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(54) **Title:** PALLET INSPECTION SYSTEM AND ASSOCIATED METHODS

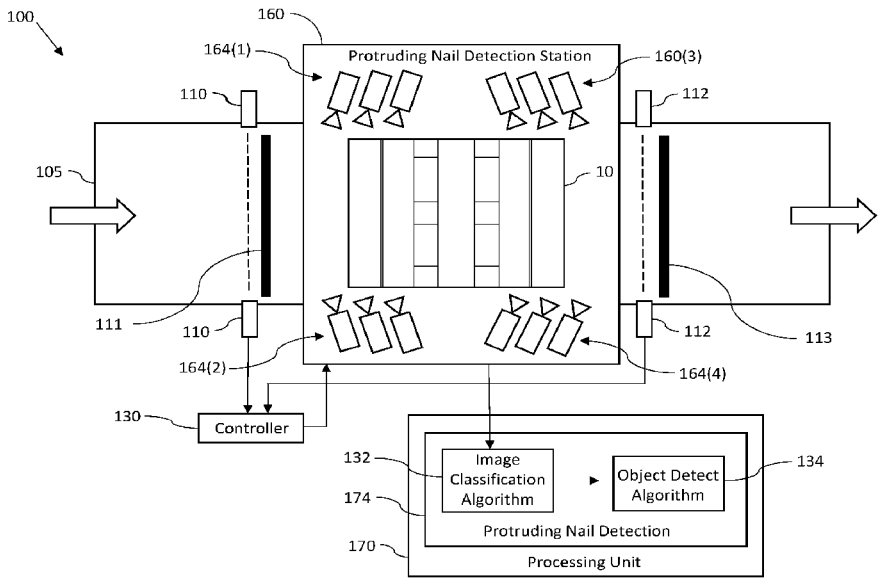

FIG. 5

(57) **Abstract:** A pallet inspection system includes a conveyor to move a pallet that is to be inspected. The pallet includes a top deck and a bottom deck separated by spaced apart support blocks positioned therebetween, with nails being used to secure the top and bottom decks to the support blocks. Cameras are positioned to generate images of the pallet as the pallet is moved on the conveyor. A processor is coupled to the cameras and receives the images for processing. The processing includes executing a first algorithm on the images to tag the images having support blocks visible therein, and executing a second algorithm on the tagged images to detect nails having exposed tips.

WO 2023/064786 A1

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PALLET INSPECTION SYSTEM AND ASSOCIATED METHODS

Related Applications

[0001] This application claims the benefit of U.S. provisional application serial no. 63/262,452 filed October 13, 2021, which is hereby incorporated herein in its entirety by reference.

Technical Field

[0002] The present invention relates to pallet inspection, and more particularly, to determining nail defects on a pallet.

Background

[0003] Wooden pallets are used to transport a variety of bulk goods and equipment as required in manufacturing and warehousing operations. In high volume industries, pallet pools provide a lower total industry cost than one-way pallets.

[0004] After the bulk goods and equipment are off loaded from the pooled pallets, the pallets are returned to pallet inspection and repair facilities. A damaged pallet will be discarded if the repairs are too extensive. Otherwise, if the damage is minor, then the pallet is repaired and painted before being returned to service.

Summary

[0005] A pallet inspection system includes a conveyor to move a pallet that is to be inspected. The pallet includes a top deck and a bottom deck separated by spaced apart support blocks positioned therebetween, with nails being used to secure the top and bottom decks to the support blocks. A plurality of cameras are positioned to generate images of the pallet as the pallet is moved on the conveyor. A processor is coupled to the plurality of cameras and receives the images for processing. The processing includes executing a first algorithm on the images to tag the images having support blocks visible therein, and executing a second algorithm on the tagged images to detect nails having exposed tips.

[0006] The pallet inspection system may further include a first sensor positioned before the plurality of cameras, and a second sensor positioned after the plurality of cameras. The processor may be configured to receive a first set of

images of the pallet in response to the first sensor being activated, and receive a second set of images of the pallet in response to the second sensor being activated.

[0007] The first and second sensors comprise photoelectric sensors. The first and second algorithms may be executed by the processor so that nails having exposed tips are detected in real time.

[0008] The plurality of support blocks are spaced apart to form a pair of outer rows and a center row therebetween, with the outer rows including corner support blocks. Each camera may be in focus on the support blocks in one of the rows and out-of-focus on the support blocks in the other rows.

[0009] The plurality of cameras may be divided into first and second camera sets, with the first camera set being directed toward an entrance of the pallet inspection system, and the second camera set being directed toward an exit of the pallet inspection system.

[0010] The first camera set may provide a front perspective of the plurality of support blocks, and the second camera set may provide a rear perspective of the plurality of support blocks, with the first and second camera sets collectively providing images on all sides of each support block.

[0011] The first camera set may include cameras adjacent each side of the conveyor, and the second camera set may include cameras adjacent each side of the conveyor. Each camera may be configured as a color camera.

[0012] The first algorithm may include an image classification algorithm, and the second algorithm may include an object detection algorithm.

[0013] The image classification algorithm may be configured to classify each image as one of the following: a block image corresponding to a support block being in focus, a non-block image corresponding to a support block being out-of-focus, or a background image corresponding to neither a support block being in focus or a support block being out-of-focus. The block images may be tagged by the image classification algorithm.

[0014] The object detection algorithm may be configured to place a bounding box around the support block in each block image, and in response to an exposed nail tip being detected, place a bounding box around the exposed nail tip.

[0015] The object detection algorithm may be configured to detect other nail defects in addition to nails having exposed tips, with the other nail defects being

ignored by the processor.

[0016] Another aspect is directed to a method for operating a pallet inspection station as described above. The method includes operating a conveyor to move a pallet that is to be inspected, the pallet comprising a top deck and a bottom deck separated by a plurality of spaced apart support blocks positioned therebetween, and with nails being used to secure the top and bottom decks to the plurality of support blocks. The method further includes operating a plurality of cameras positioned to generate images of the pallet as the pallet is moved on the conveyor, and receiving the images for processing. The processing may include executing a first algorithm on the images to tag the images having support blocks visible therein, and executing a second algorithm on the tagged images to detect nails having exposed tips.

[0017] Another aspect is directed to a method for training an object detection algorithm as described above. The method includes creating a database of images of pallets with protruding nails and other nail defects, defining different categories that are to be detected in the database, and annotating the images in the database corresponding to the different categories to be detected. A model is trained using machine learning to learn a function that produces mappings between the annotated images and the different categories to be detected. The method further includes analyzing the output data from the model, and optimizing the model based on the analyzed output data.

[0018] Yet another aspect is directed to a method for operating an object detect algorithm as described above. The method includes receiving images of pallets to be inspected, and executing a machine learning model trained to learn a function that produces mappings between annotated images of pallets with protruding nails and other nail defects to be detected. The annotated images correspond to different categories to be detected. The method further includes identifying objects by location in the received images corresponding to the different categories to be detected, providing confidence values for the categories that were detected in the received images, and identifying the pallets with protruding nail based on the confidence values.

Brief Description of the Drawings

[0019] FIG. 1 is a top perspective view of a wooden pallet in which various aspects of the disclosure may be implemented.

[0020] FIG. 2 is a bottom perspective view of the wooden pallet illustrated in FIG. 1.

[0021] FIG. 3 is a partial cross-sectional view of the wooden pallet illustrated in FIG. 1 with a protruding nail.

[0022] FIG. 4 is a block diagram of a pallet inspection system in which various aspects of the disclosure may be implemented.

[0023] FIG. 5 is a more detailed block diagram of the protruding nail detection station illustrated in FIG. 4 for detecting protruding nails in a wooden pallet.

[0024] FIGS. 6-8 are images generated by the protruding nail detection station illustrated in FIG. 5 that have been classified by the image classification algorithm as a block image, a non-block image or a background image.

[0025] FIG. 9 is a block diagram of example object detect algorithm used by the protruding nail detection station illustrated in FIG. 5 for detecting protruding nails in a wooden pallet.

[0026] FIG. 10 is a flow diagram for training the object detect algorithm illustrated in FIG. 9.

[0027] FIGS. 11-13 are annotated images used to train the object detect algorithm illustrated in FIG. 9.

[0028] FIG. 14 is a flow diagram for operating the object detect algorithm illustrated in FIG. 9.

[0029] FIGS. 15-17 are image outputs from the object detect algorithm illustrated in FIG. 9.

[0030] FIG. 18 is a flow diagram for operating the pallet inspection system illustrated in FIG. 4.

Detailed Description

[0031] The present description is made with reference to the accompanying drawings, in which exemplary embodiments are shown. However, many different embodiments may be used, and thus the description should not be construed as limited to the particular embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete. Like numbers

refer to like elements throughout.

[0032] Nail defects in a pallet are a concern, particularly when the nail defect is a protruding nail. A protruding nail is when a tip of a nail is exposed. The form factor of a pallet is not affected, but the protruding nail needs to be detected during inspection of the pallet so the defect can be corrected.

[0033] Typically, when a worker manually handles a pallet, their hands are placed within one or more pockets on the pallet. Each side of the pallet has a pocket which is formed between the top and bottom decks that are separated by support blocks positioned therebetween. The worker could potentially be injured when their hand is placed within a pocket with a protruding nail.

[0034] Referring now to FIGS. 1-3, an example wooden pallet **10** will be discussed. The wooden pallet **10** is for discussion purposes on nail placement in general within a wooden pallet **10**. The wooden pallet **10** as illustrated is not to be limiting as other wooden pallet configurations are readily available.

[0035] The wooden pallet **10** includes a bottom deck **20**, a top deck **30**, and a plurality of wooden support blocks **40, 46** coupled between the bottom and top decks. The support blocks **40, 46** form a gap **50** (i.e., pockets) between the bottom and top decks **20, 30** for receiving a lifting member, such as fork lift tines.

[0036] The top deck **30** includes a pair of spaced apart wooden end deck boards **32**, and wooden intermediate deck boards **34** positioned between the end deck boards **32**. Also included within the top deck **30** are a pair of spaced apart wooden connector boards **36** and a wooden intermediate connector board **37**. The connector boards **36** and the intermediate connector boards **37** are orthogonal to the end deck boards **32** and the intermediate deck boards **34**. The end deck boards **32** and the intermediate deck boards **34** are positioned on the connector boards **36** and are directly coupled to the support blocks **40, 46** via nails **70**.

[0037] The bottom deck **20** includes bottom deck boards **22, 26** orientated in the same direction as the end deck boards **32** and the intermediate deck boards **34** in the top deck **30**. The bottom deck boards **22, 26** are also directly coupled to the support blocks **40, 46** via nails **70**.

[0038] The support blocks include corner support blocks **40** and center support blocks **46** between the corner support blocks **40**. In total, there are 9 support blocks **40, 46** positioned in rows of 3. The outer rows each include a pair of outer

support blocks **40** and a single center support block **46**, and the center row includes all center support blocks **46**. The actual number of support blocks may vary based on the configuration and size of the wooden pallet **10**.

[0039] The corner support blocks **40** and the center support blocks **46** each have a rectangular shape. In other configurations, one or more of the supports blocks **40, 46** may have a non-rectangular shape, such as a circular shape.

[0040] A partial cross-sectional view of the wooden pallet **10** is provided in FIG. 3 to illustrate placement of the nails **70** within the support blocks **40, 46**. When the wooden pallet **10** is formed, nails enter from the bottom and top decks **20, 30** into the support blocks **40, 46**.

[0041] A protruding nail **80** may occur when a nail operator places the nail **70** off center causing the tip **72** to be exposed. A protruding nail **80** may also occur when a nail **70** is driven into the location of an existing nail and bounces off the existing nail causing the tip **72** to be exposed. In other cases, wear and tear on the wooden pallet **10** may cause part of a support block **40, 46** to break off resulting in a nail tip **72** being exposed. A protruding nail **80** is not limited to protruding from support blocks **40, 46**. A protruding nail **80** may also protrude from other regions or areas of the pallet **10**, such as from one of the connector boards **36**, for example.

[0042] Detecting protruding nails **80** in a wooden pallet **10** is challenging. As will be described in detail below, cameras are used to collect images of each wooden pallet **10** during inspection. The images are sent to a processing unit for processing. The processing unit executes a machine learning object detection algorithm that has been trained to detect protruding nails **80**. How the algorithm is trained and executed will also be described in detail below. The processing unit may be a graphics processing unit (GPU), a central processing unit (CPU) or an edge computing device, for example.

[0043] An overview of a pallet inspection system **140** will be discussed with reference to FIG. 4. Pooled pallets **10** from different customers are returned to a pallet pooling company for inspection, and if necessary, repair, before the pallets **10** are returned to service.

[0044] Prior to inspection, the pallets **10** are provided to a stack in-feed **152**. The stack in-feed **152** squares each stack of pallets before being passed to a tipper/accumulator **154**. The tipper/accumulator **154** provides a steady stream of

spaced apart pallets **10** to a conveyor, for example. As the pallets **10** are moved on the conveyor, they pass through a preparation screening line **156**.

[0045] In the preparation screening line **156**, each pallet **10** is visually inspected by a human operator to remove any loose debris or trash that may affect inspection. If necessary, the human operator will also make minor repairs. In some cases, a pallet **10** may be discarded during the preparation screening line **156** if it is damaged too badly, as indicated by block **158**.

[0046] From the preparation screening line **156**, each pallet **10** is moved to a protruding nail detection station **140** for inspection. The pallets **10** are inspected for pallet classification, and to detect protruding nails **80**.

[0047] Pallet classification by the protruding nail detection station **160** is to determine if a pallet **10** being inspected belongs to the pallet pooling company operating the pallet inspection system **140**. A first set of cameras **162** within the protruding nail detection station **166** generate upper and lower images of each pallet **10**. The images may be video images or still images. The images may be in color or monochrome, and are provided to a processing unit **170.** The processing unit **170** executes a first algorithm for pallet classification **172**. The first algorithm may be a machine learning (ML) image classification algorithm, for example.

[0048] The image classification algorithm compares the generated image data to an expected profile. The expected profile is used for pallet classification. The image classification algorithm labels or tags each image as to whether or not the pallet **10** belongs to the pallet pooling company. For example, if 75 images were generated of the pallet **10**, and a majority of these images are tagged as belonging to the pallet pooling company, then the pallet **10** is classified as such.

[0049] The image classification algorithm associated with the first set of cameras **162** may also detect certain obvious nail defects, such as raised nails and free standing nails. In a raised nail, the head of the nail extends slightly above the top deck. A raised nail could potentially impact any product placed on the pallet. In a free standing nail, the head and body of the nail are visible but not the tip.

[0050] Protruding nail detection by the protruding nail detection station **160** is to determine a protruding nail **80** in a pallet **10**. A second set of cameras **164** within the protruding nail detection station **160** generate images of the sides of each pallet **10**. The images are in color, and are provided to the processing unit **170.**

Alternatively, the images may be monochrome. The processing unit **170** executes a second algorithm that is trained for detecting protruding nails **80**. The second algorithm may be a machine learning (ML) object detection algorithm, for example.

[0051] The pallet sort line **180** receives the pallets **10** as they exit the protruding nail detection station **160**. The pallet sort line **180** queries the processing unit **170** to determine pallet classification. If the inspected pallet **10** does not belong to the pallet pooling company operating the pallet inspection system **140**, then the pallet **10** is sent to a discard line **182**.

[0052] In the illustrated embodiment, the protruding nail detection station **160** includes first and second sets of cameras **162, 164**. In an alternative embodiment, the cameras may be combined such that the same set of cameras used for pallet classification are also used for protruding nail detection. That is, the cameras are not mutually exclusive.

[0053] Alternatively, if the inspected pallet **10** belongs to the pallet pooling company operating the pallet inspection system **140**, then the pallet sort line **180** queries the processing unit **170** to determine if the pallet **10** is good or bad.

[0054] If the inspected pallet **10** is bad, this means that the pallet requires repair and is sent to a repair line **184**. After repair, the pallet **10** is sent to a paint line **186** for painting before being returned to service. If the inspected pallet **10** is good, this means that the pallet does not require repair and is instead sent to the paint line **186** before being returned to service.

[0055] Referring to FIG. 5, operation of the protruding nail detection station **160** for detecting protruding nails **70** will be discussed. The conveyor **105** moves the pallet **10** through the protruding nail detection station **160** in the direction of the illustrated arrows. The conveyor **105** includes a first sensor **110** at the entrance of the protruding nail detection station **160**, and a second sensor **112** at the exit of the protruding nail detection station **160**. In other embodiments, a single sensor may be used. The first and second sensors **110, 112** may be configured as photoelectric sensors, for example. Each photoelectric sensor includes a transmitter and receiver on opposite sides of the conveyor **105**. The transmitter transmits a light signal, which may be visible or infrared, to the receiver. The pallet **10** is detected when the light beam is blocked from getting to the receiver from the transmitter.

[0056] Output from the first and second sensors **110, 112** is provided to a

controller **130**. In response to receiving an output from the first and second sensors **110, 112**, the controller **130** is configured to trigger the second set of cameras **164** as the pallet is being moved on the conveyor **105**. The second set of cameras **164** are divided into a first camera set **164(1), 164(2)** and a second camera set **164(1), 164(2)**.

[0057] The cameras in the first camera set **164(1), 164(2)** are triggered by the first sensor **110**. In response to the first sensor **110** detecting arrival of the pallet **10**, a first stopper **111** in the path of the pallet **10** is dropped below the conveyor **105** to allow the pallet **10** to enter the protruding nail detection station **160**. As the pallet **10** enters the protruding nail detection station **160**, the controller **130** activates or triggers the cameras in the first camera set **164(1), 164(2)** to provide images to the processing unit 170 for processing.

[0058] The images generated by the first camera set **164(1), 164(2)** are a subset of the overall images received by the GPU **170** for the pallet **10**. The remaining images received by the processing unit **170** are generated by the second camera set **164(3), 164(4)**.

[0059] The cameras in the first camera set **164(1), 164(2)** are positioned to view a front perspective of the support blocks **40, 46**. The cameras in the second camera set **164(3), 164(4)** are positioned to view a rear perspective of the support blocks **40, 46**. Collectively, the combined images are of all sides of each support block **40, 46**.

[0060] The cameras in the second camera set **164(3), 164(4)** are triggered by the second sensor **112**. In response to the second sensor **112** detecting exit of the pallet **10**, a second stopper **113** in the path of the pallet **10** is dropped below the conveyor **105** to allow the pallet **10** to exit the protruding nail detection station **160**. As the pallet **10** exits the protruding nail detection station **160**, the controller **130** activates or triggers the cameras in the second camera set **164(3), 164(4)** to provide images to the processing unit 170 for processing.

[0061] Having two different triggers insures that a complete set of images of the support blocks **40, 46** are acquired. If the first and second camera sets **164(1)-164(4)** were to be triggered at the same time by a single photoelectric sensor, and the conveyor **105** becomes jammed causing the pallet **10** to stop moving, then images on the rear perspective view of the support blocks **40, 46** would not be

provided to the processing unit **170**.

[0062] The first camera set **164(1), 164(2)** includes 6 cameras, and the second camera set **164(3), 164(4)** also includes 6 cameras. Half of the cameras are on each side of the conveyor **105**. Even though 12 cameras are being used, a different number of cameras may be used in other embodiments.

[0063] The support blocks **40, 46** in each pallet **10** are spaced apart to form a pair of outer rows and a center row therebetween. The illustrated pallet includes 9 support blocks **40, 46** with 3 support blocks **40, 46** in each row. Each row is parallel with the conveyor **105**. Each of the outer rows includes a pair of corner support blocks **40** and a center support block **46**. The center row includes center support blocks **46** only.

[0064] Each camera in the first and second camera sets **164(1)-164(4)** is focused on a particular row of support blocks. For example, camera group **164(1)** includes 3 cameras. A first camera is focused on the outer row of support blocks **40, 46** closet to the camera group **164(1)**. A second camera is focused on the center row of support blocks **46**. A third camera in focused on the outer row of support blocks **40, 46** farthest from the camera group **164(1)**. Similarly, each camera in camera group **164(2)** on the opposite side of the conveyor **105** is focused on a particular row of support blocks **40, 46**.

[0065] As noted above, the cameras in the first camera set **164(1), 164(2)** are positioned to view a front perspective of the support blocks **40, 46**. There is typically a delay between the 6 cameras in camera groups **164(1), 164(2)** on when the support blocks **40, 46** in a particular row are in focus.

[0066] The pair of cameras focused on the outer row of support blocks **40, 46** closet to each respective camera come into focus first. This pair of cameras may be immediately triggered in response to the first sensor **110** detecting arrival of the pallet **10**. The pair of cameras focused on the center row of support blocks **46** come into focus next since the center support blocks **46** are further away from the cameras. Consequently, this pair of cameras may be delayed 25 milliseconds, for example, before being triggered by the controller **130** to generate images. The pair of cameras focused on the outer row of support blocks **40, 46** farthest away come into focus next after the support blocks **46** in the center row come into focus since they are the farthest away from the cameras. Consequently, this pair of cameras

may be delayed 50 milliseconds, for example, before being triggered by the controller **130** to generate images. Once a camera is triggered to provide images to the processing unit **170**, the trigger lasts a predetermined time period. The predetermined time period may between 3 to 4 seconds, for example, and may be varied based on the speed of the conveyor **10**.

[0067] The cameras in the second camera set **164(3), 164(4)** are configured similar to the cameras in the first camera set **164(1), 164(2)**. Each camera in the second camera set **164(3), 164(4)** is likewise focused on a particular row of support blocks. As noted above, the cameras in the second camera set **164(3), 164(4)** are positioned to view a rear perspective of the support blocks **40, 46**.

[0068] In response to the second sensor **112** detecting exit of the pallet **10** from the protruding nail detection station **160**, the controller **130** may immediately trigger the pair of cameras focused on the outer row of support blocks **40, 46** closet to the respective cameras, and delay triggering of the pair of cameras focused on the center row of support blocks **46** and the pair of cameras focused on the outer row of support blocks **40, 46** farthest away from the respective cameras.

[0069] Operation of the processing unit **170** to detect protruding nails **80** from the received images is a two-step process. A first step is to determine the images having a support block **40, 46** therein that is in focus by one of the cameras. A second step is to analyze only the images having a focused support block **40, 46** therein for protruding nails **80**.

[0070] The rational for determining the images with support blocks that are in focus is that a protruding nail **80** will be adjacent a support block **40, 46** since the nails **70** are driven into the support blocks **40, 46**. The number of images to be analyzed for protruding nails **80** is significantly reduced by the first step.

[0071] Each camera may generate about 40 images per pallet **10**. With 12 cameras, this corresponds to about 480 images per pallet. The actual number of images generated is variable, and can change from one deployment site to another. The processing unit **170** executes a first algorithm on the 480 images. The first algorithm may be an image classification algorithm **132**, for example. The image classification algorithm **132** is trained using artificial intelligence (AI) and machine learning (ML) to determine images with focused support blocks **40, 46** therein.

[0072] If an image has a focused support block **40, 46** therein, it is tagged by

the image classification algorithm **132**. The image classification algorithm **132** functions as a pre-filter on the images provided by the second set of cameras **164** to the processing unit **170**.

[0073] The tagged images are provided to a second algorithm, which may be an object detect algorithm **134**, for example. The images that are not tagged are not passed to the object detect algorithm **134**. As an example, out of the 480 images, about one-half to one-third of the images may not be tagged.

[0074] Execution of the object detect algorithm **134** is computationally more extensive then execution of the image classification algorithm **132**. Reducing the number of images to be executed by the object detect algorithm **134** simplifies the overall processing to determine protruding nails **80**.

[0075] The image classification algorithm **132** is trained to classify each image as a block image, a non-block image, or a background image. A block image corresponds to a support block **40, 46** that is in focus. A non-block image corresponds to a support block **40, 46** this is out-of-focus. A background image corresponds to neither a support block **40, 46** that is in focus or a support block **40, 46** that is out-of-focus.

[0076] Referring now to FIGS. 6-8, images generated by the protruding nail detection station **160** that have been classified by the image classification algorithm **132** will be discussed. The image **200** in FIG. 6 is a block image since the support block **40** is in focus. The image **202** in FIG. 7 is a non-block image since the support block **40** is out-of-focus. The image **204** in FIG. 8 is a background image since an in focus or out-of-focus support block is not visible. A background image is typically generated when the pallet **10** first arrives at the protruding nail detection station **160**, and when the pallet **10** exits the protruding nail detection station **160**.

[0077] The image classification algorithm **132** uses percentages to classify each image. The classification percentage varies as the pallet moves **10** on the conveyor **105**. The classification percentages are displayed for each image and are to total 100%. A percentage number is assigned by the image classification algorithm **132** to each of the three possible classifications. In response to a classification percentage being over a threshold, such as 75%, for example, the image classification algorithm **132** will classify the image accordingly.

[0078] In image **200**, classification as a block image is 100% whereas

classification as a non-block image or a background image are each 0%. In image **202**, a non-block image is classified as 99.9511%, whereas classification as a block image is 0.0333% and as a background image as 0.0156%. In image **204**, a background image is classified as 82.796%, whereas classification as a non-block image is 17.0867% and as a block image as 0.1173%. In this image **204**, the pallet **10** is partially visible as it is exiting the protruding nail detection station **160**.

[0079] The tagged images that have a focused support block **40, 46** will be generally referred to as tagged images **200**. These images are passed to the object detect algorithm **134** for processing. Instead of tagging the images, the object detect algorithm **134** is trained to locate objects within the tagged images **200**. The objects to be located are support blocks and visible nails overlapping with the support blocks. The visible nails **70** may be protruding nails **80** or may be nails **70** where the body of the nail is visible but not the tip.

[0080] As will be discussed below, the object detect algorithm **134** is trained using annotated images that include a number of different categories that are to be detected, where each category corresponds to a particular type object to be detected and located. By learning the different categories, the object detect algorithm **134** will be able to differentiate between a protruding nail that is to be corrected and other types of nail defects that do not need to be corrected. The different categories provide contextual details to the object detect algorithm **134**.

[0081] The object detect algorithm **134** may operate based on artificial intelligence (AI) and machine learning (ML) to determine objects within the images **200** having the focused support blocks **40, 46** therein. In one example, the object detect algorithm **134** may be a single shot detector (SSD) **210** as illustrated in FIG. 9. Other types of object detectors may be used as an alternative to the illustrated SSD **210**. In the SSD **210**, only one single shot is taken of the image **200** to detect multiple objects within the image **200**. The SSD **210** is an open source algorithm modified to detect protruding nails **80**.

[0082] A SSD **210**, in general, has a base VGG-16 network **212** followed by multibox convolution layers **214, 216**. The base VGG-16 network **212** is used to extract features within an image **200**. Convolutional layers **214** are for detection, and convolutional layers **216** help with detection of objects at multiple scales since these layers decrease in size progressively. The convolutional model for detection is

different for each feature layer.

[0083] The multibox convolution layers **214, 216** are applied to multiple feature maps from the later stages of a network. This helps perform detection at multiple scales. Prediction for the bounding boxes and confidence for different objects in the image **200** is done not by one but by multiple feature maps of different sizes that represent multiple scales.

[0084] The problem of detecting protruding nails can be addressed in different ways. One way is to use object detection using bounding boxes, as will be discussed below. In another way, a segmentation approach to segment pixels may be used to define a contour of protruding nail pixels in an image. In yet another way, the algorithm may be trained to detect regions using both bounding boxes and segmentation pixels.

[0085] Referring now to the flow diagram **250** in FIG. 10, training of the object detect algorithm **134** will be discussed. From the start (Block **252**), a database of images of pallets **10** with protruding nails **70** and other nail defects is created at Block **254**. The number of pallets **10** may be rather large, such as 100 or more, for example. The images from all 12 cameras for each pallet **10** are collected and stored in the database. There are about 480 images associated with each pallet **10**.

[0086] The different categories that are to be detected are defined at Block **256**. These categories include support blocks, protruding nails, partially visible nails, clinched nails, free standing nails, and splinters. Other types of categories may be defined to help the object detect algorithm **134** detect protruding nails **80**.

[0087] The images in the database are annotated at Block **258** to reflect the different categories to be detected. Each image is manually reviewed, and if the image has a category that is to be detected by the object detect algorithm **134**, then the image is annotated with a bounding box and labeled accordingly.

[0088] Example images that have been annotated are provided in FIGS. 11-13. A green bounding box **202** is placed around each support block **40, 46**. For protruding nails **80**, a red bounding box **204** is used. In response to a detected nail not being a protruding nail, a yellow bounding box is used. In FIG. 12, for example, a yellow bounding box **206** is placed around a nail **70** having the body of the nail being visible but not the tip. The support block **40** in FIG. 13 is splintered resulting in a pair of protruding nails 80 being visible.

[0089] Detecting splintered support blocks is helpful. At times it could be hard to differentiate between a splintered support block and a nail that has been colored. Normally, the nail would appear as a gray/block color. However, if the splintered support block was not detected earlier and the pallet was sent to paint, now the exposed nail is painted the same color as the block.

[0090] In addition to detecting nail defects and splintered support blocks, the images may be annotated for identifying other types of defects. The images may be annotated for detecting stickers and stretch wrap, for example, that remain on the pallet **10**. Normally, each pallet **10** is visually inspected by a human operator to remove any loose debris or trash that may affect inspection. Adding sticker and shrink wrap detection helps to identify such areas that may not be caught during the visual inspection of each pallet **10**.

[0091] A model is trained at Block **260** using machine learning to learn a function that produces mappings between the annotated images and the different categories to be detected. In some embodiments, the machine learning may be based on a neural network to train the model. In other embodiments, a neural network is not used to train the model. Since a neural network based model/algorithm or another type of non-neural network based model/algorithm may be used, we are not limited to a single or a set of algorithms.

[0092] The output data from the model is analyzed at Block **262**. The model is optimized at Block **264** based on the analyzed output data. The method ends at Block **266**

[0093] Referring now to the flow diagram **300** in FIG. 14, operating the object detect algorithm **134** will be discussed. From the start (Block **302**), images of pallets **10** to be inspected are received at Block **304**. The images are the images **200** that were tagged by the image classification algorithm **132** as having a focused support block **40, 46** therein.

[0094] At Block **306**, the method includes executing a machine learning model that has been trained to learn a function that produces mappings between annotated images of pallets **10** with protruding nails **80** and other nail defects to be detected. The annotated images correspond to the different categories to be detected, as discussed above.

[0095] Detected objects corresponding to the different categories to be

detected in the images **200** are identified by location at Block **308**. A bounding box is placed around each identified object. Example images that have detected objects are provided in FIGS. 15-17.

[0096] In the image **320** in FIG. 15, a bounding box **330** is placed around the support block **46**. The support block **46** has been detected even though a chunk of wood has been removed. For the protruding nails **80**, separate bounding boxes **332, 334** are used. Similarly, in the image **322** in FIG. 16, a bounding box **336** is placed around the splintered support block **46**. For the protruding nails **80**, separate bounding boxes **338, 340** are used.

[0097] As another example, in the image **324** in FIG. 17, a bounding box **342** is placed around the splintered support block **46**. A pair of clinched nails **71** have been detected where the tips are exposed. In this case, bounding boxes **344, 346** are placed around the clinched nails **71**. The body of a nail **70** is visible within the image **324**, but since the tip of the nail is not exposed, this nail is ignored.

[0098] For each bonding box, a location in pixels is determined by the object detect algorithm **134**. For example, the image **320** in FIG. 15 is 1,000 pixels by 1,000 pixels. The 0, 0 coordinates, for example, are at the bottom left of the image **320**. The x-axis of the bounding box **330** around the support block **46** starts at 250 pixels, and the y-axis of the bounding box **330** starts at 100 pixels. A width and height of the bounding box **330** is then determined.

[0099] Similarly, for the bounding box **334** indicating a protruding nail **80**, the x-axis starts at 720 pixels, and the y-axis of the bounding box **334** starts at 110 pixels. A width and height of the bounding box **334** is then determined. This is performed for each bounding box.

[00100] The method further includes providing confidence values at Block **310** for the categories that were detected in the received images **322, 322, 324**. The confidence value for each of the support blocks is 99%. The confidence value also has the detected category associated therewith. The work “block” is used to indicate a support block **40, 46**.

[00101] A “protruding nail” label and a confidence value of each detected protruding nail are also provided. With the object detect algorithm **134** having been trained to contextual observe each image, protruding nails **80** typically have a high confidence value. In the examples, the confidence vales range from 87% to 99%.

For the clinched nails **71** in the image **324**, a “clinch nail” label and a confidence value are provided.

[00102] The pallets **10** with protruding nails **80** are identified based on the confidence values at Block **312**. If the confidence value is above a threshold, such as 75%, then each bounding box is labeled accordingly. The method ends at Block **314**.

[00103] Another aspect is directed to a method for operating the pallet inspection system **140** as described above. Referring now to the flow diagram **350** in FIG. 18, from the start (Block **352**), the method includes operating a conveyor **105** at Block **354** to move a pallet **10** that is to be inspected. As described above, the pallet **10** includes a top deck **30** and a bottom deck **20** separated by a plurality of spaced apart support blocks **40, 46** positioned therebetween. Nails **70** are used to secure the top and bottom decks **30, 20** to the support blocks **40, 46**.

[00104] Cameras **162, 164** positioned adjacent the conveyor **105** are operated at Block **356** to generate images of the pallet **10** as the pallet **10** is moved on the conveyor **105**. The images are received by the processing unit **170** at Block **358** for processing.

[00105] The processing includes executing a first algorithm **132** at Block **360** on the images to tag the images having support blocks **40, 46** visible therein. At Block **362**, a second algorithm **134** is executed on the tagged images to detect nails **70** having exposed tips **72**. The first algorithm **132** is an image classification algorithm, and the second algorithm **134** is an object detection algorithm. The method ends at Block **364**.

[00106] Many modifications and other embodiments will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the foregoing is not to be limited to the example embodiments, and that modifications and other embodiments are intended to be included within the scope of the appended claims.

CLAIMS:

1. A pallet inspection system comprising:

a conveyor configured to move a pallet that is to be inspected, the pallet comprising a top deck and a bottom deck separated by a plurality of spaced apart support blocks positioned therebetween, with nails being used to secure the top and bottom decks to the plurality of support blocks;

a plurality of cameras positioned to generate images of the pallet as the pallet is moved on said conveyor; and

a processor coupled to said plurality of cameras and configured to receive the images for processing, the processing comprising

executing a first algorithm on the images to tag the images having support blocks visible therein, and

executing a second algorithm on the tagged images to detect nails having exposed tips.

2. The pallet inspection system according to Claim 1 further comprising a first sensor positioned before the plurality of cameras, and a second sensor positioned after the plurality of cameras, and wherein said processor is configured to

receive a first set of images of the pallet in response to the first sensor being activated; and

receive a second set of images of the pallet in response to the second sensor being activated.

3. The pallet inspection system according to Claim 2 wherein the first and second sensors comprise photoelectric sensors.

4. The pallet inspection system according to Claim 1 wherein the first and second algorithms are executed by said processor so that nails having exposed tips are detected in real time.

5. The pallet inspection system according to Claim 1 wherein the plurality of support blocks are spaced apart to form a pair of outer rows and a center

row therebetween, with the outer rows including corner support blocks, and wherein each camera is in focus on the support blocks in one of the rows and out-of-focus on the support blocks in the other rows.

6. The pallet inspection system according to Claim 1 wherein said plurality of cameras are divided into first and second camera sets, with the first camera set being directed toward an entrance of the pallet inspection system station, and the second camera set being directed toward an exit of the pallet inspection system station.

7. The pallet inspection system according to Claim 6 wherein the first camera set provides a front perspective of the plurality of support blocks, and the second camera set provides a rear perspective of the plurality of support blocks, with the first and second camera sets collectively providing images on all sides of each support block.

8. The pallet inspection system according to Claim 6 wherein the first camera set includes cameras adjacent each side of the conveyor, and the second camera set includes cameras adjacent each side of the conveyor.

9. The pallet inspection system according to Claim 1 wherein each camera is configured as a color camera.

10. The pallet inspection system according to Claim 1 wherein the first algorithm comprises an image classification algorithm, and the second algorithm comprises an object detection algorithm.

11. The pallet inspection system according to Claim 10 wherein the image classification algorithm is configured to classify each image as one of the following:

a block image corresponding to a support block being in focus;

a non-block image corresponding to a support block being out-of-focus; or

a background image corresponding to neither a support block being in

focus or a support block being out-of-focus; and

with the block images being tagged by the image classification algorithm.

12. The pallet inspection system according to Claim 11 wherein the object detection algorithm is configured to place a bounding box around the support block in each block image, and in response to an exposed nail tip being detected, place a bounding box around the exposed nail tip.

13. The pallet inspection system according to Claim 11 wherein the object detection algorithm is configured to detect other nail defects in addition to nails having exposed tips, with the other nail defects being ignored by said processor.

14. A method for operating a pallet inspection station comprising:

operating a conveyor to move a pallet that is to be inspected, the pallet comprising a top deck and a bottom deck separated by a plurality of spaced apart support blocks positioned therebetween, with nails being used to secure the top and bottom decks to the plurality of support blocks;

operating a plurality of cameras positioned to generate images of the pallet as the pallet is moved on the conveyor; and

receiving the images for processing, the processing comprising

executing a first algorithm on the images to tag the images having support blocks visible therein, and

executing a second algorithm on the tagged images to detect nails having exposed tips.

15. The method according to Claim 14 wherein the pallet inspection station further comprises a first sensor positioned before the plurality of cameras, and a second sensor positioned after the plurality of cameras, the method further comprising:

receiving a first set of images of the pallet in response to the first sensor being activated; and

receiving a second set of images of the pallet in response to the

second sensor being activated.

16. The method according to Claim 14 wherein the plurality of support blocks are spaced apart to form a pair of outer rows and a center row therebetween, with the outer rows including corner support blocks, and wherein each camera is in focus on the support blocks in one of the rows and out-of-focus on the support blocks in the other rows.

17. The method according to Claim 14 wherein the first algorithm comprises an image classification algorithm, and the second algorithm comprises an object detection algorithm.

18. The method according to Claim 17 wherein the image classification algorithm is configured to classify each image as one of the following:

a block image corresponding to a support block being in focus;

a non-block image corresponding to a support block being out-of-focus; or

a background image corresponding to neither a support block being in focus or a support block being out-of-focus; and

with the block images being tagged by the image classification algorithm.

19. The method according to Claim 17 wherein the object detection algorithm is configured to place a bounding box around the support block in each block image, and in response to an exposed nail tip being detected, place a bounding box around the exposed nail tip.

20. A method for training an object detect algorithm comprising:

creating a database of images of pallets with protruding nails and other nail defects;

defining different categories that are to be detected in the database;

annotating the images in the database corresponding to the different categories to be detected;

training a model using machine learning to learn a function that produces mappings between the annotated images and the different categories to be detected;

analyzing the output data from the model; and

optimizing the model based on the analyzed output data.

21. The method according to Claim 20 wherein the defined different categories to be detected comprise at least one of support blocks, protruding nails, partially visible nails, clinched nails, free standing nails, and splintered support blocks.

22. The method according to Claim 20 wherein the annotating comprises placing a respective bounding box around each defined category appearing in the images.

23. A method for operating an object detect algorithm comprising:

receiving images of pallets to be inspected;

executing a machine learning model trained to learn a function that produces mappings between annotated images of pallets with protruding nails and other nail defects to be detected, with the annotated images corresponding to different categories to be detected;

identifying objects by location in the received images corresponding to the different categories to be detected;

providing confidence values for the categories that were detected in the received images; and

identifying the pallets with protruding nail based on the confidence values.

24. The method according to Claim 23 wherein identifying an object by location comprises placing a bounding box around the object.

25. The method according to Claim 23 further comprising labeling each detected category along with providing the confidence values.

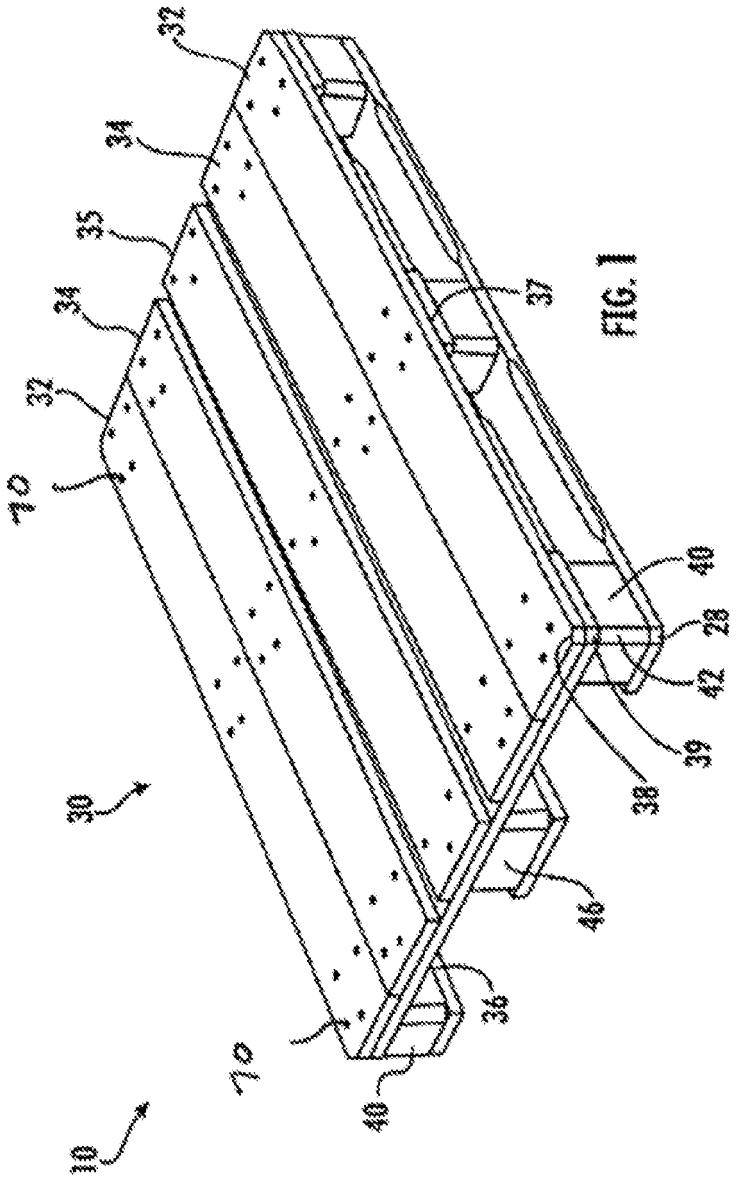

FIG. 1

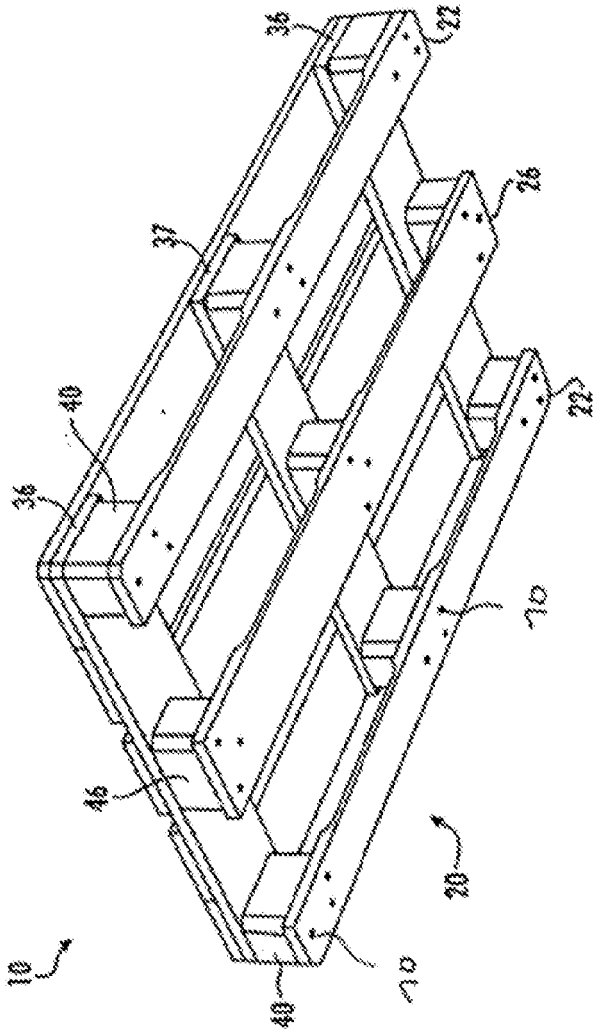

FIG. 2

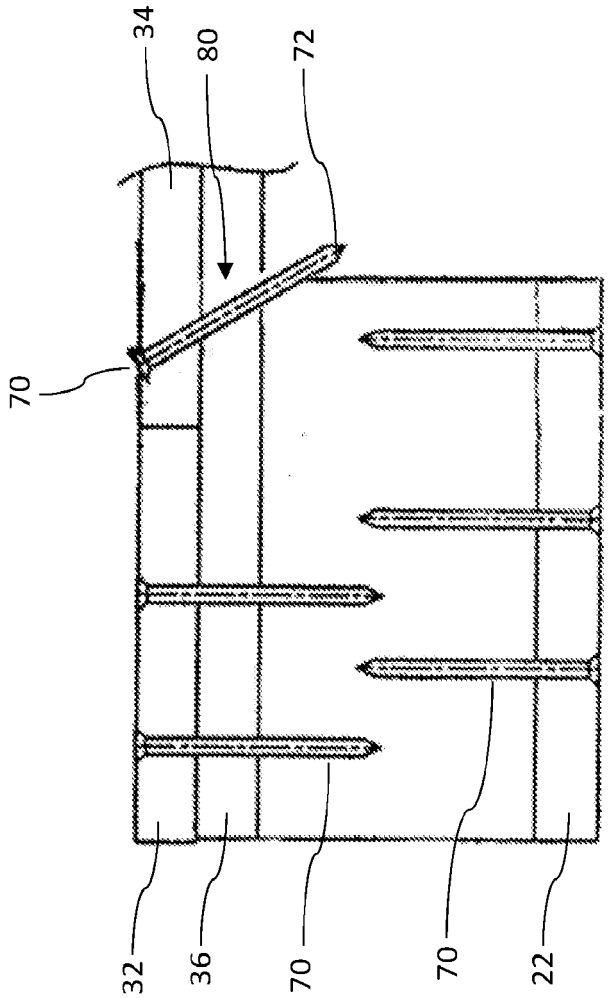

FIG. 3

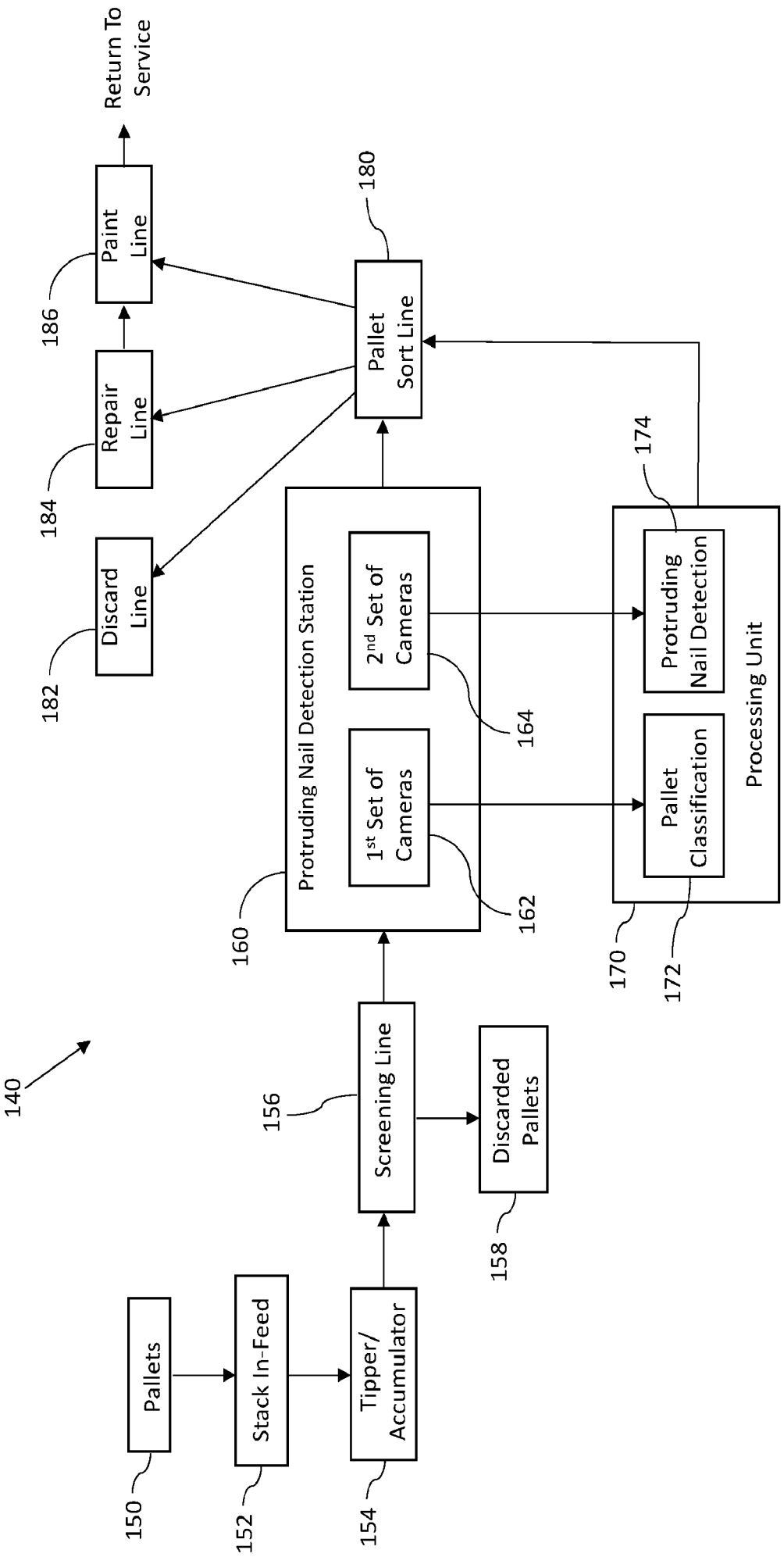
140
Pallets
150
Stack In-Feed
152
Tipper/ Accumulator
154
Screening Line
156
Discarded Pallets
158
Protruding Nail Detection Station
160
1st Set of Cameras
162
2nd Set of Cameras
164
Processing Unit
170
Pallet Classification
172
Protruding Nail Detection
174
Pallet Sort Line
180
Discard Line
182
Repair Line
184
Paint Line
186
Return To Service

FIG. 4

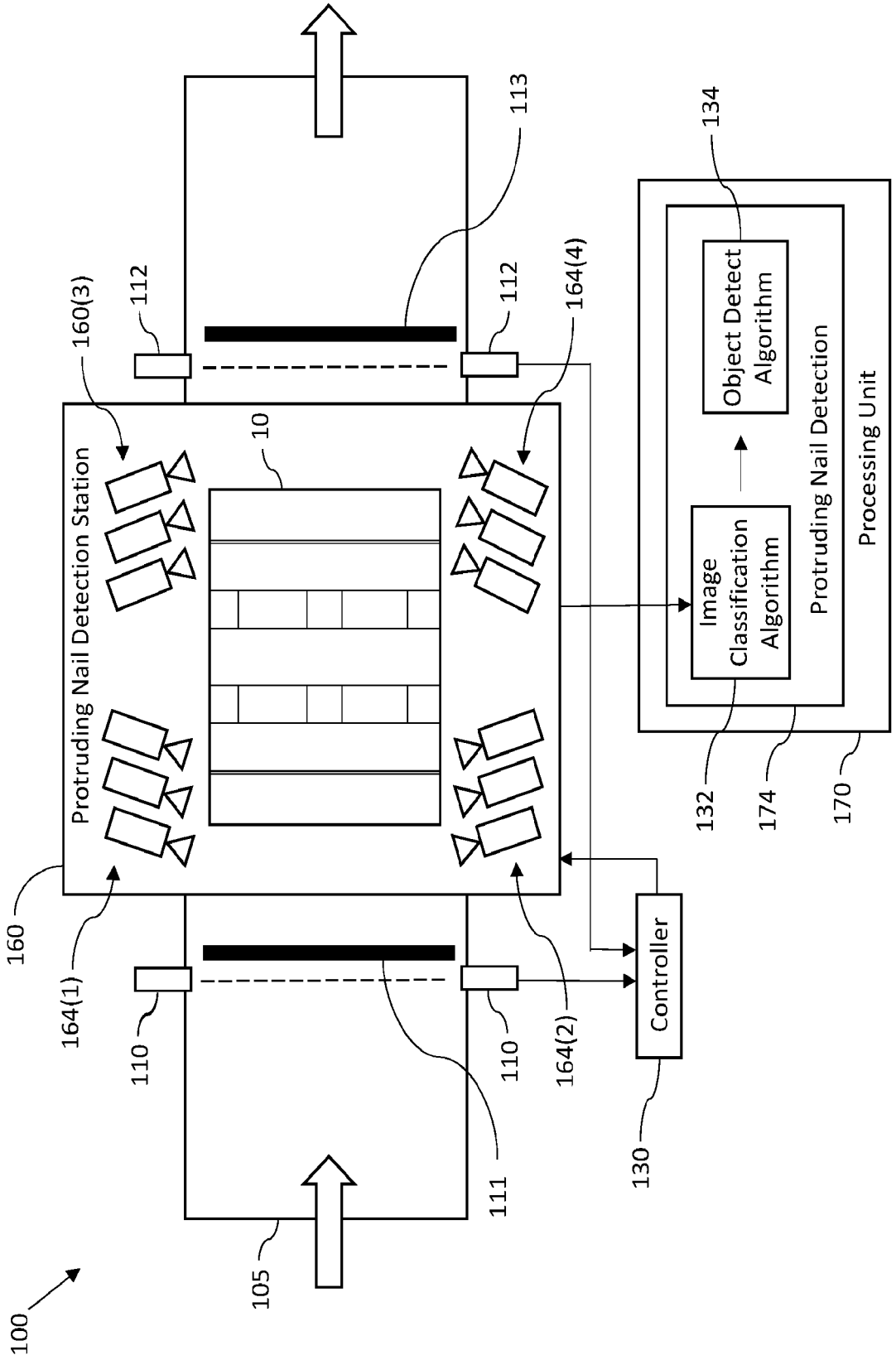
100
105
111
130
Controller
110
110
164(1)
164(2)
160
Protruding Nail Detection Station
10
160(3)
112
112
113
164(4)
132
Image Classification Algorithm
174
Protruding Nail Detection
Object Detect Algorithm
134
170
Processing Unit

FIG. 5

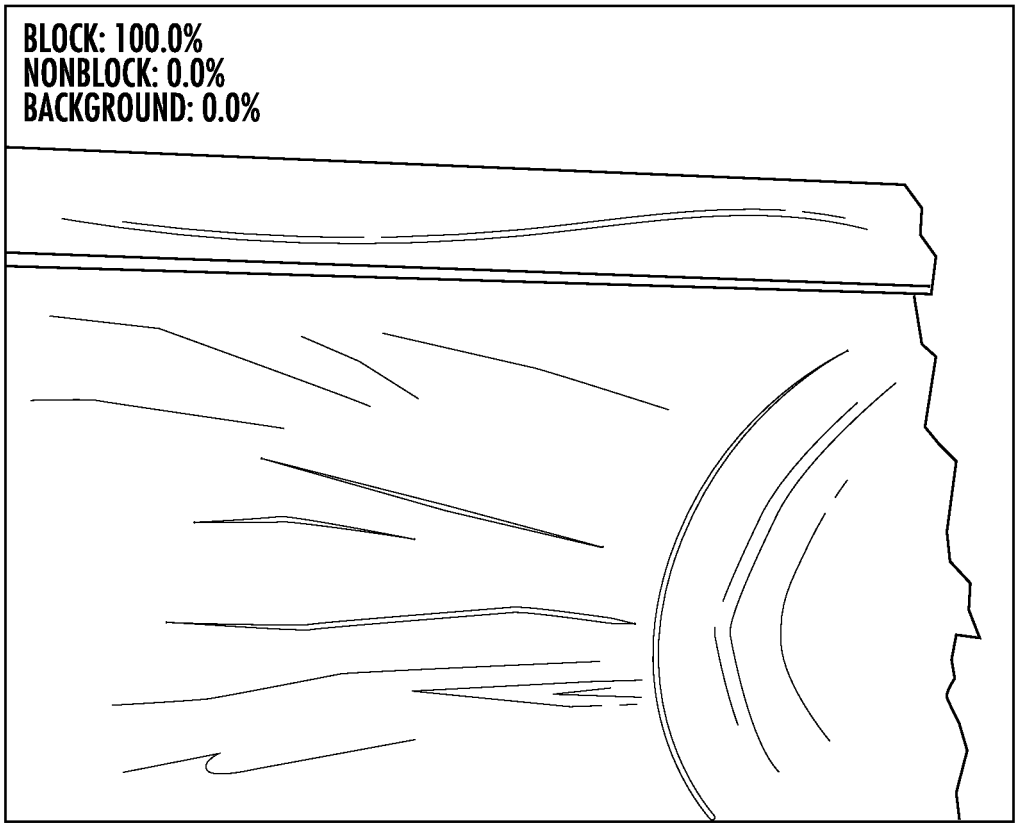

FIG. 6

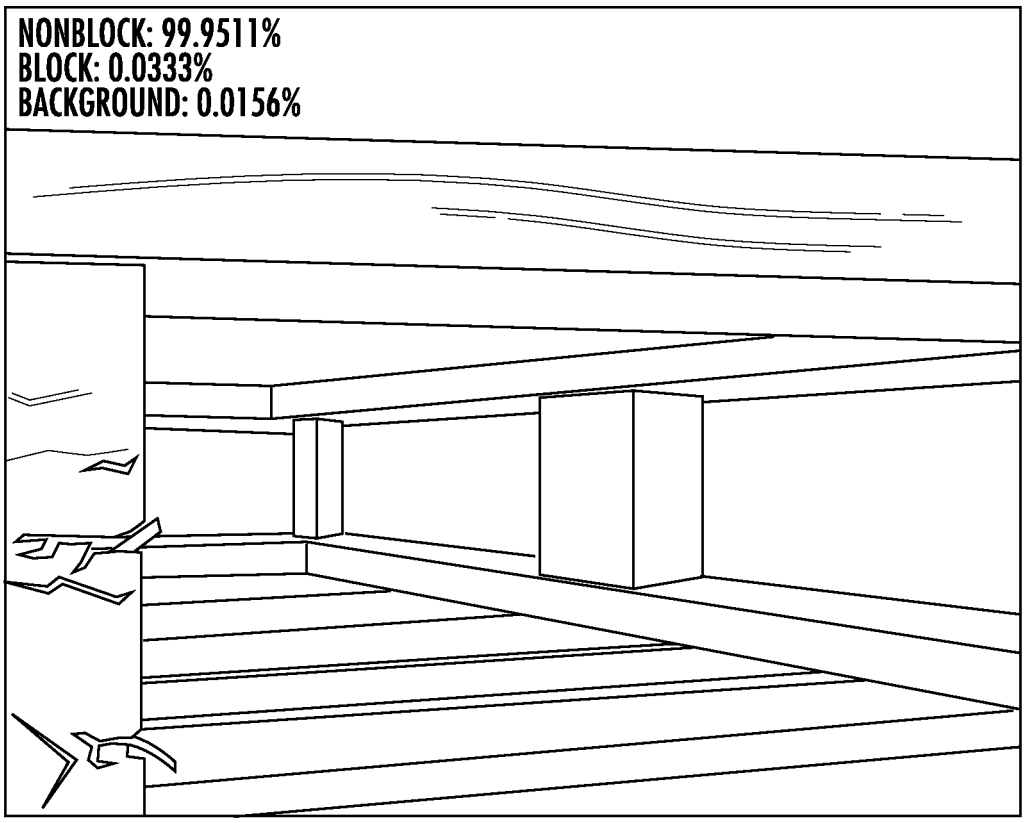

FIG. 7

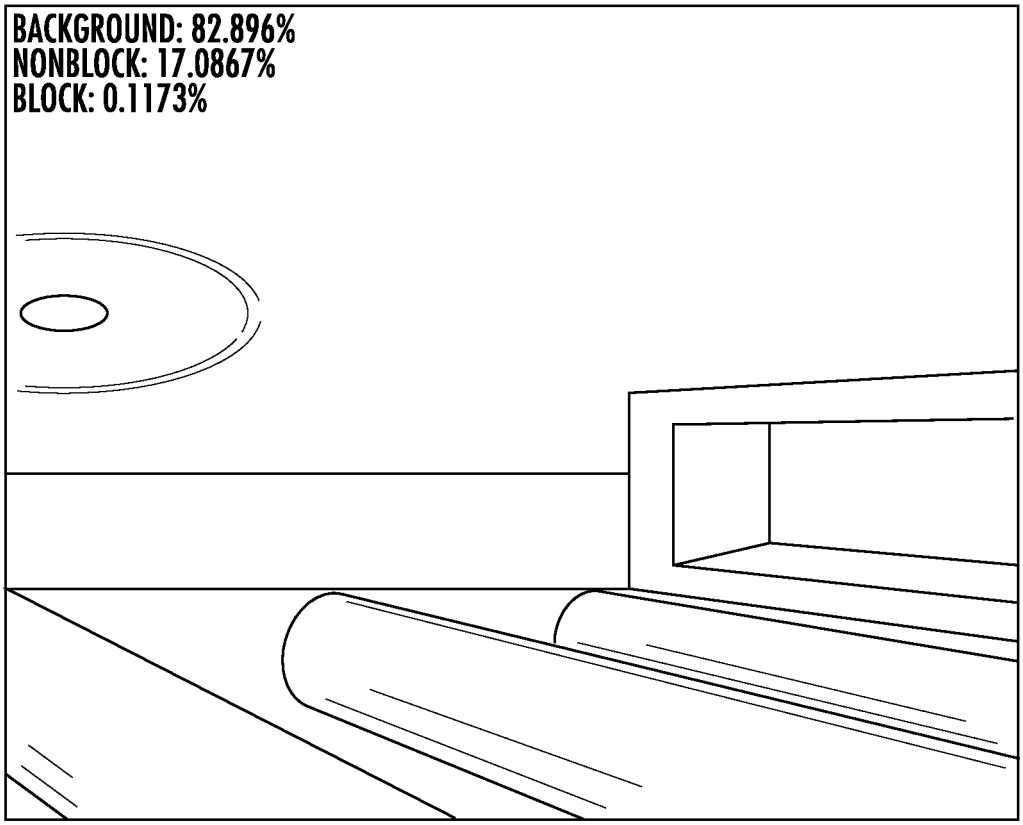

FIG. 8

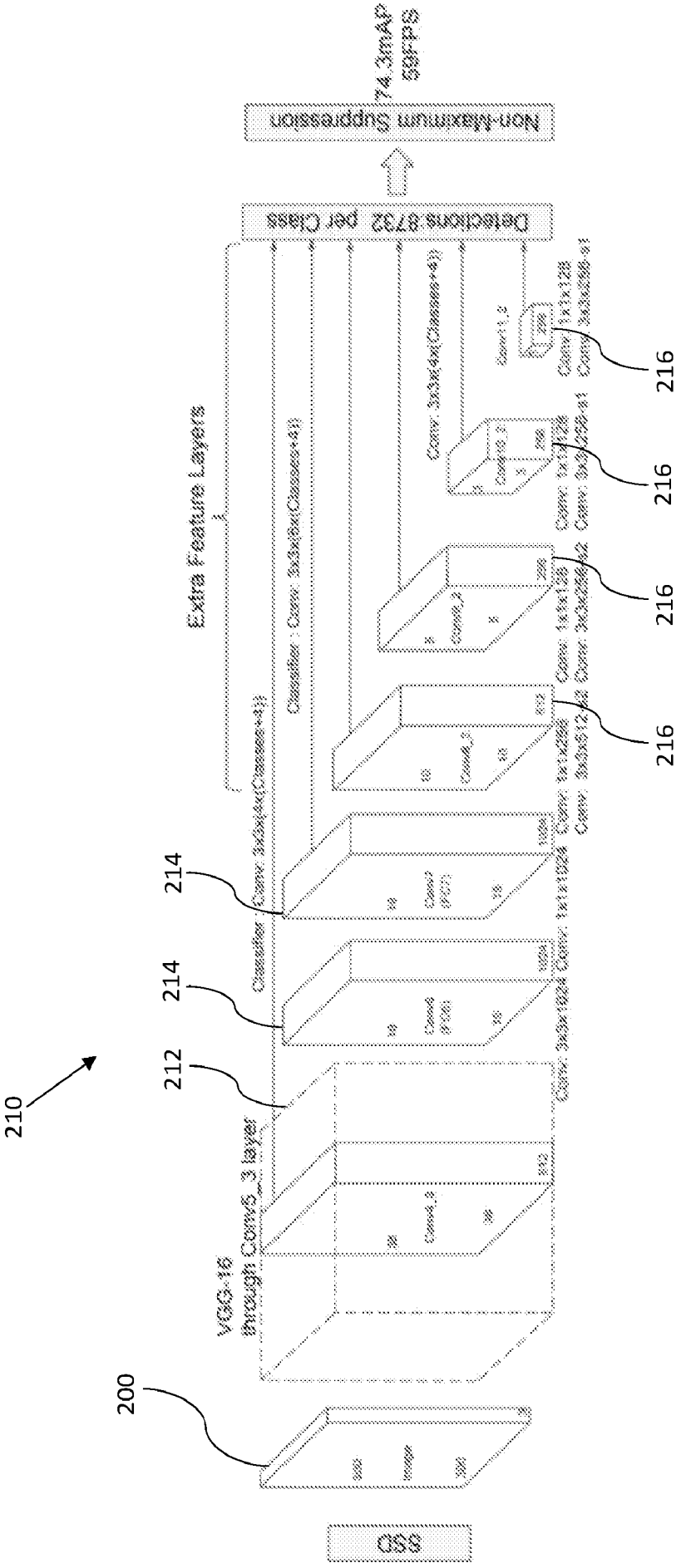
74.3mAP
59FPS
Non-Maximum Suppression
Detections 8732 per Class
Extra Feature Layers
Classifier : Conv: 3x3x4x(Classes+4))
Conv: 3x3x1024
Conv: 1x1x1024
Conv: 1x1x256
Conv: 3x3x512-s2
Conv: 1x1x128
Conv: 3x3x256-s2
Conv: 3x3x256-s1
Conv: 1x1x128
Conv: 3x3x256-s1
VGG-16
through Conv5_3 layer
300
300
3
CSS
200
210
212
214
214
216
216
216
216

FIG. 9

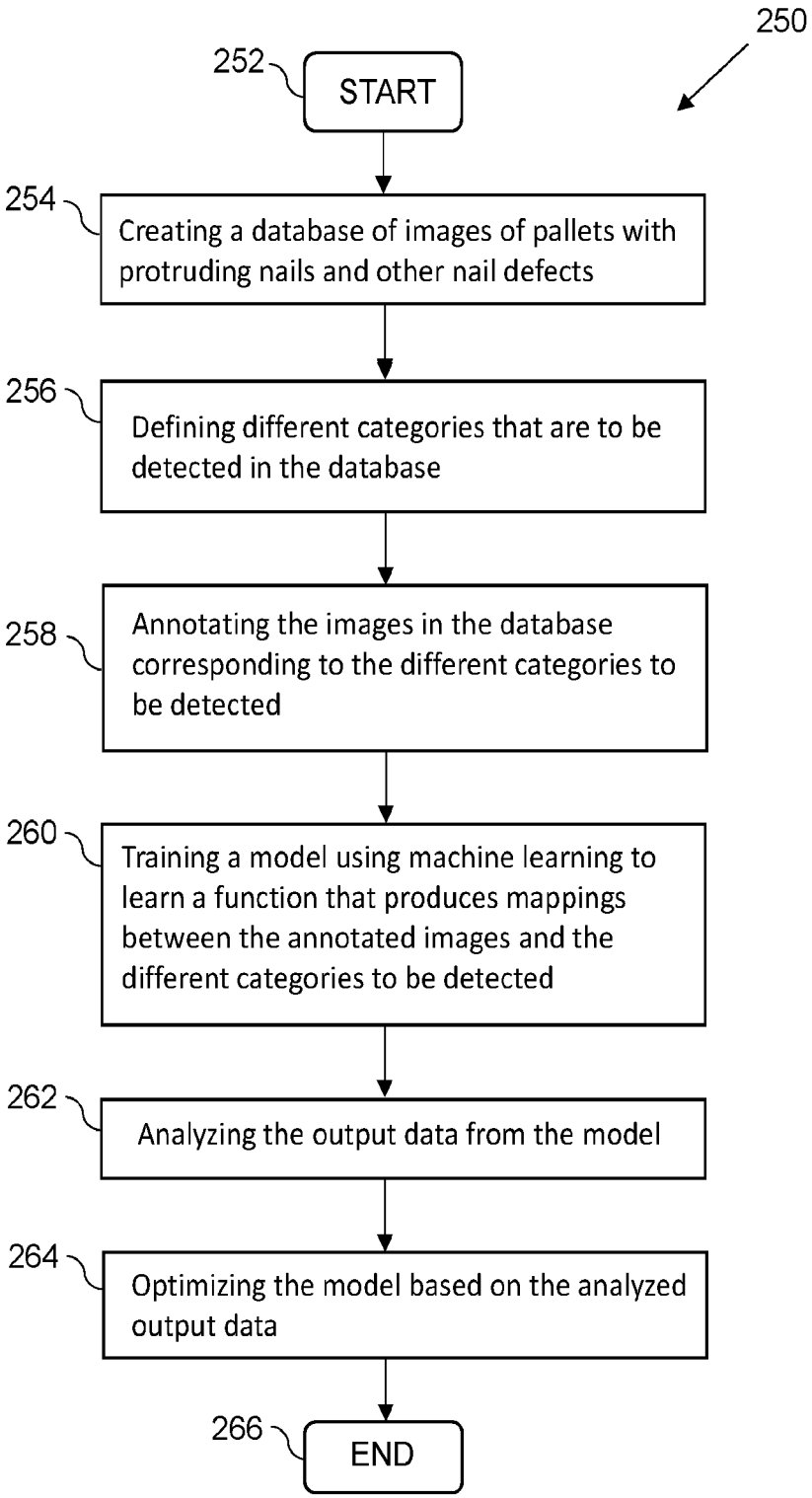
250
252
START
254
Creating a database of images of pallets with protruding nails and other nail defects
256
Defining different categories that are to be detected in the database
258
Annotating the images in the database corresponding to the different categories to be detected
260
Training a model using machine learning to learn a function that produces mappings between the annotated images and the different categories to be detected
262
Analyzing the output data from the model
264
Optimizing the model based on the analyzed output data
266
END

FIG. 10

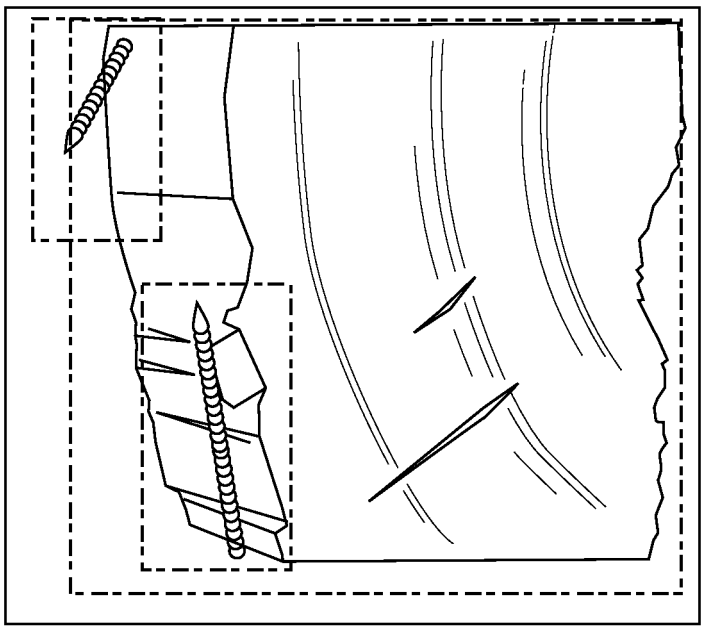

FIG. 11

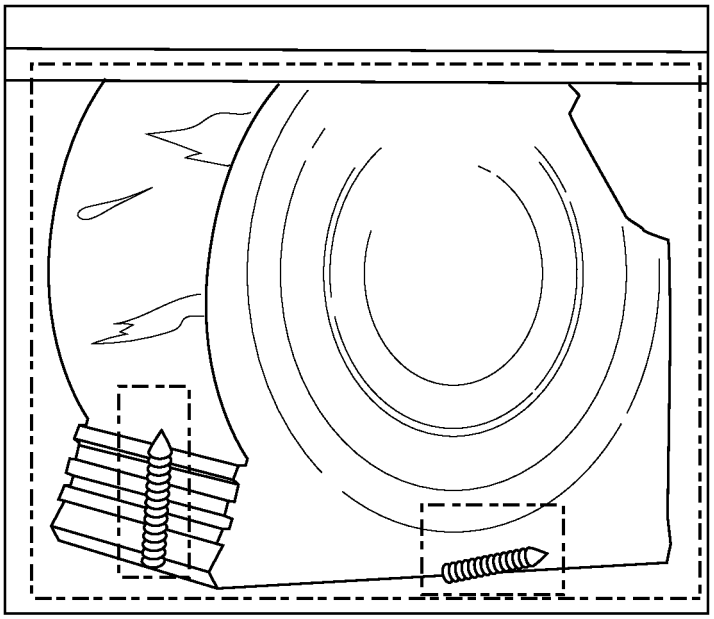

FIG. 12

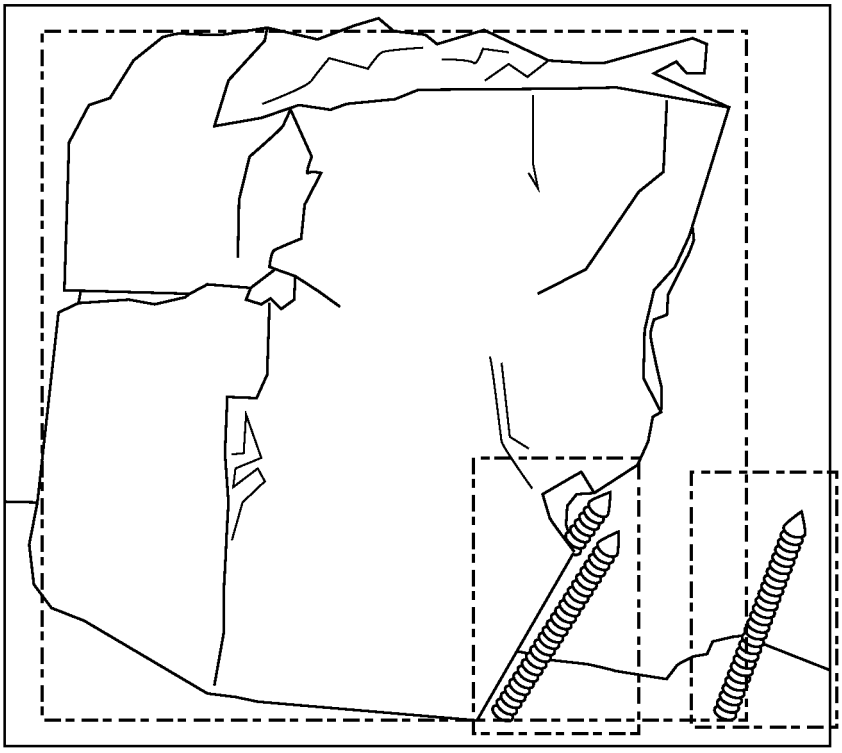

FIG. 13

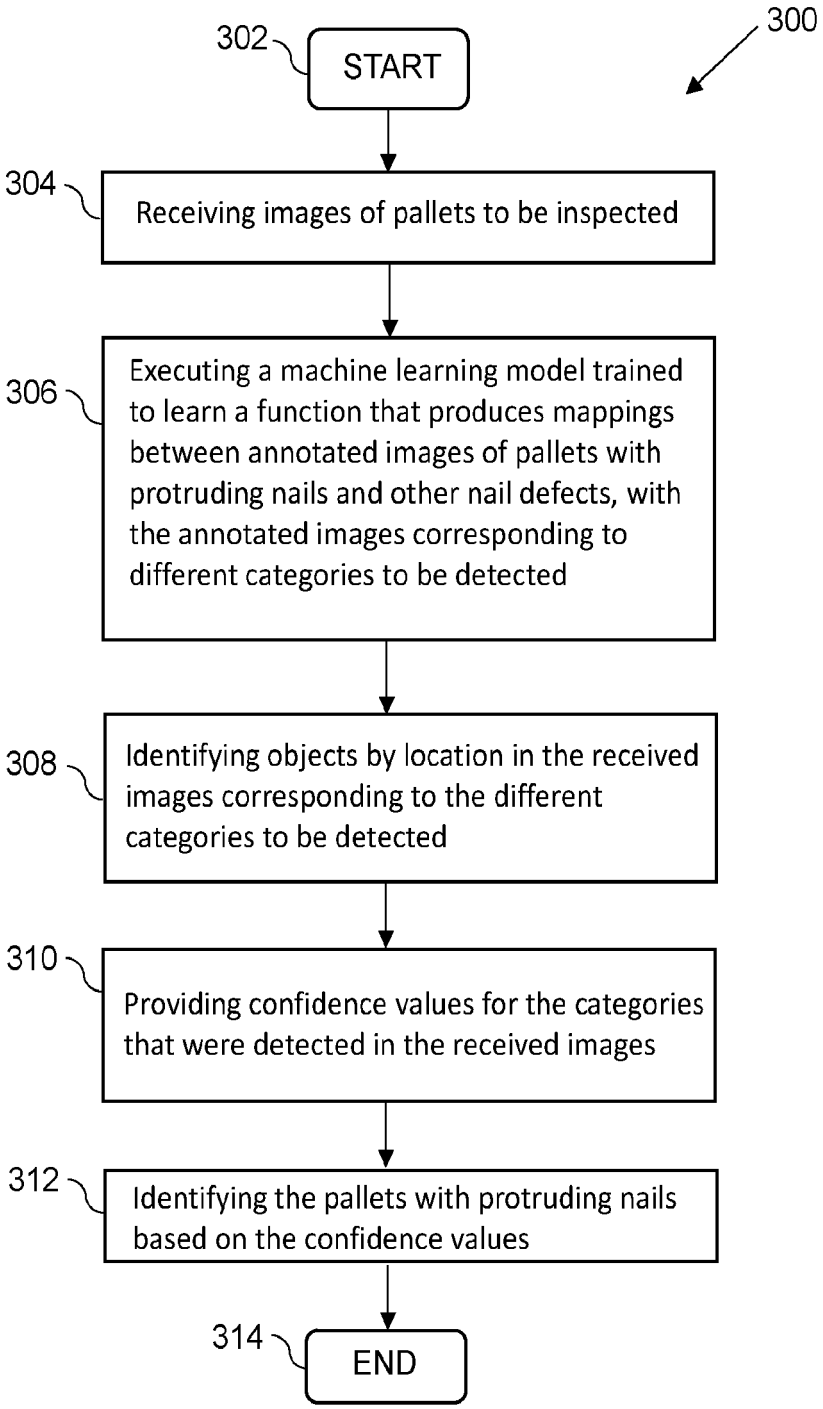
300
302
START
304
Receiving images of pallets to be inspected
306
Executing a machine learning model trained to learn a function that produces mappings between annotated images of pallets with protruding nails and other nail defects, with the annotated images corresponding to different categories to be detected
308
Identifying objects by location in the received images corresponding to the different categories to be detected
310
Providing confidence values for the categories that were detected in the received images
312
Identifying the pallets with protruding nails based on the confidence values
314
END

FIG. 14

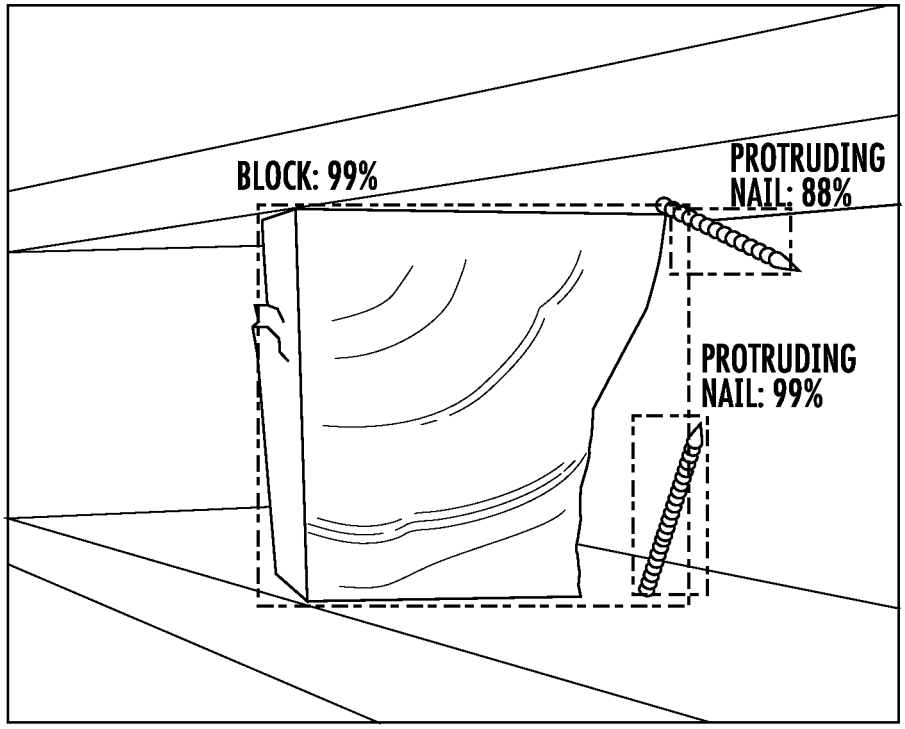

FIG. 15

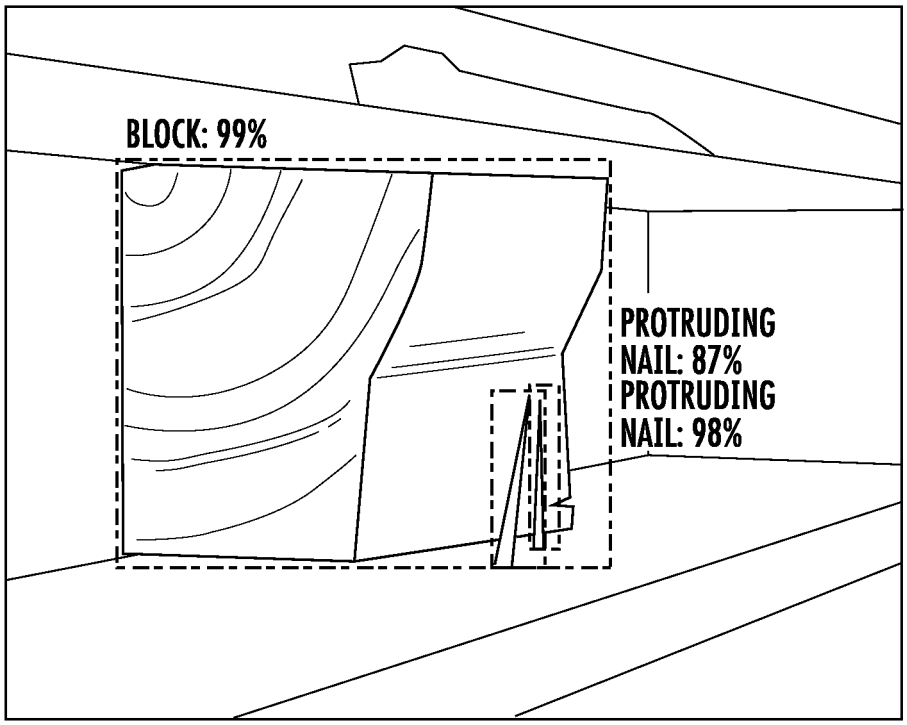

FIG. 16

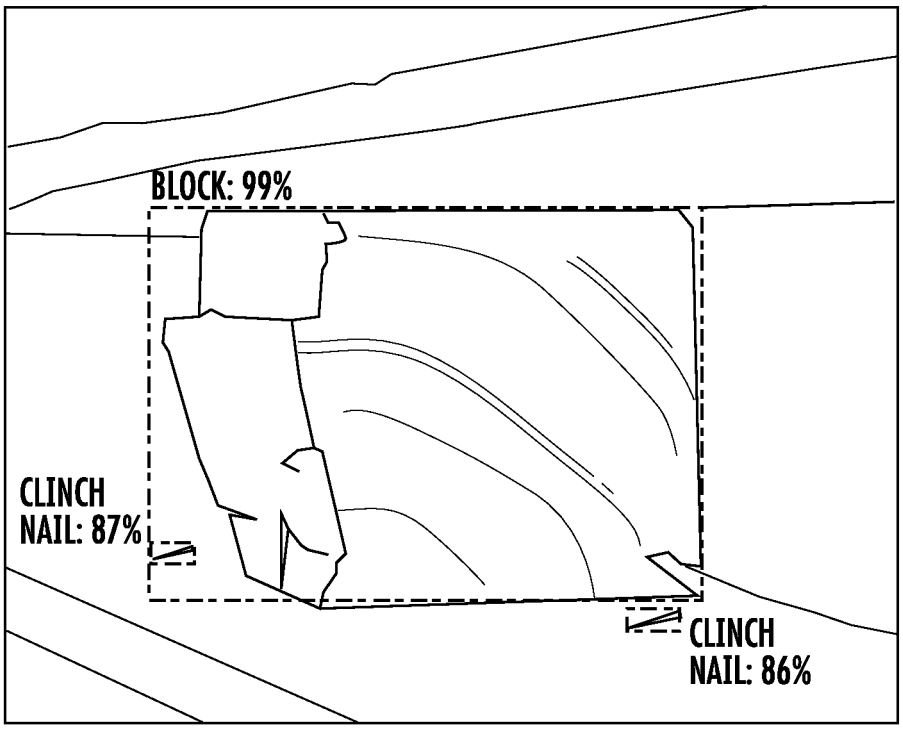

FIG. 17

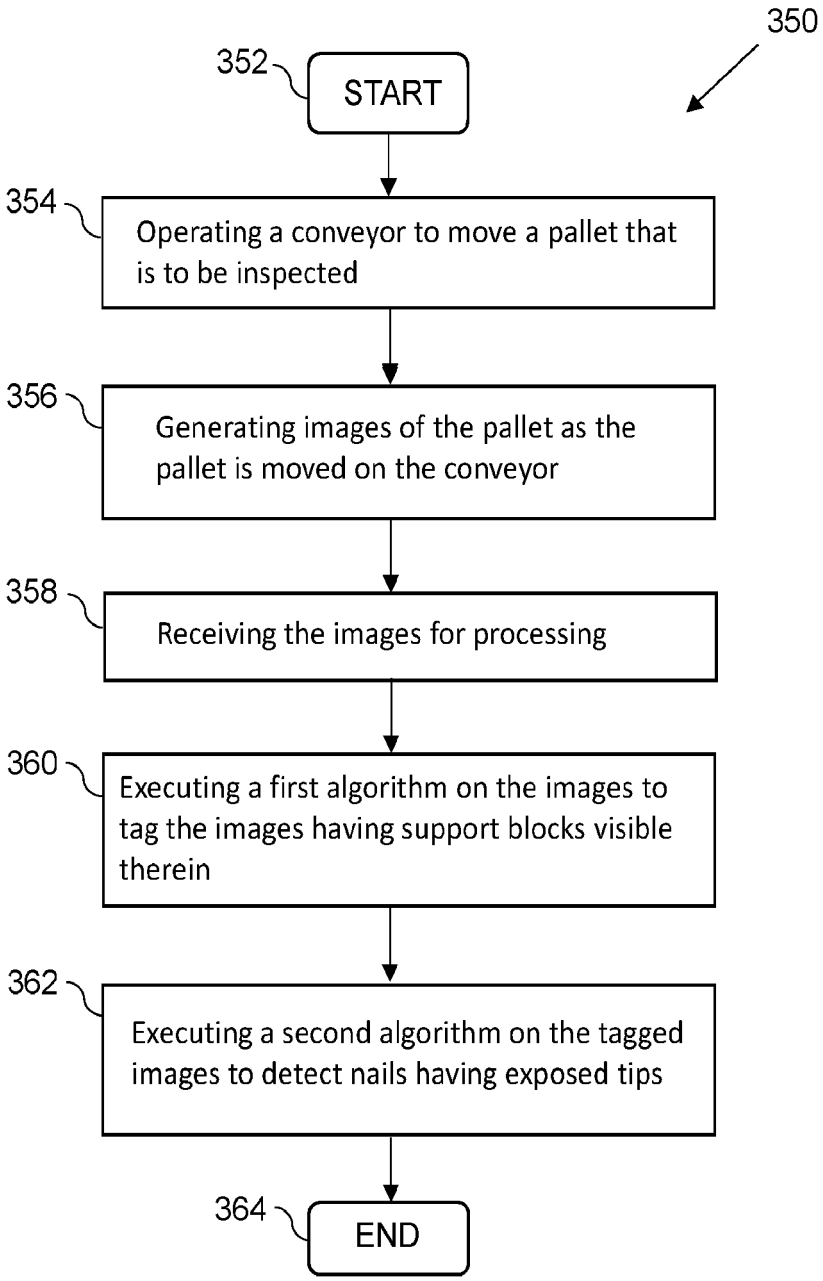
350
352
START
354
Operating a conveyor to move a pallet that is to be inspected
356
Generating images of the pallet as the pallet is moved on the conveyor
358
Receiving the images for processing
360
Executing a first algorithm on the images to tag the images having support blocks visible therein
362
Executing a second algorithm on the tagged images to detect nails having exposed tips
364
END

FIG. 18