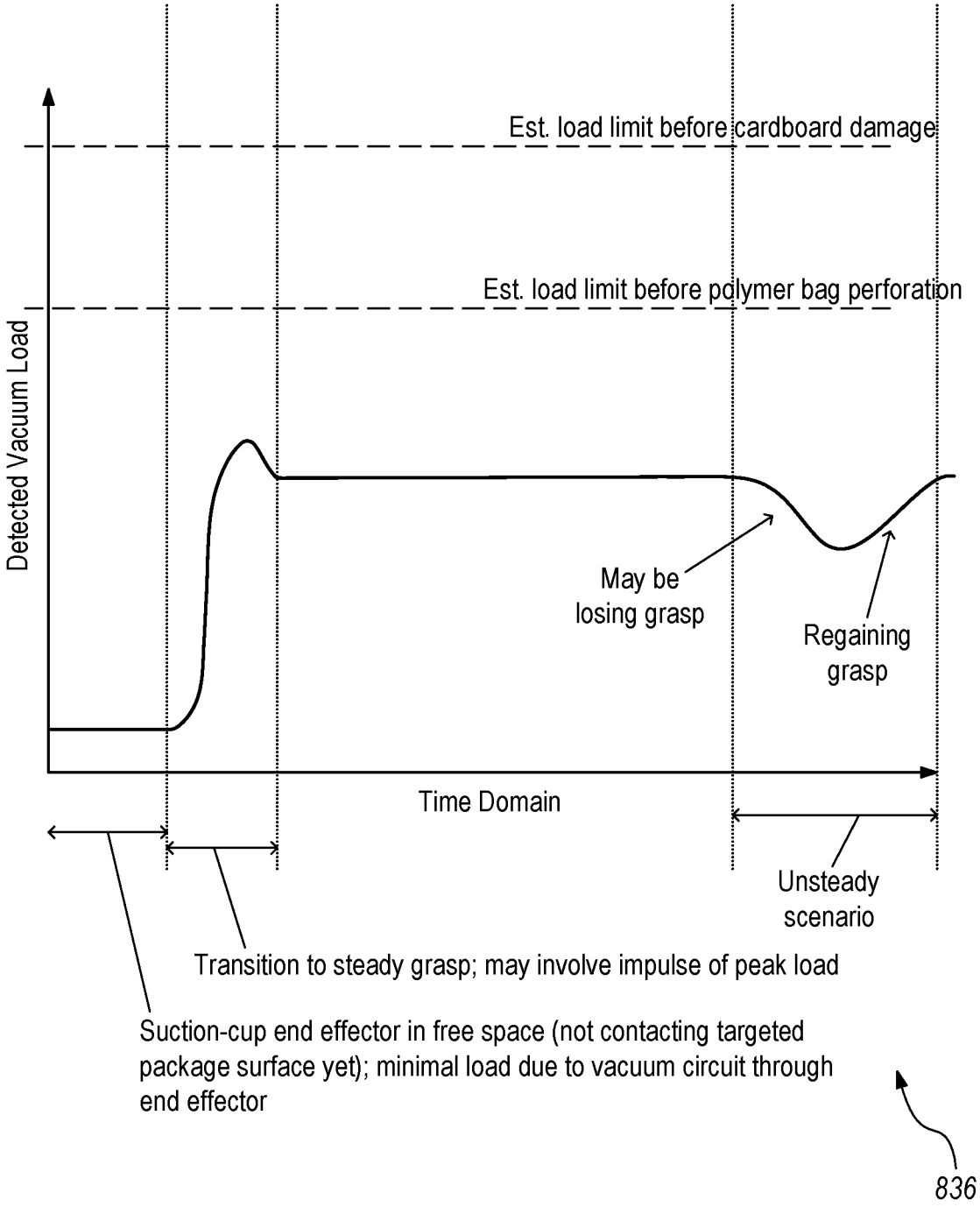

Est. load limit before cardboard damage
Est. load limit before polymer bag perforation
Detected Vacuum Load
May be losing grasp
Regaining grasp
Time Domain
Unsteady scenario
Transition to steady grasp; may involve impulse of peak load
Suction-cup end effector in free space (not contacting targeted package surface yet); minimal load due to vacuum circuit through end effector
836

FIG. 58

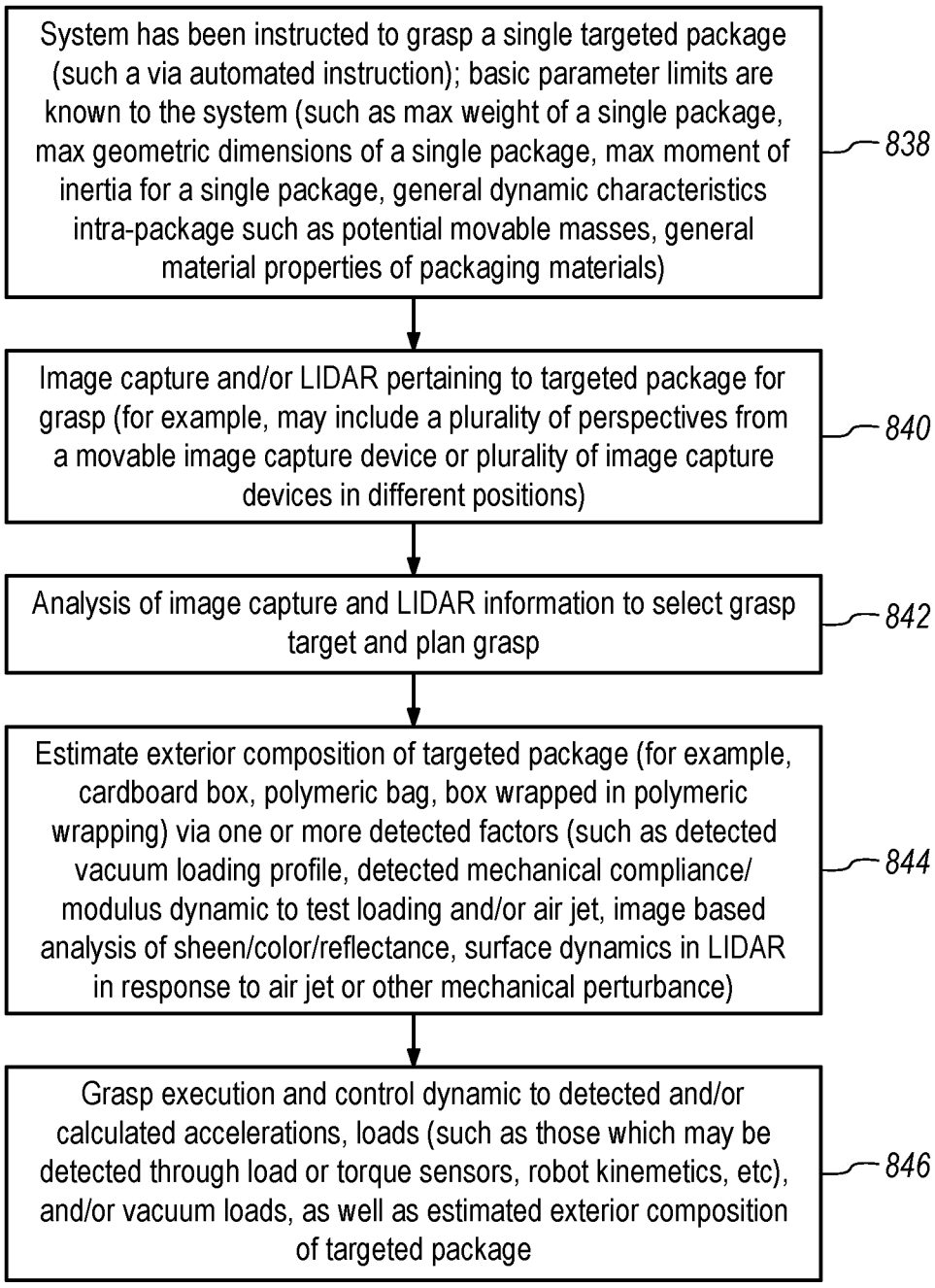

System has been instructed to grasp a single targeted package (such a via automated instruction); basic parameter limits are known to the system (such as max weight of a single package, max geometric dimensions of a single package, max moment of inertia for a single package, general dynamic characteristics intra-package such as potential movable masses, general material properties of packaging materials)
838
Image capture and/or LIDAR pertaining to targeted package for grasp (for example, may include a plurality of perspectives from a movable image capture device or plurality of image capture devices in different positions)
840
Analysis of image capture and LIDAR information to select grasp target and plan grasp
842
Estimate exterior composition of targeted package (for example, cardboard box, polymeric bag, box wrapped in polymeric wrapping) via one or more detected factors (such as detected vacuum loading profile, detected mechanical compliance/ modulus dynamic to test loading and/or air jet, image based analysis of sheen/color/reflectance, surface dynamics in LIDAR in response to air jet or other mechanical perturbance)
844
Grasp execution and control dynamic to detected and/or calculated accelerations, loads (such as those which may be detected through load or torque sensors, robot kinemetics, etc), and/or vacuum loads, as well as estimated exterior composition of targeted package
846

FIG. 59

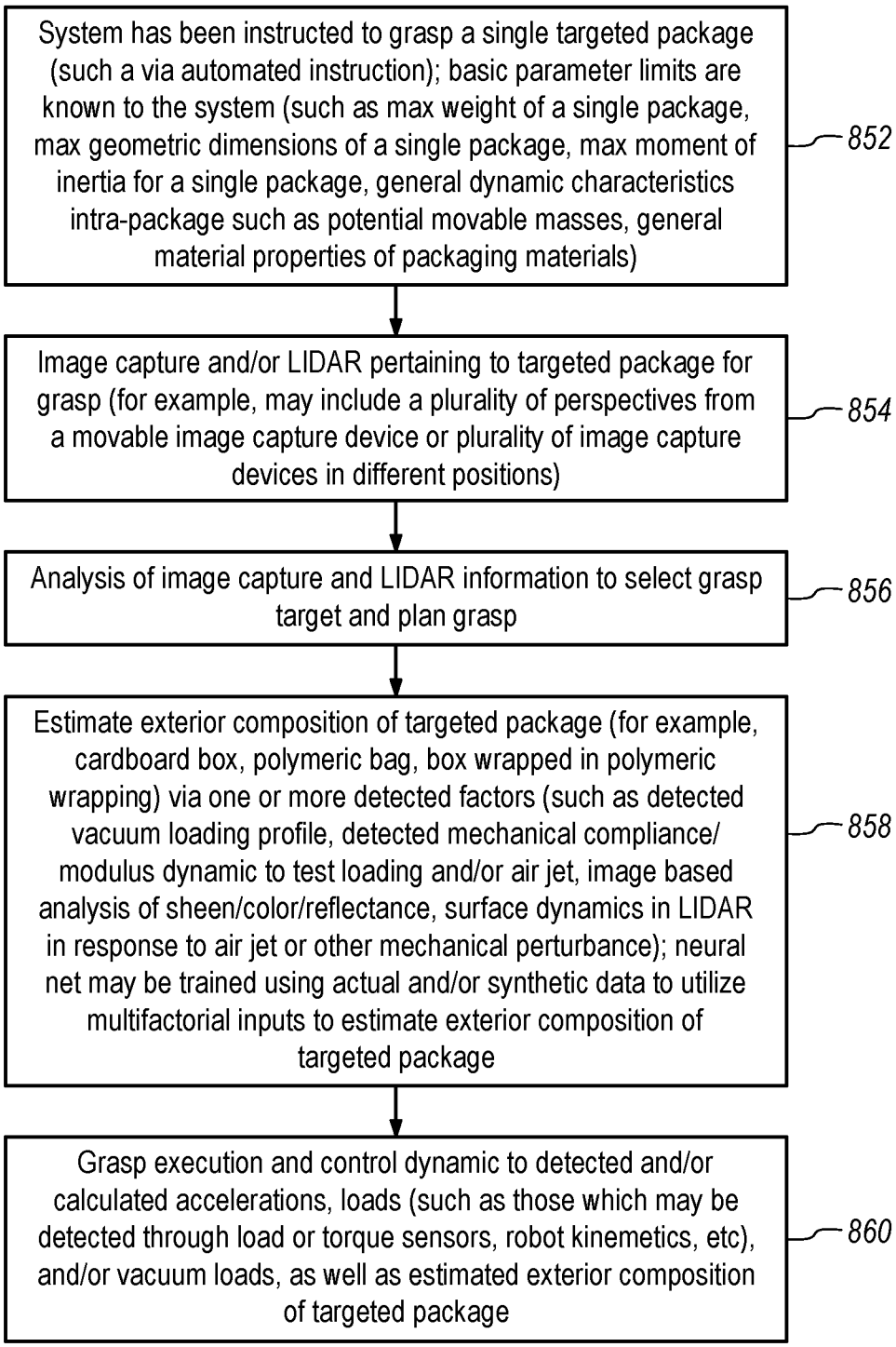

System has been instructed to grasp a single targeted package (such a via automated instruction); basic parameter limits are known to the system (such as max weight of a single package, max geometric dimensions of a single package, max moment of inertia for a single package, general dynamic characteristics intra-package such as potential movable masses, general material properties of packaging materials)
852
Image capture and/or LIDAR pertaining to targeted package for grasp (for example, may include a plurality of perspectives from a movable image capture device or plurality of image capture devices in different positions)
854
Analysis of image capture and LIDAR information to select grasp target and plan grasp
856
Estimate exterior composition of targeted package (for example, cardboard box, polymeric bag, box wrapped in polymeric wrapping) via one or more detected factors (such as detected vacuum loading profile, detected mechanical compliance/ modulus dynamic to test loading and/or air jet, image based analysis of sheen/color/reflectance, surface dynamics in LIDAR in response to air jet or other mechanical perturbance); neural net may be trained using actual and/or synthetic data to utilize multifactorial inputs to estimate exterior composition of targeted package
858
Grasp execution and control dynamic to detected and/or calculated accelerations, loads (such as those which may be detected through load or torque sensors, robot kinemetics, etc), and/or vacuum loads, as well as estimated exterior composition of targeted package
860

FIG. 60

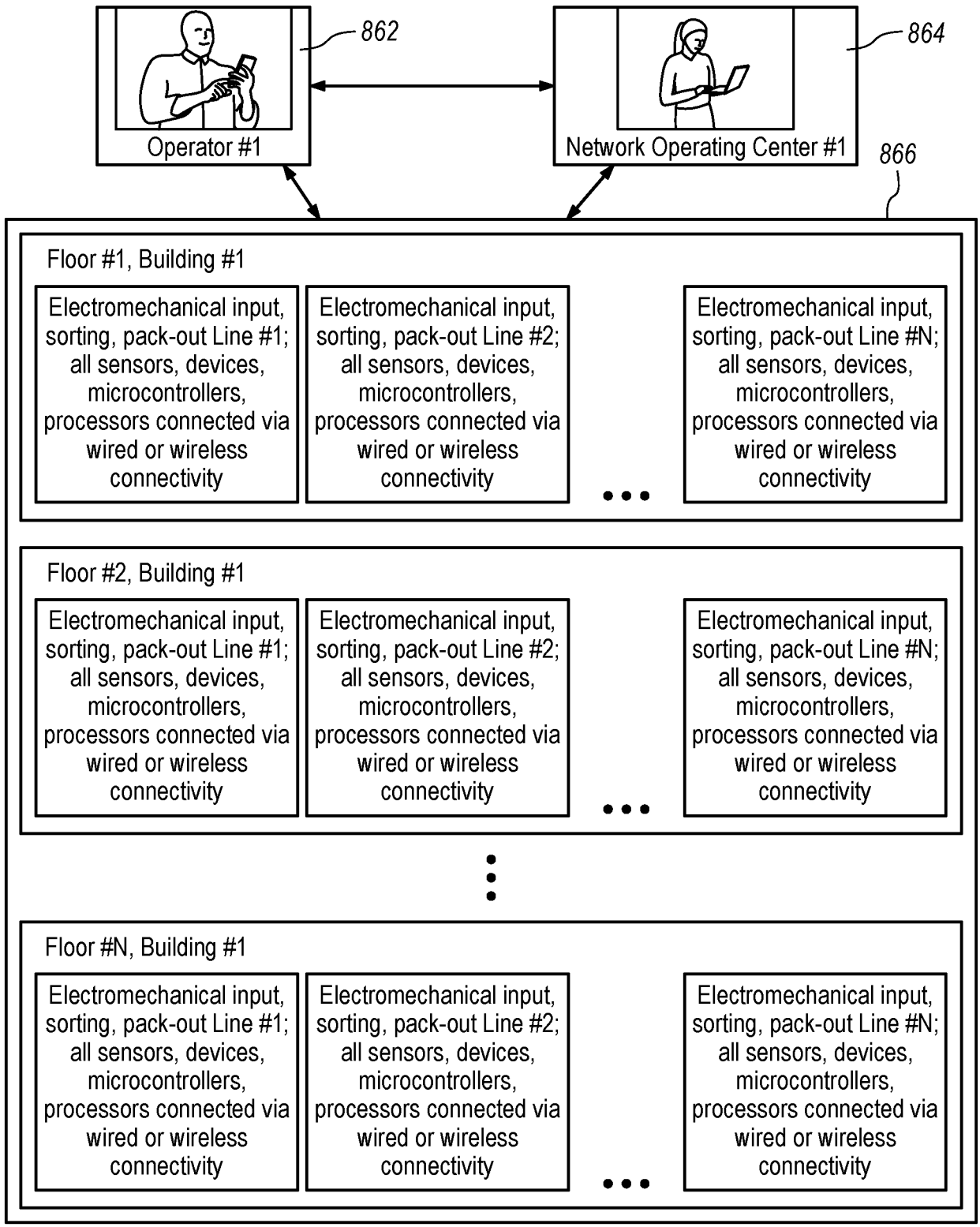

862
Operator #1
864
Network Operating Center #1
866
Floor #1, Building #1
Electromechanical input, sorting, pack-out Line #1; all sensors, devices, microcontrollers, processors connected via wired or wireless connectivity
Electromechanical input, sorting, pack-out Line #2; all sensors, devices, microcontrollers, processors connected via wired or wireless connectivity
Electromechanical input, sorting, pack-out Line #N; all sensors, devices, microcontrollers, processors connected via wired or wireless connectivity
Floor #2, Building #1
Electromechanical input, sorting, pack-out Line #1; all sensors, devices, microcontrollers, processors connected via wired or wireless connectivity
Electromechanical input, sorting, pack-out Line #2; all sensors, devices, microcontrollers, processors connected via wired or wireless connectivity
Electromechanical input, sorting, pack-out Line #N; all sensors, devices, microcontrollers, processors connected via wired or wireless connectivity
Floor #N, Building #1
Electromechanical input, sorting, pack-out Line #1; all sensors, devices, microcontrollers, processors connected via wired or wireless connectivity
Electromechanical input, sorting, pack-out Line #2; all sensors, devices, microcontrollers, processors connected via wired or wireless connectivity
Electromechanical input, sorting, pack-out Line #N; all sensors, devices, microcontrollers, processors connected via wired or wireless connectivity

FIG. 61

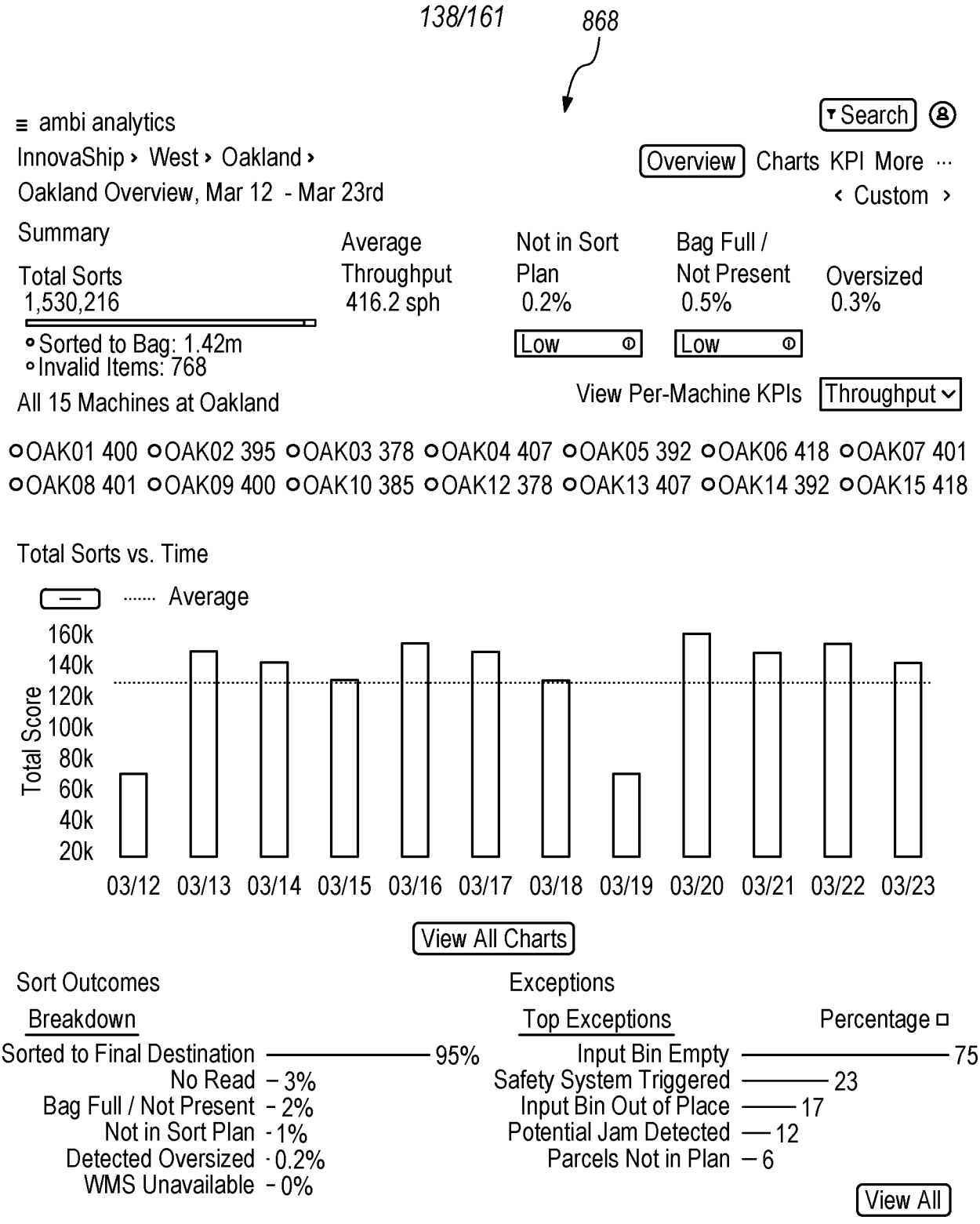

138/161
868
≡ ambi analytics
Search
InnovaShip › West › Oakland ›
Overview Charts KPI More ···
Oakland Overview, Mar 12 - Mar 23rd
‹ Custom ›
Summary
Total Sorts
1,530,216
Sorted to Bag: 1.42m
Invalid Items: 768
Average Throughput
416.2 sph
Not in Sort Plan
0.2%
Low
Bag Full / Not Present
0.5%
Low
Oversized
0.3%
All 15 Machines at Oakland
View Per-Machine KPIs
Throughput
OAK01 400 OAK02 395 OAK03 378 OAK04 407 OAK05 392 OAK06 418 OAK07 401
OAK08 401 OAK09 400 OAK10 385 OAK12 378 OAK13 407 OAK14 392 OAK15 418
Total Sorts vs. Time
Average
160k
140k
120k
100k
80k
60k
40k
20k
Total Score
03/12 03/13 03/14 03/15 03/16 03/17 03/18 03/19 03/20 03/21 03/22 03/23
View All Charts
Sort Outcomes
Breakdown
Sorted to Final Destination 95%
No Read 3%
Bag Full / Not Present 2%
Not in Sort Plan 1%
Detected Oversized 0.2%
WMS Unavailable 0%
Exceptions
Top Exceptions
Percentage
Input Bin Empty 75
Safety System Triggered 23
Input Bin Out of Place 17
Potential Jam Detected 12
Parcels Not in Plan 6
View All

FIG. 62

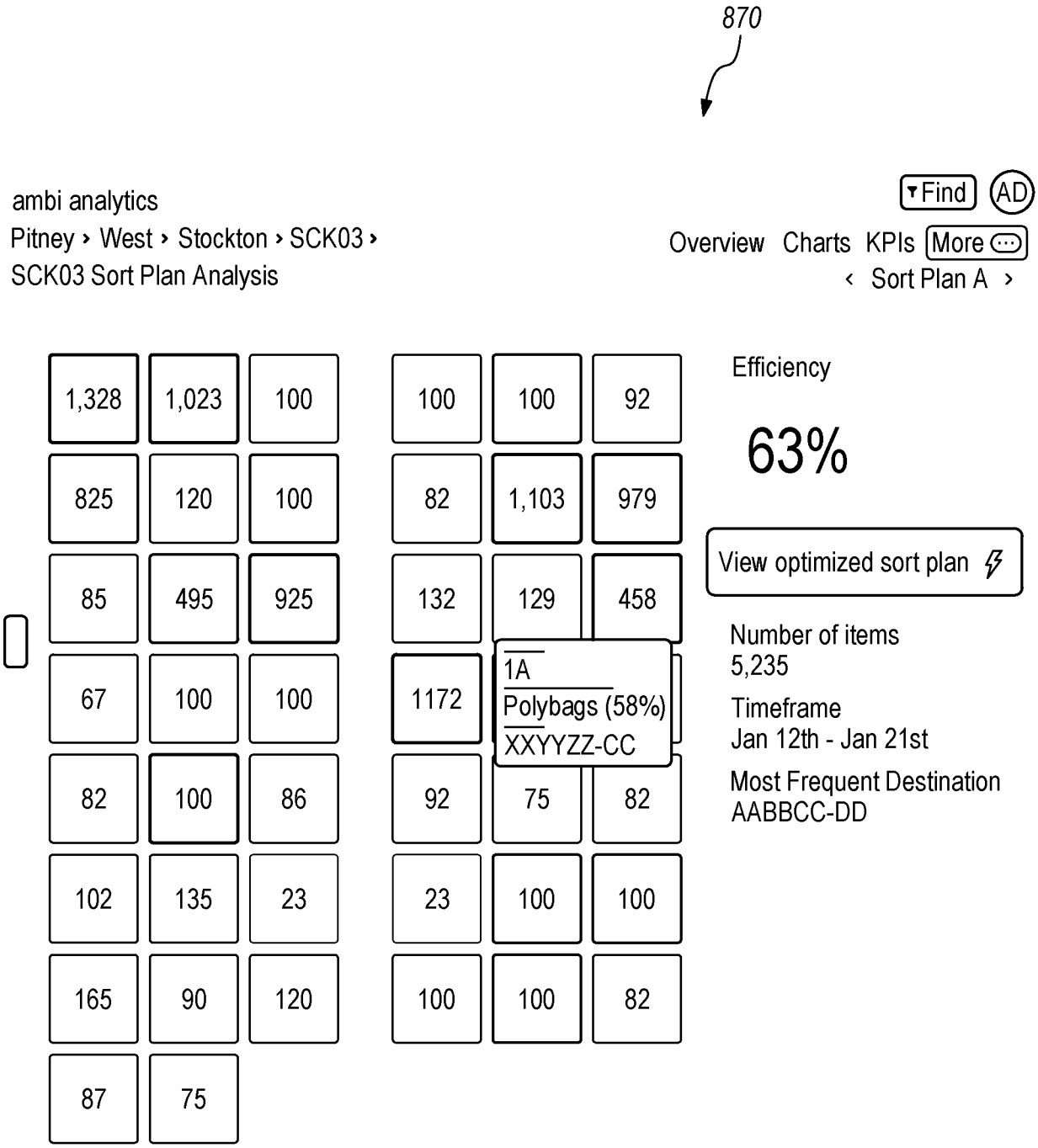

870
ambi analytics
Pitney › West › Stockton › SCK03 ›
SCK03 Sort Plan Analysis
Find
AD
Overview Charts KPIs More
‹ Sort Plan A ›
1,328 1,023 100
825 120 100
85 495 925
67 100 100
82 100 86
102 135 23
165 90 120
87 75
100 100 92
82 1,103 979
132 129 458
1172
1A
Polybags (58%)
XXYYZZ-CC
92 75 82
23 100 100
100 100 82
Efficiency
63%
View optimized sort plan
Number of items
5,235
Timeframe
Jan 12th - Jan 21st
Most Frequent Destination
AABBCC-DD

FIG. 63

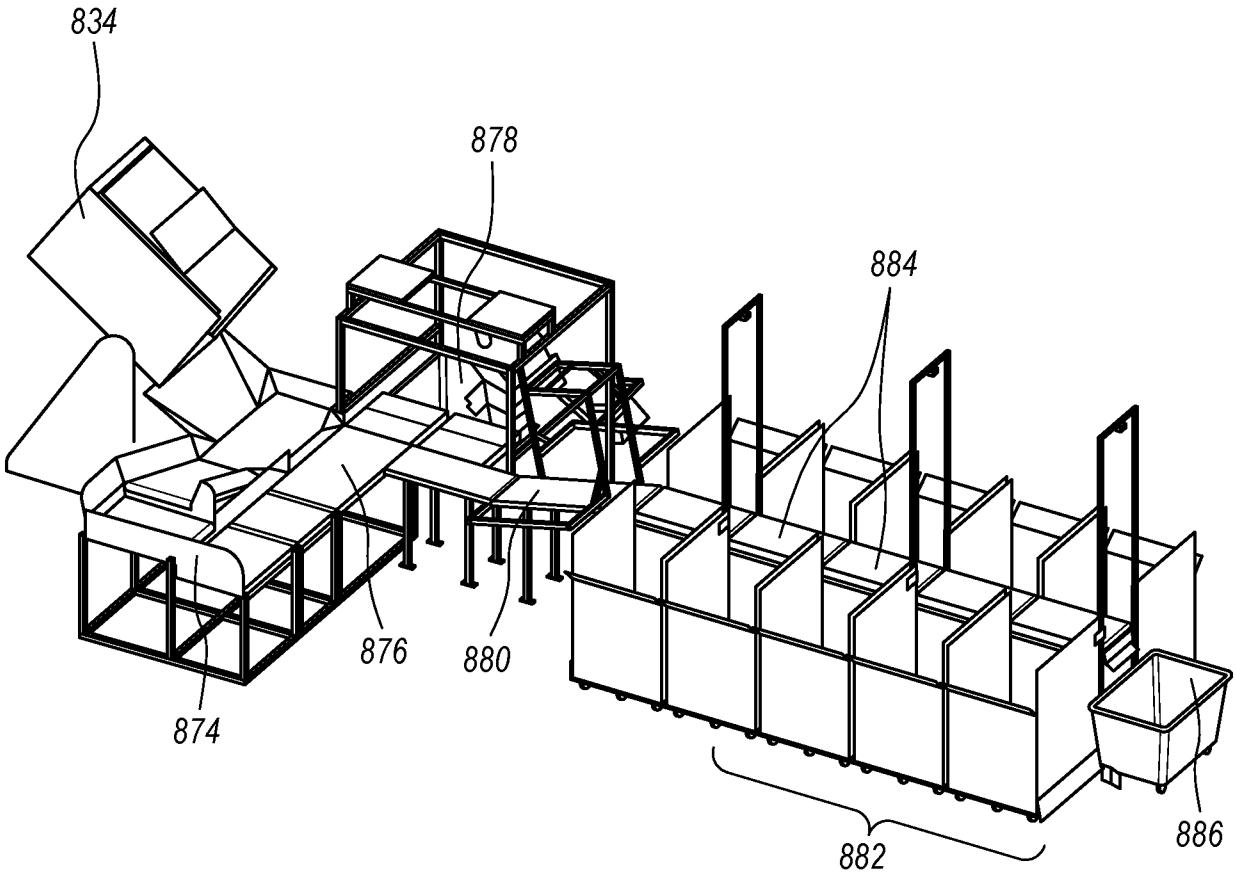


FIG. 64

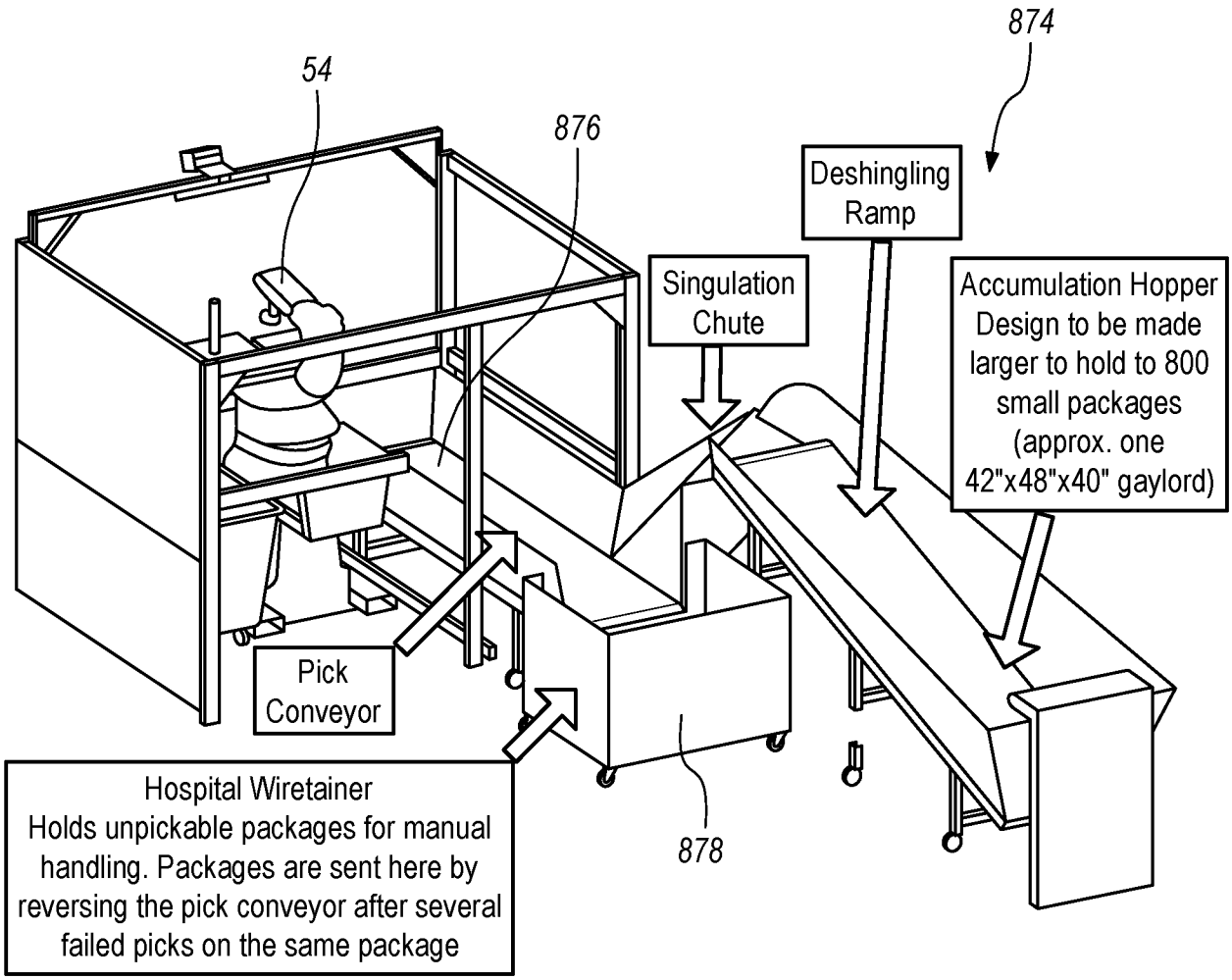

874
54
876
Deshingling Ramp
Singulation Chute
Accumulation Hopper Design to be made larger to hold to 800 small packages (approx. one 42"x48"x40" gaylord)
Pick Conveyor
Hospital Wiretainer
Holds unpickable packages for manual handling. Packages are sent here by reversing the pick conveyor after several failed picks on the same package
878

FIG. 65

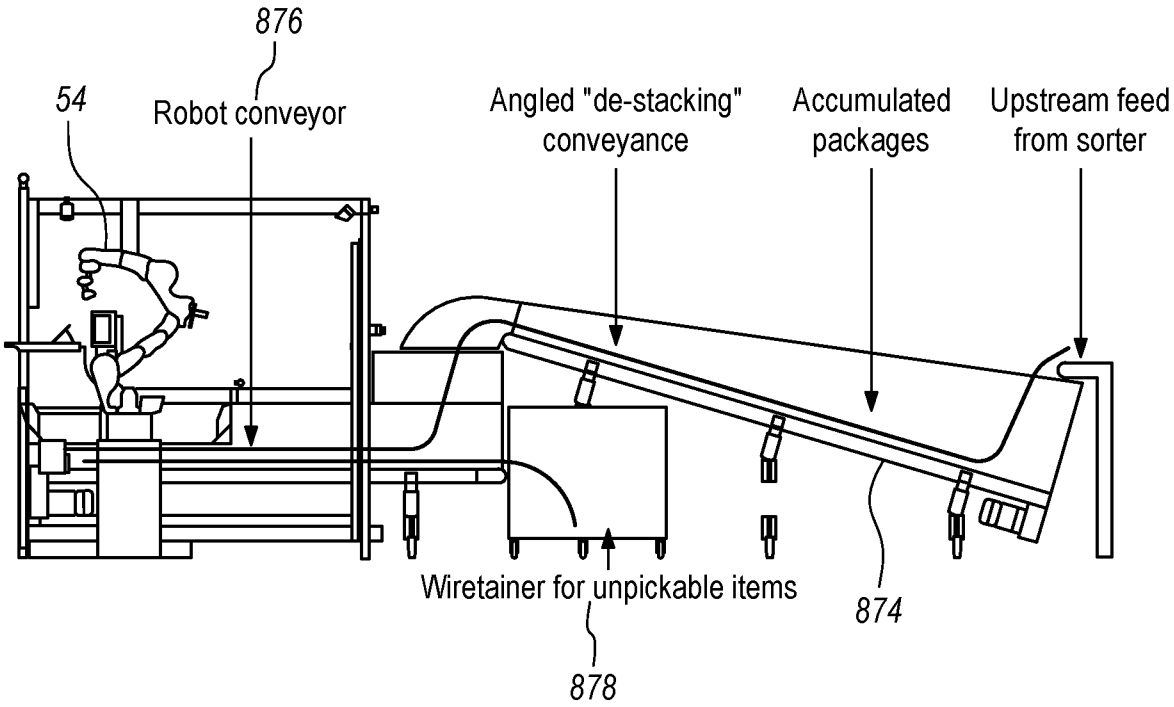

876
54
Robot conveyor
Angled "de-stacking" conveyance
Accumulated packages
Upstream feed from sorter
Wiretainer for unpickable items
874
878

FIG. 66

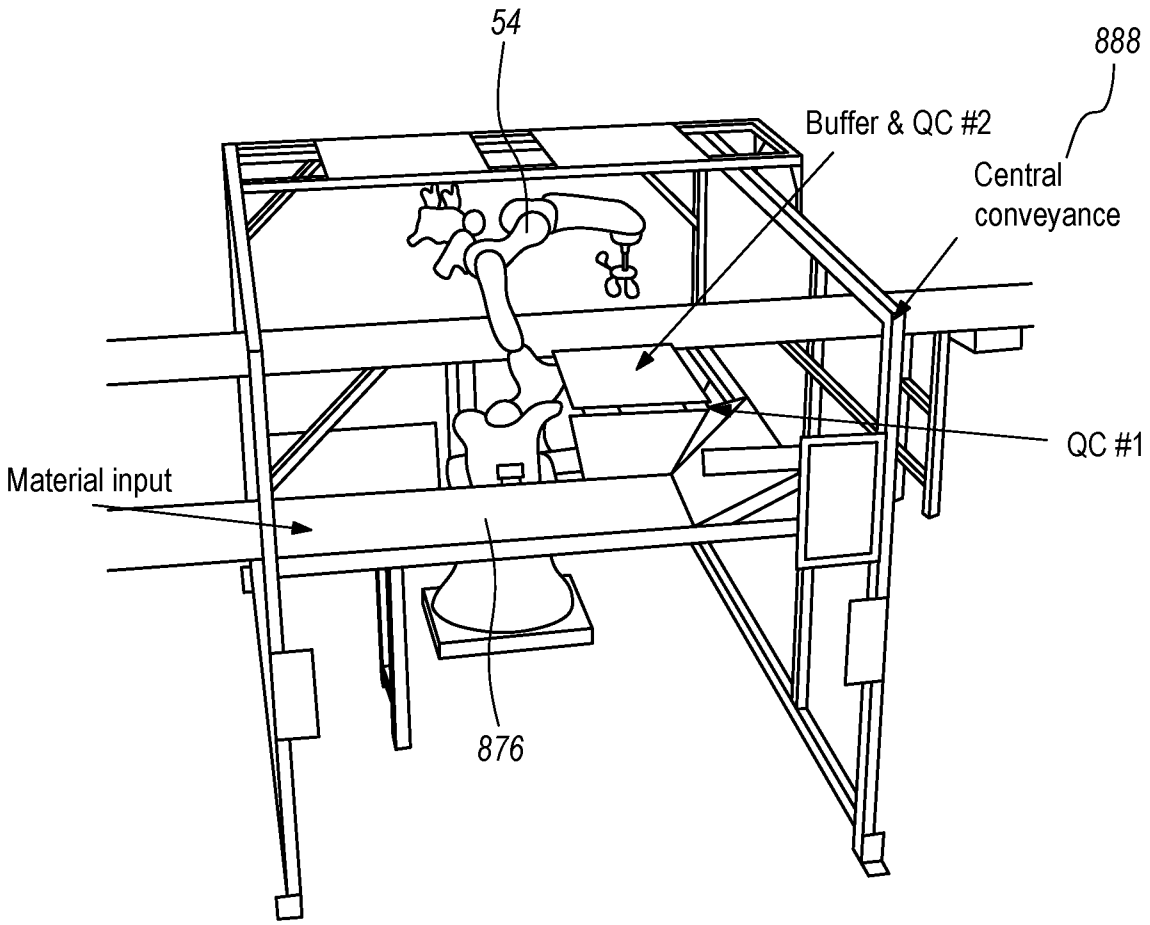

54
888
Buffer & QC #2
Central
conveyance
QC #1
Material input
876

FIG. 67

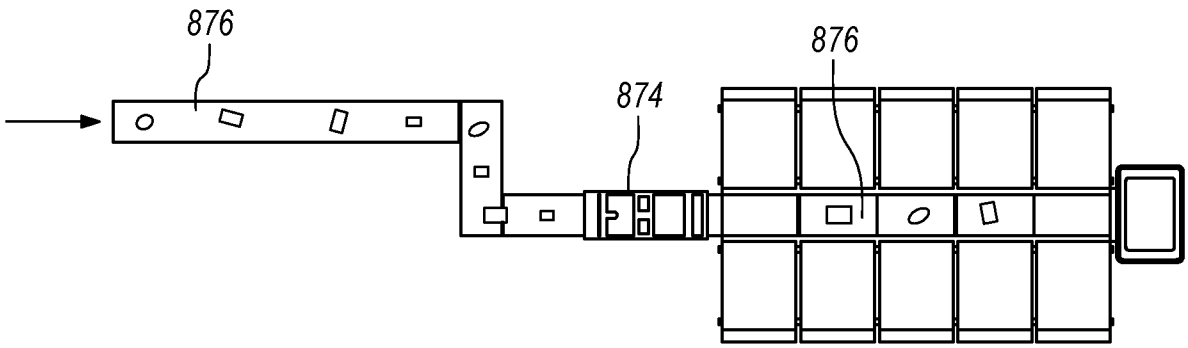


FIG. 68

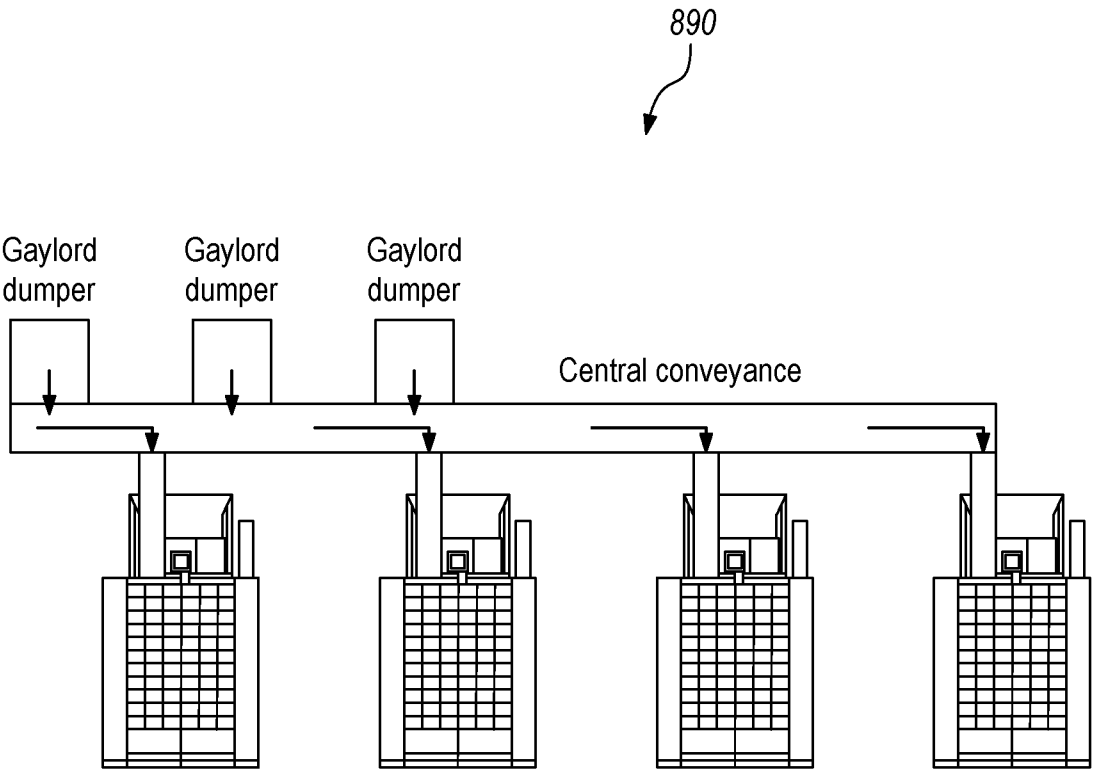

890
Gaylord dumper
Gaylord dumper
Gaylord dumper
Central conveyance

FIG. 69

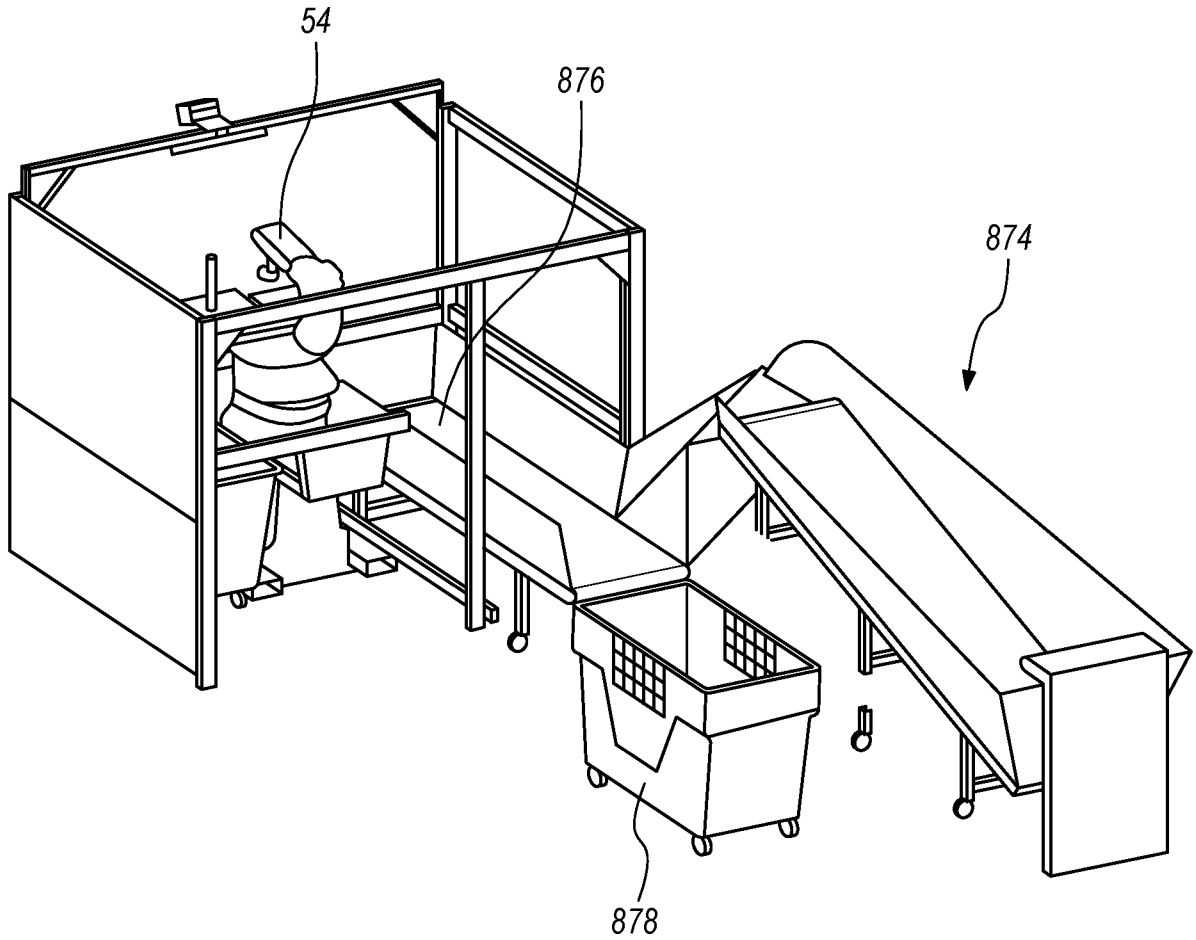


FIG. 70

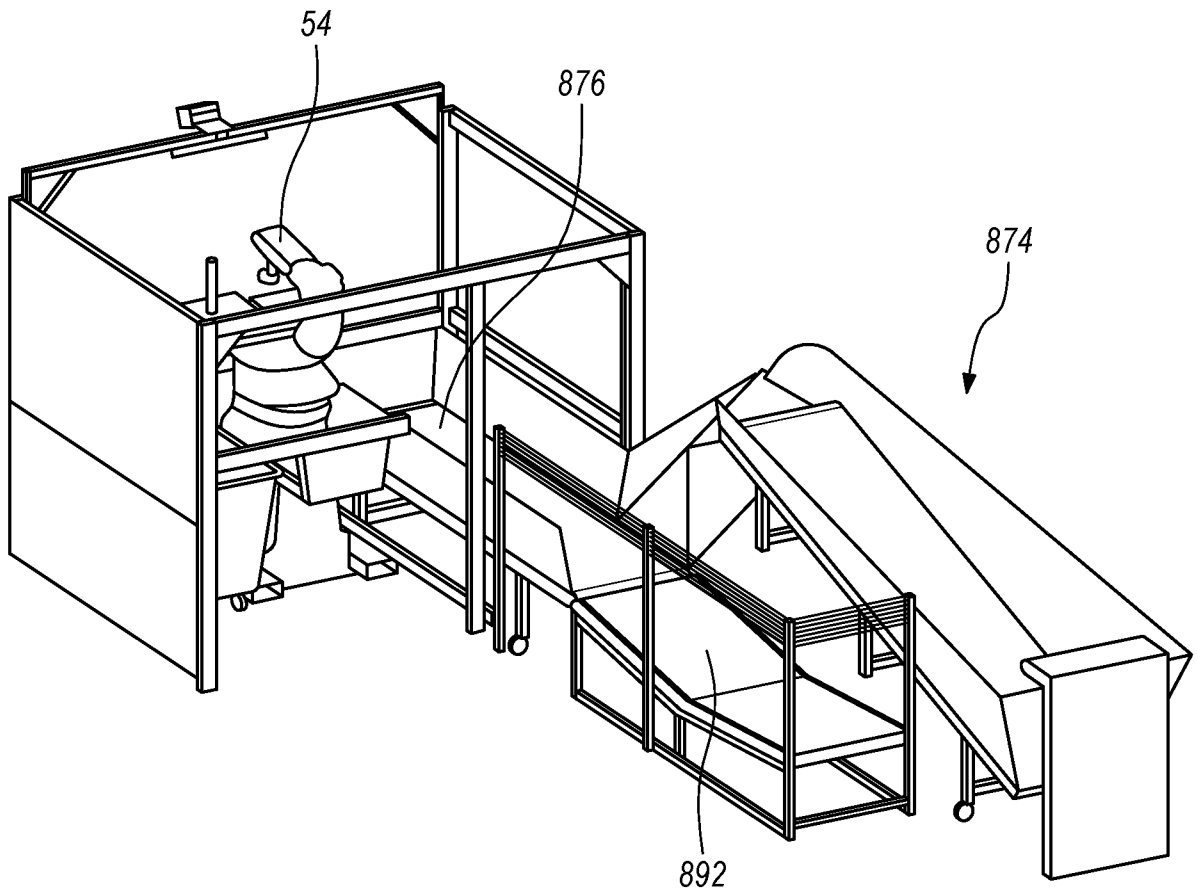


FIG. 71

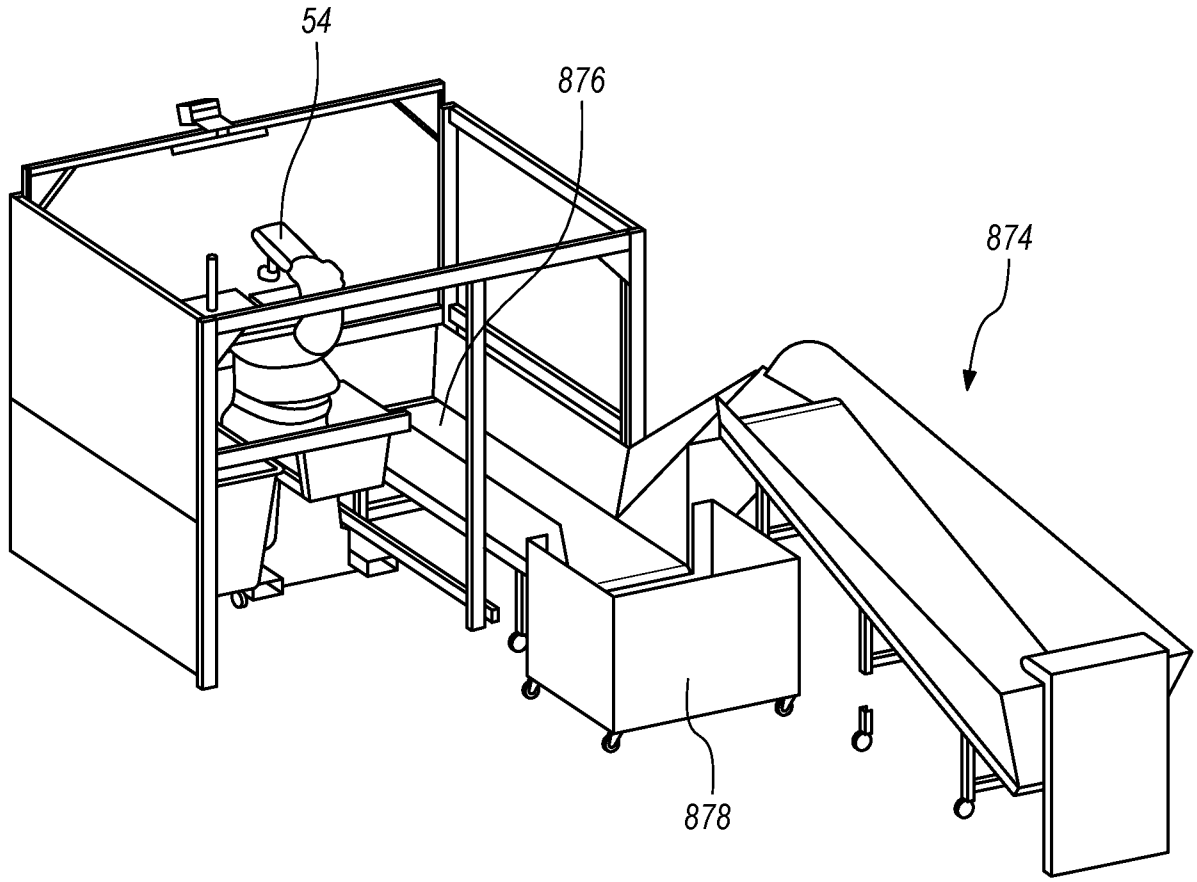


FIG. 72

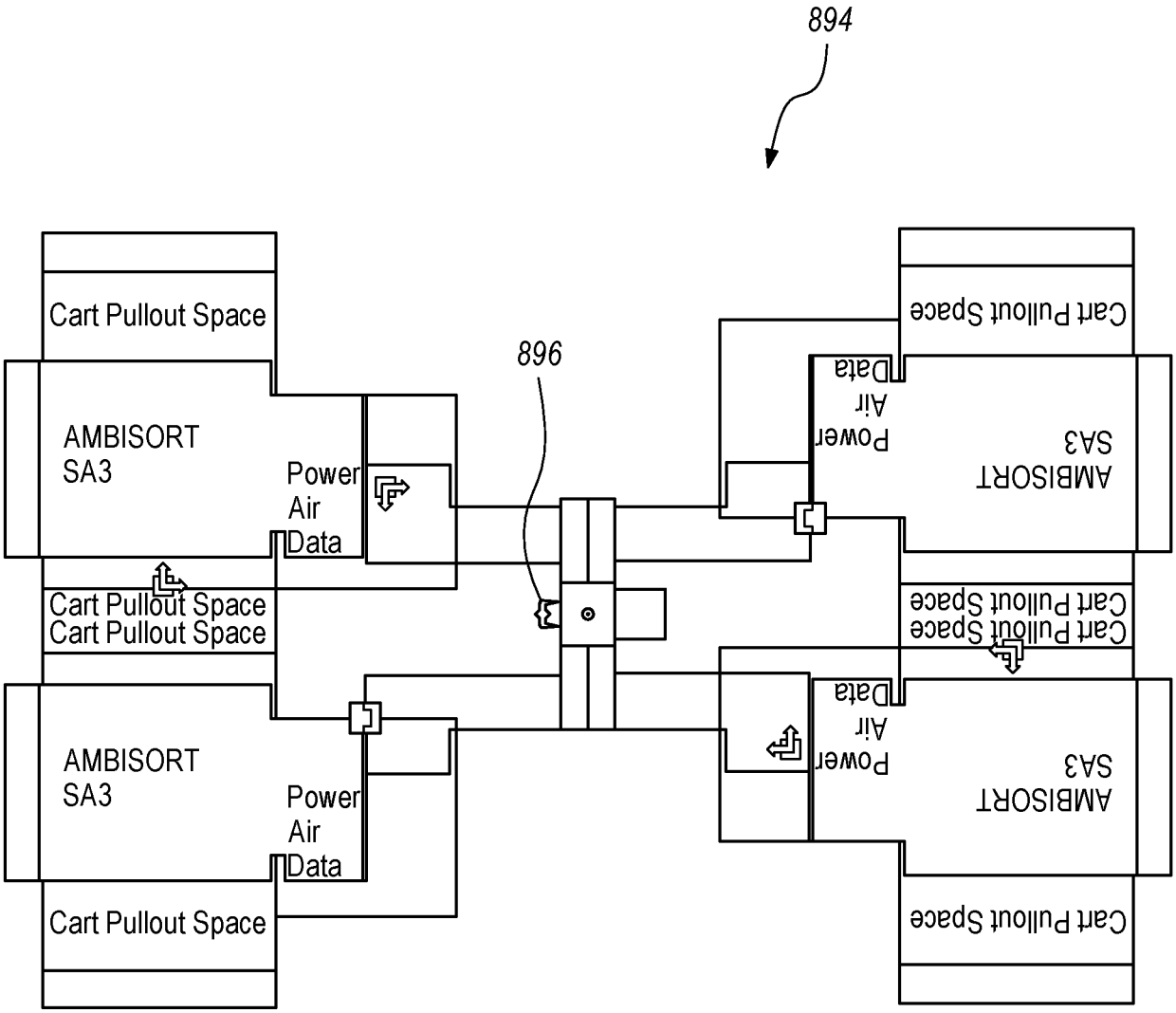

894
896
Cart Pullout Space
AMBISORT
SA3
Power
Air
Data
Cart Pullout Space
Cart Pullout Space
AMBISORT
SA3
Power
Air
Data
Cart Pullout Space
Cart Pullout Space
Cart Pullout Space
AMBISORT
SA3
Power
Air
Data
Cart Pullout Space

FIG. 73

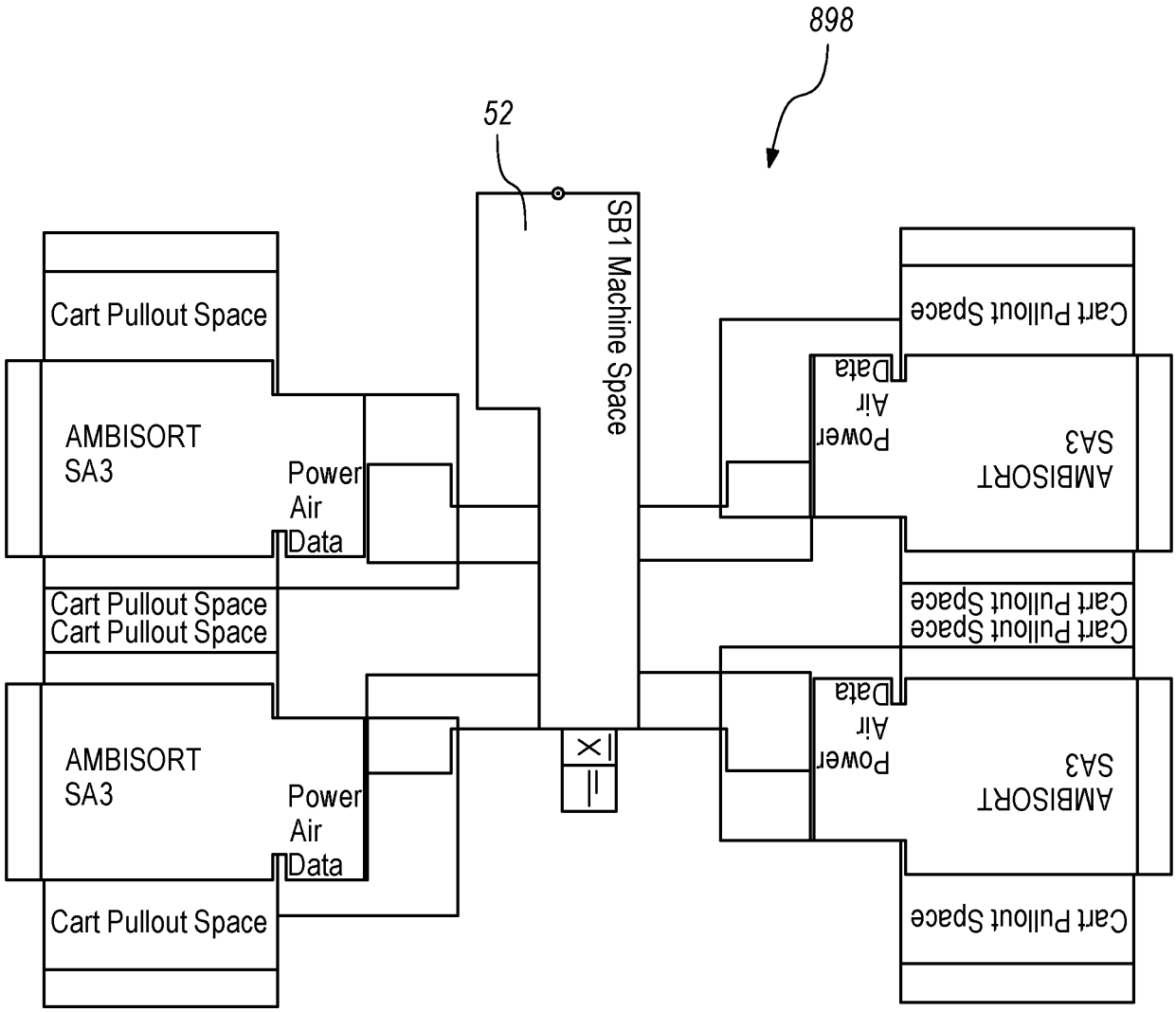

898
52
SB1 Machine Space
Cart Pullout Space
AMBISORT
SA3
Power
Air
Data
Cart Pullout Space
Cart Pullout Space
AMBISORT
SA3
Power
Air
Data
Cart Pullout Space
Cart Pullout Space
Cart Pullout Space
AMBISORT
SA3
Power
Air
Data
Cart Pullout Space

FIG. 74

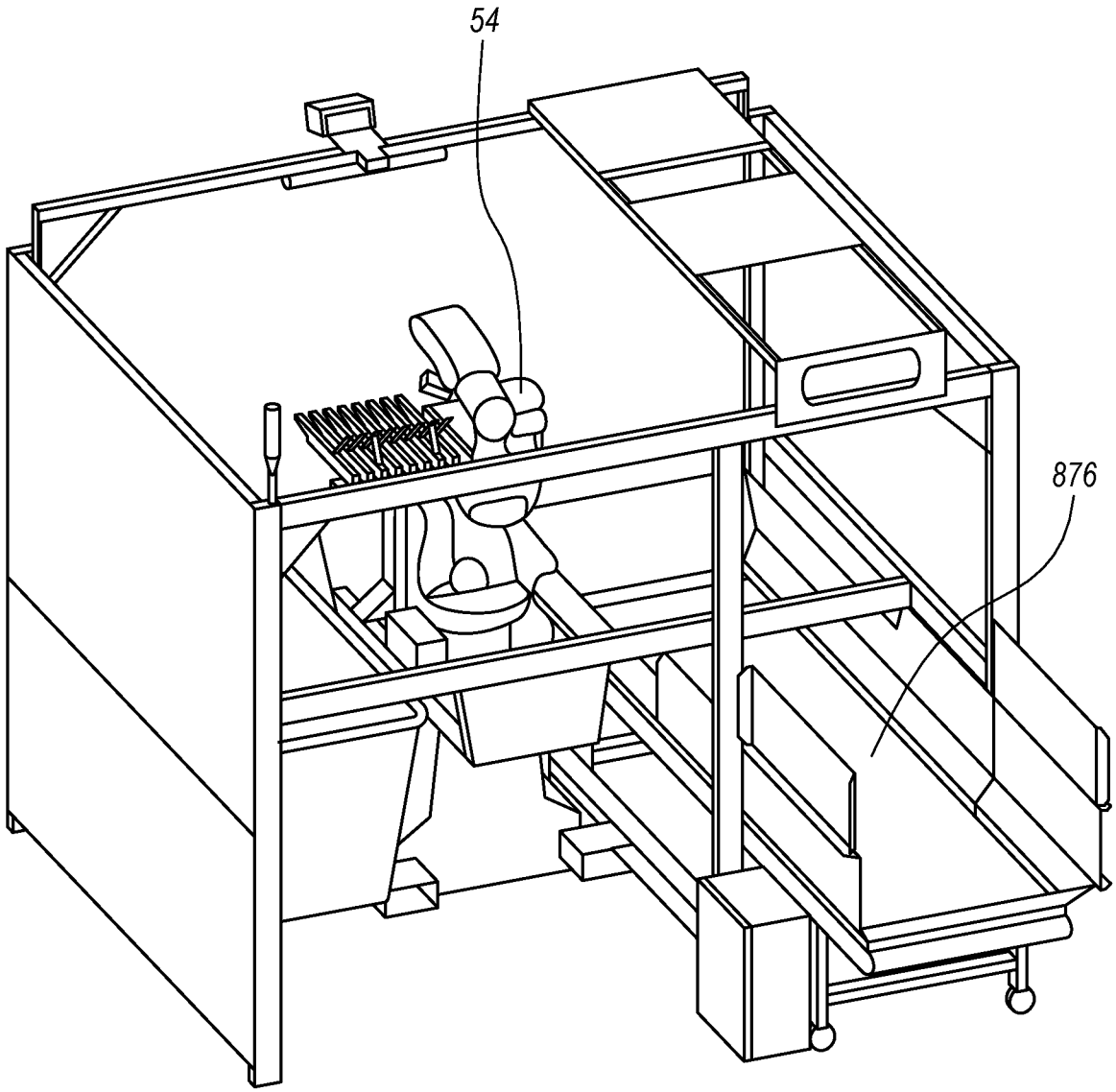


FIG. 75

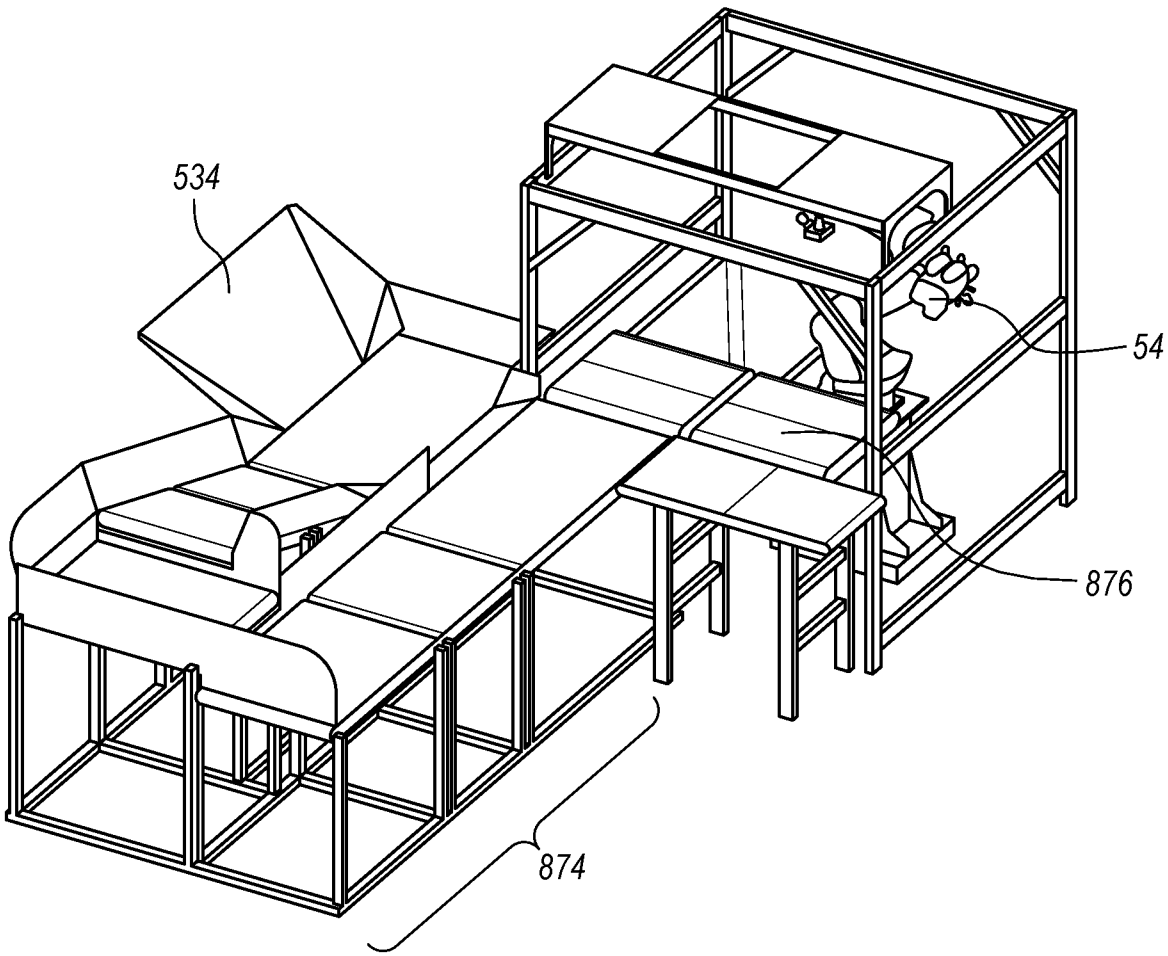


FIG. 76

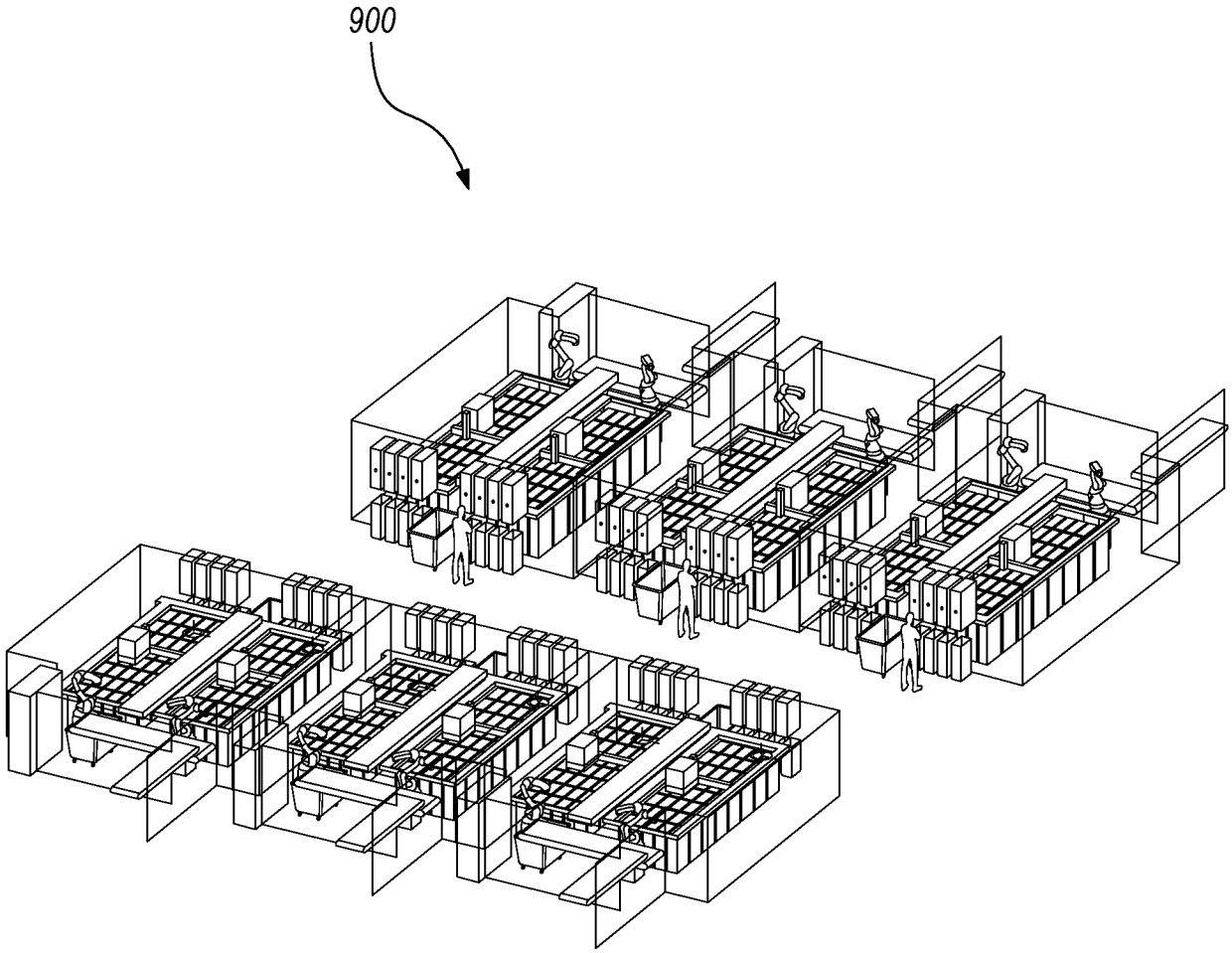


FIG. 77

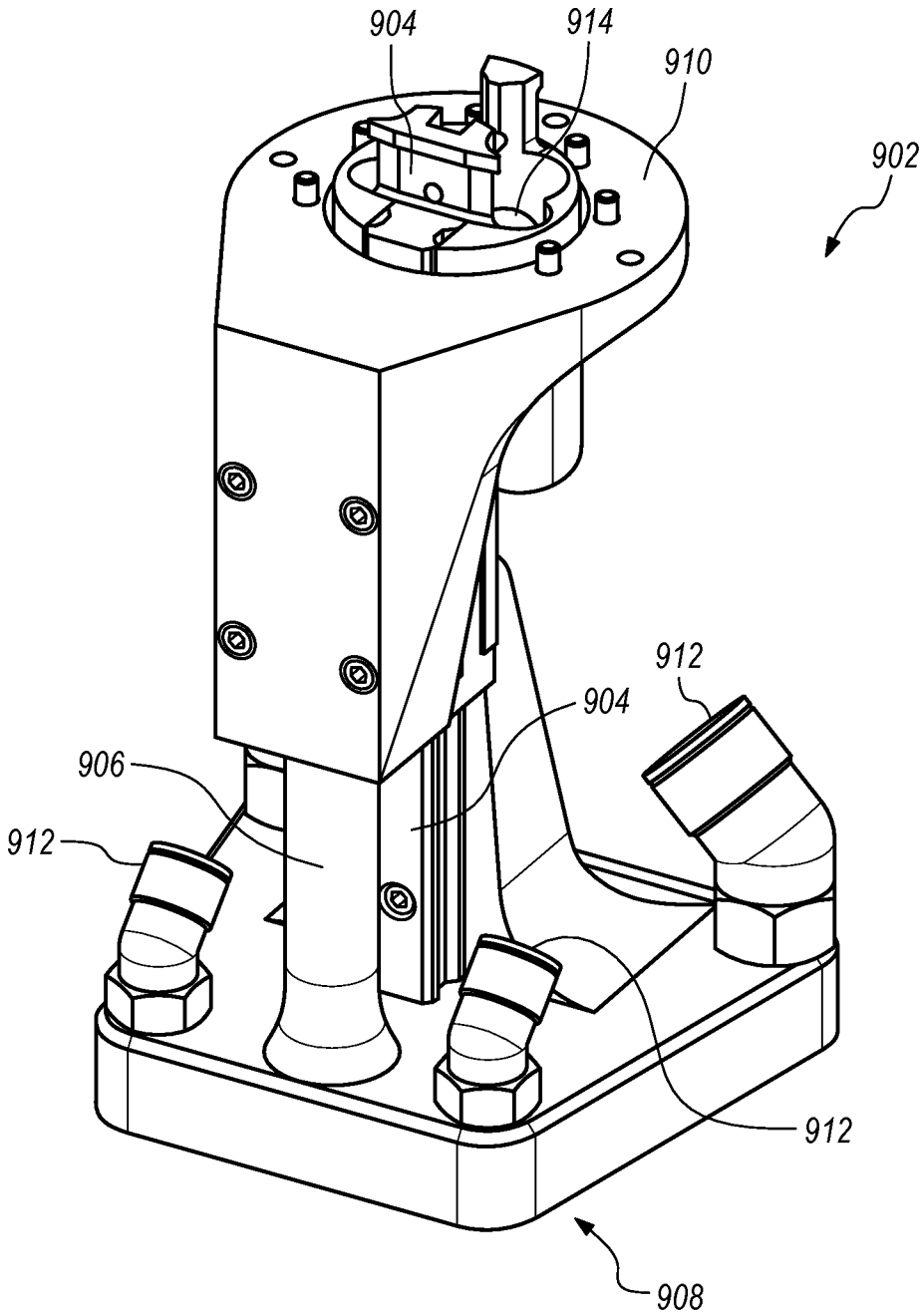


FIG. 78

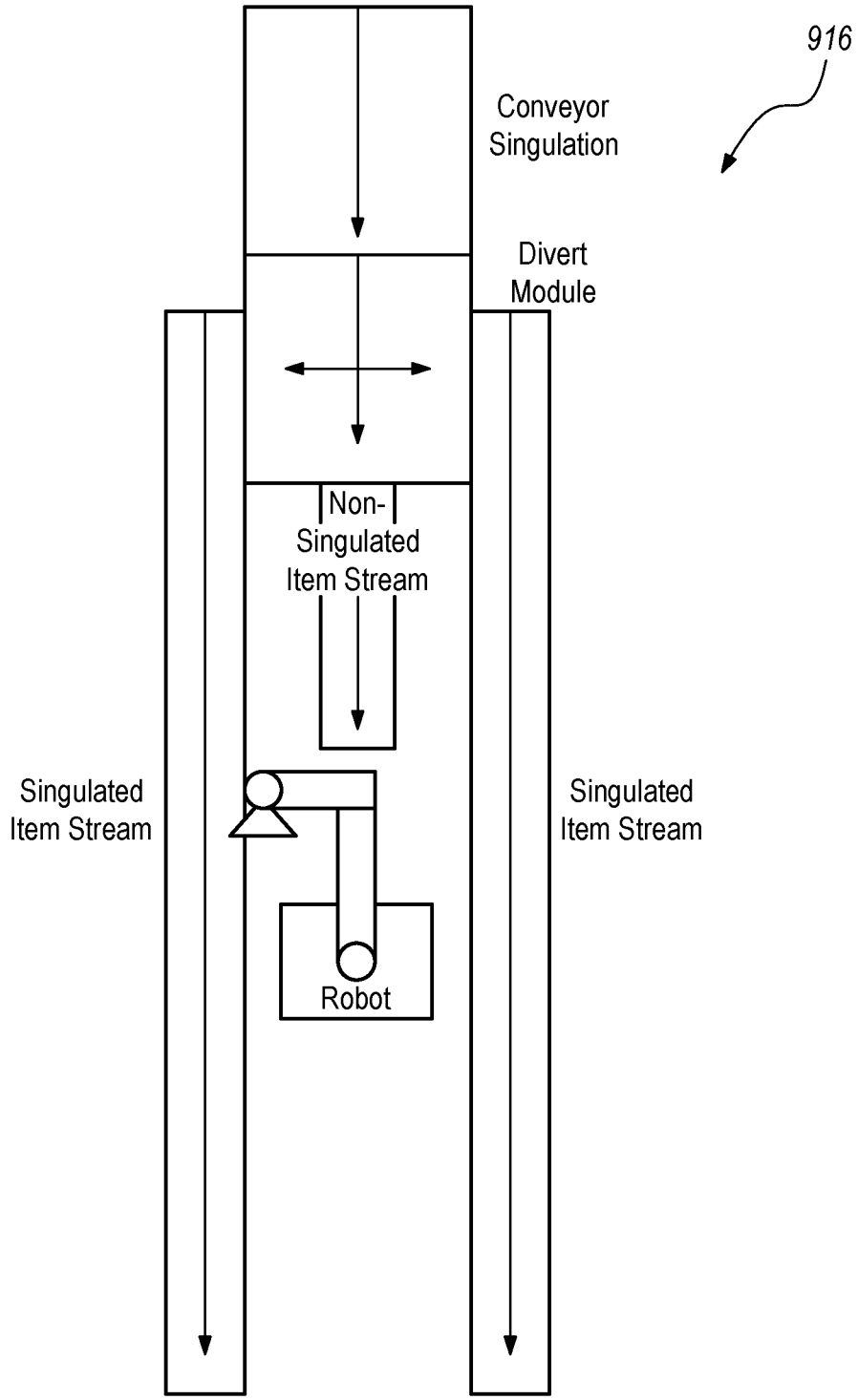

916
Conveyor Singulation
Divert Module
Non-Singulated Item Stream
Singulated Item Stream
Singulated Item Stream
Robot

FIG. 79

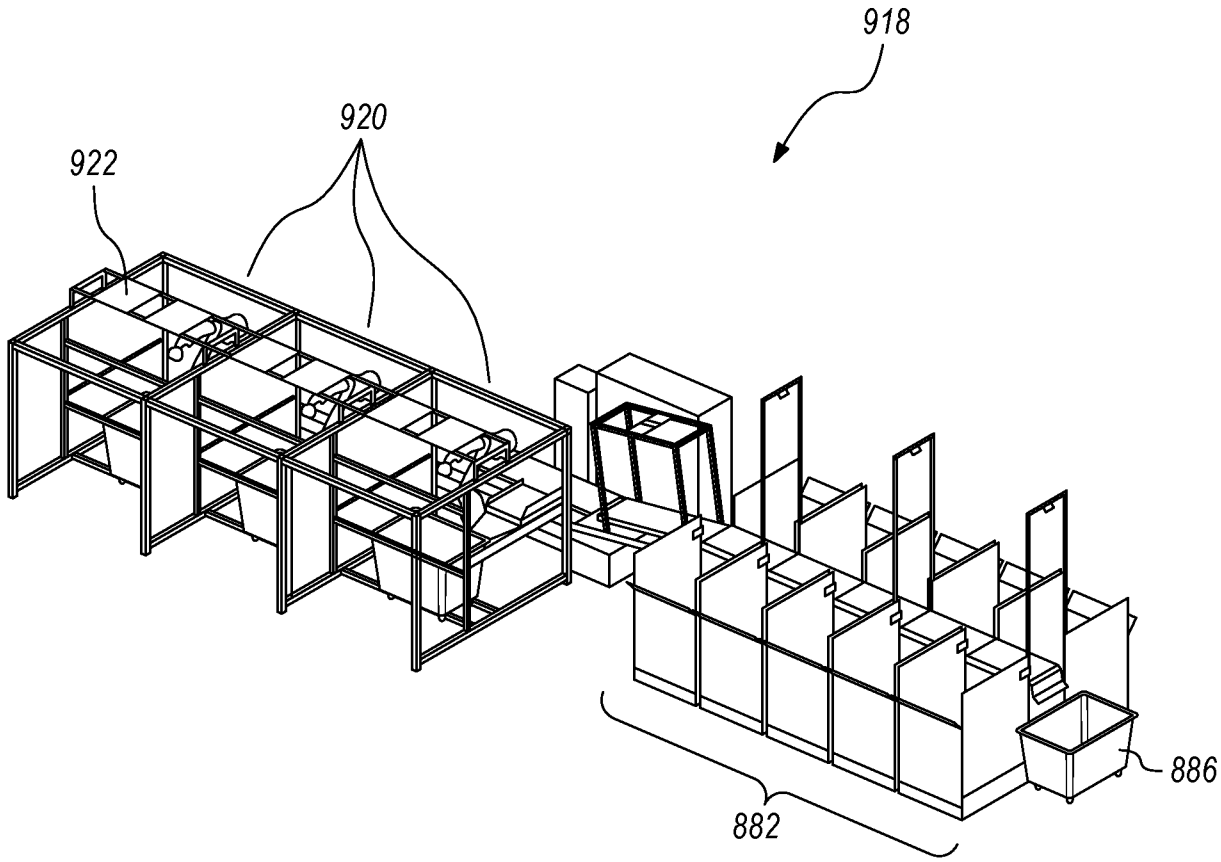


FIG. 80

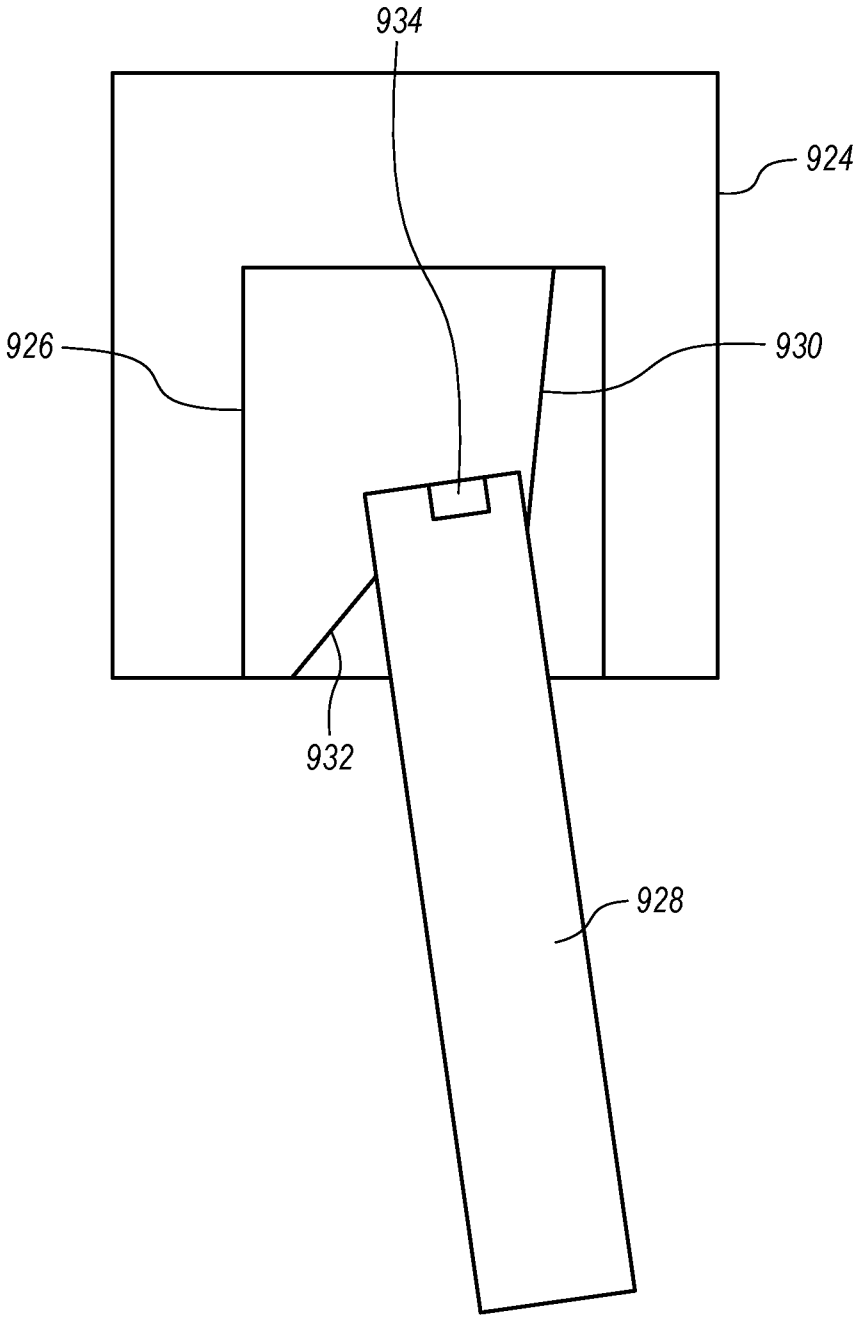


FIG. 81

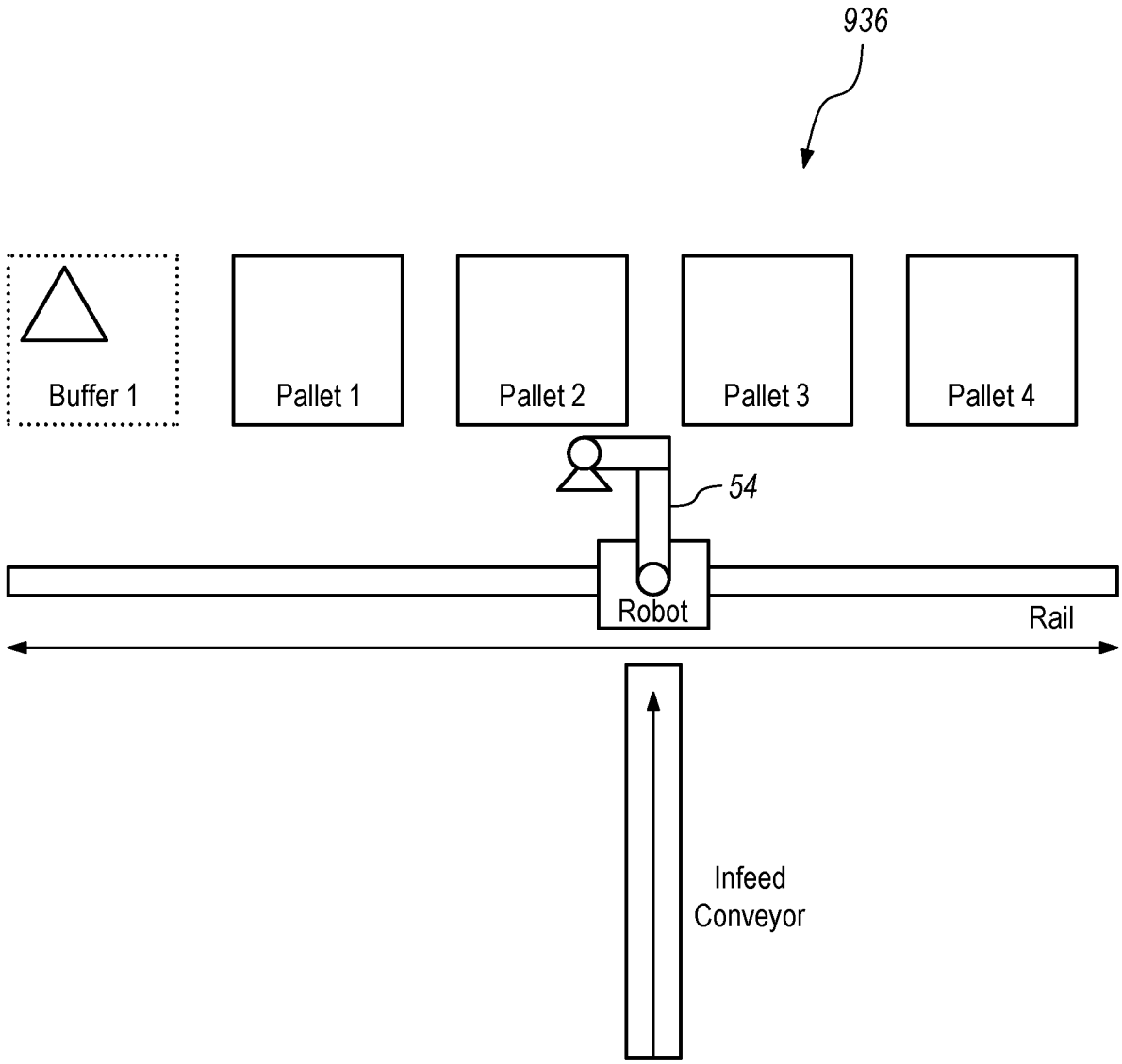

936
Buffer 1
Pallet 1
Pallet 2
Pallet 3
Pallet 4
54
Robot
Rail
Infeed
Conveyor

FIG. 82

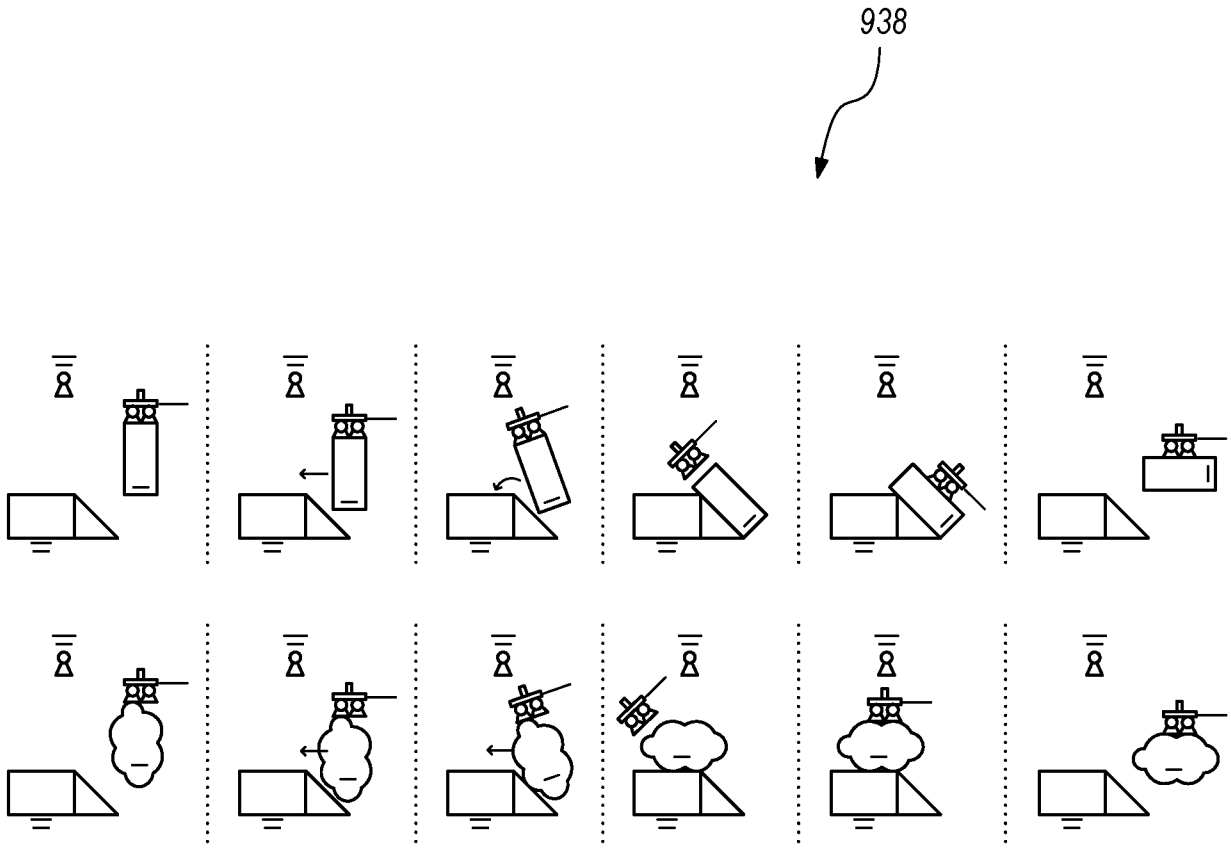


FIG. 83

160/161

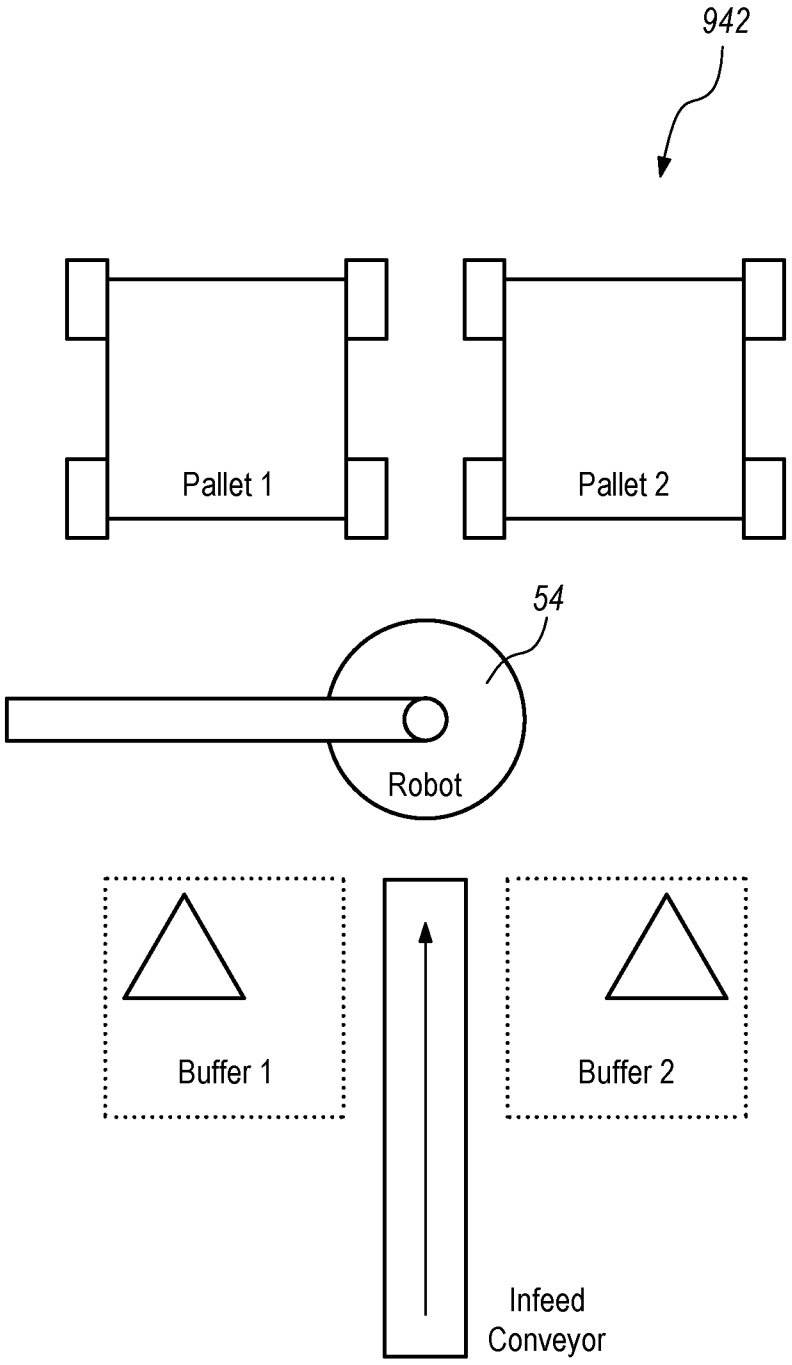


FIG. 84

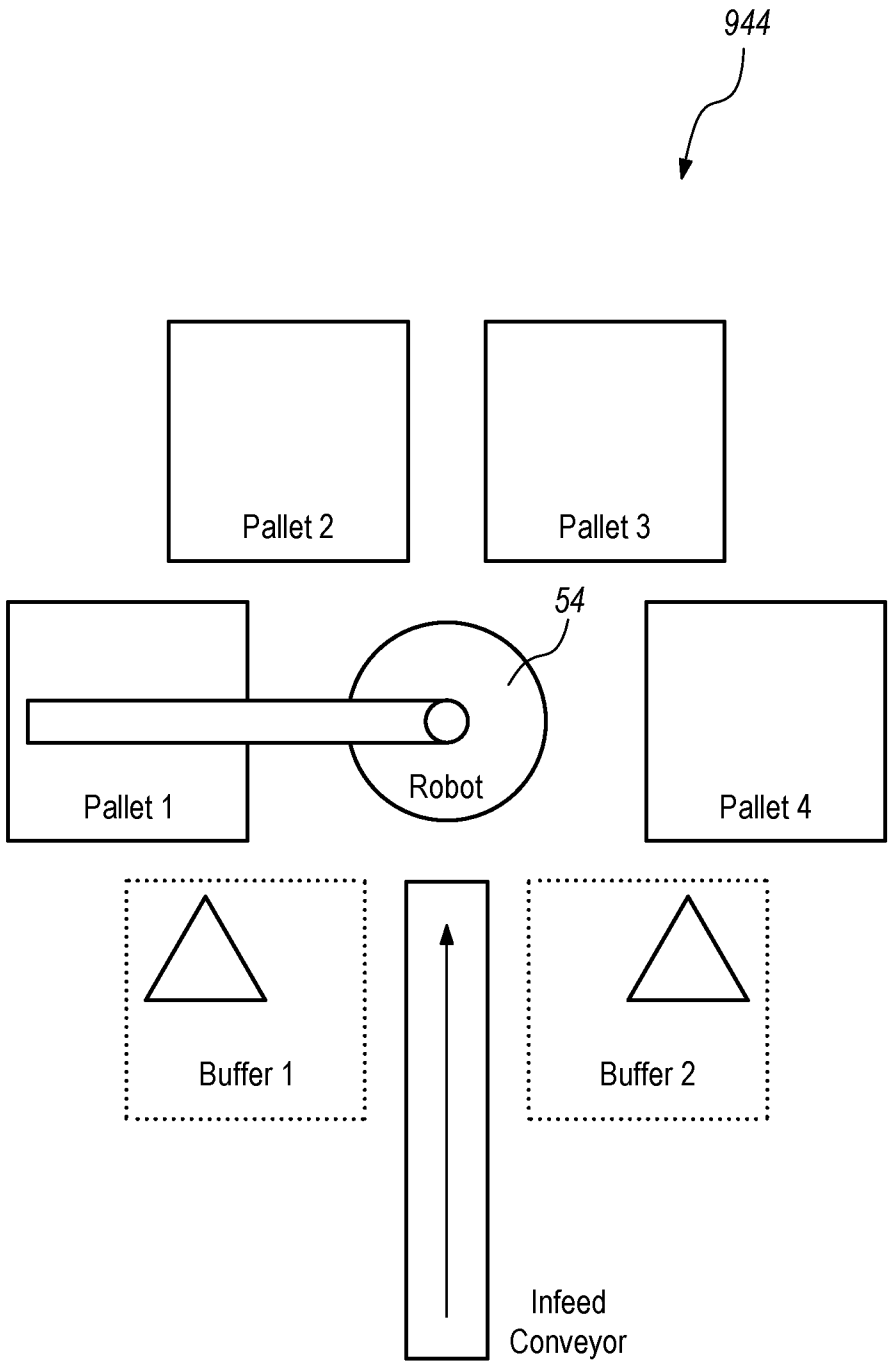

944
Pallet 2
Pallet 3
54
Pallet 1
Robot
Pallet 4
Buffer 1
Buffer 2
Infeed
Conveyor

FIG. 85