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(54) **Title**: CENTRIFUGE SYSTEM AND WORKFLOW

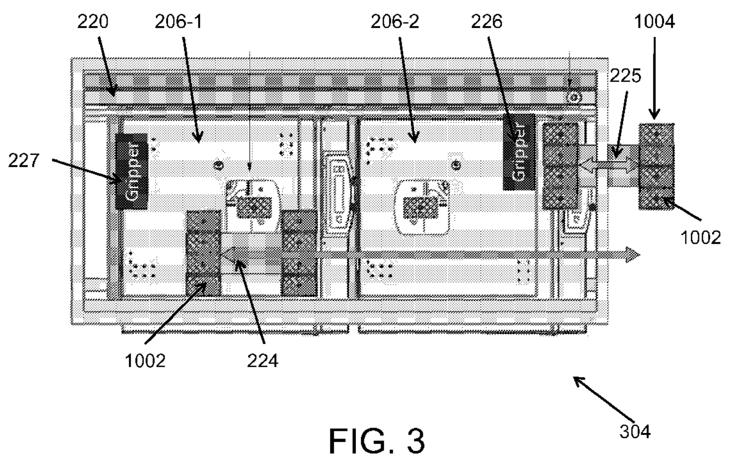

FIG. 3

(57) **Abstract**: Systems, methods and apparatus are described for a centrifuge module of a laboratory analysis system. Specimen containers may be weighed, loaded into a centrifuge adapter, and transported to a centrifuge module by an adapter shuttle. A centrifuge adapter gripper may transport the centrifuge adapter into a centrifuge for centrifugation. The centrifuge adapter may be transported by the centrifuge adapter gripper to an adapter shuttle for unloading of the specimen containers, which may be performed by a specimen container gripper. A centrifuge drawer that allows a centrifuge to be extended from its installed position is also described. Additional embodiments pertain to a sequence for replacing, in a centrifuge, a set of centrifuge adapters that have been centrifuged with a set of centrifuge adapters that have not been centrifuged. A sequence for loading specimen containers into centrifuge adapters is also described.

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CENTRIFUGE SYSTEM AND WORKFLOW

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/556,667, filed November 7, 2011 and entitled "Analytical System and Method for Processing Samples." This application also claims priority to U.S. Provisional Patent Application No. 61/616,994, filed March 28, 2012 and entitled "Analytical System and Method for Processing Samples." This application further claims priority to U.S. Provisional Patent Application No. 61/680,066, filed August 6, 2012 and entitled "Analytical System and Method for Processing Samples." All of these applications are herein incorporated by reference in their entirety for all purposes.

BACKGROUND

[0002] Conventional medical laboratory systems implement a variety of processes for analyzing medical specimens. These systems have become more efficient due to the increasing extent to which laboratory analysis processes have become automated. However, there remain several components of medical laboratory systems that can be automated. Automation can beneficially reduce the time required to analyze a sample, reduce the need for manual operation of the system, and reduce the space required by machinery.

[0003] Medical specimens may require centrifuging before analysis can be performed. A centrifuge may have one or more buckets capable of receiving a centrifuge adapter. A centrifuge adapter is a tray that can receive multiple specimen containers. Centrifuge imbalance may occur when centrifuge adapters are loaded unevenly. The weights of specimen containers to be inserted into centrifuge adapters may be used in determining how to balance centrifuge adapters.

[0004] A centrifuge may be mounted on a drawer to allow improved access to the centrifuge. However, centrifuge operation may be impeded or the centrifuge may be damaged if the centrifuge is operated when the drawer is partially or fully extended. Additionally, cables required for the operation of the centrifuge may be damaged by the operation of the drawer if they become entangled in components of the drawer.

[0005] Embodiments of the invention address these and other problems, individually and collectively.

BRIEF SUMMARY

[0006] Embodiments of the technology relate to systems and methods for efficiently processing patient samples.

[0007] A first embodiment is directed to a method for loading specimen containers into centrifuge adapters. A first specimen container gripper loads a plurality of specimen containers into a centrifuge adapter. The first specimen container gripper sequentially loads single specimen containers of the plurality of specimen containers into the centrifuge adapter until the plurality of specimen containers are loaded. The centrifuge adapter is transported to a centrifuge area by an adapter shuttle. A centrifuge adapter gripper transports the centrifuge adapter into a centrifuge. The centrifuge centrifuges the centrifuge adapter. The centrifuge adapter gripper transports the centrifuge adapter from the centrifuge to an adapter shuttle. A second specimen container gripper unloads the plurality of specimen containers from the centrifuge adapter. The second specimen container gripper sequentially unloads single specimen containers of the plurality of specimen containers until the plurality of specimen containers are unloaded.

[0008] In another embodiment, a method for replacing a set of centrifuged adapters with a set of uncentrifuged adapters is described. A centrifuge adapter gripper transports a first centrifuge adapter from which all specimen containers have been removed to a temporary holding area. The centrifuge adapter gripper transports a second centrifuge adapter containing previously centrifuged sample containers from a centrifuge to a first shuttle position. The centrifuge adapter gripper transports a third centrifuge adapter containing sample containers that have not been centrifuged from a second shuttle position to a centrifuge. The centrifuge adapter gripper transports a fourth centrifuge adapter from a temporary holding area to a second shuttle position, wherein the centrifuge adapter contains sample containers that have not been centrifuged.

[0009] In a further embodiment, a method for loading specimen containers into a set of centrifuge adapters is described. A specimen container gripper loads a first specimen container that is first in a sequential order into a first position of a first centrifuge adapter. The first position of the first centrifuge adapter is one of a first set of positions that are within a first distance from the center of the first centrifuge adapter. A specimen container gripper loads a second specimen container that is second in the sequential order into a first position of a second centrifuge adapter. The first position of the second centrifuge adapter is in a first set of positions that are within a first distance from the center of the second centrifuge adapter. A specimen container gripper a third specimen container that is third in the sequential order into a first position of a third centrifuge adapter. The first position of the third centrifuge adapter is in a first set of positions that are within a first distance from the center of the third centrifuge adapter. A specimen container gripper loads a fourth specimen container that is fourth in the sequential order into a first position of a fourth centrifuge adapter. The first position of the fourth centrifuge adapter is in a first set of positions that within a first distance from the center of the fourth centrifuge adapter. When all of the first set of positions that are within a first distance from the center of the first centrifuge adapter are filled, all of the first set of positions that are within a first distance from the center of the second centrifuge adapter are filled, all of the first set of positions that are within a first distance from the third centrifuge adapter are filled, and all of the first set of positions that are within a first distance from the center of the fourth centrifuge adapter are filled, a specimen container gripper loads a fifth specimen container into a second position of a first centrifuge adapter. The second position of the first centrifuge adapter is one of a second set of positions that are not within a first distance from the center of the first centrifuge adapter. The fifth specimen container follows a previously loaded specimen container in the sequential order. A specimen container gripper loads a sixth specimen container into a second position of a second centrifuge adapter. The second position of the second centrifuge adapter is one of a second set of positions that are not within a first distance from the center of the second centrifuge adapter. The sixth specimen container follows a previously loaded specimen container in the sequential order. A specimen container gripper loads a seventh specimen container into a second position of a third centrifuge adapter. The second position of the third centrifuge adapter is one of a second set of positions that are not within a first distance from the center of the third centrifuge adapter, wherein the seventh specimen container follows a previously loaded specimen container in the sequential order. A specimen container gripper loads an eighth specimen container into a second position of a fourth centrifuge adapter. The second position of the fourth centrifuge adapter is one of a second set of positions that are not within a first distance from the center of the fourth centrifuge adapter. The eighth specimen container follows a previously loaded specimen container in the sequential order.

[0010] Another embodiment is directed to a centrifuge drawer. The centrifuge drawer includes a platform coupled to a frame via telescoping rails. The platform is configured to support a centrifuge. The centrifuge drawer also includes a latch coupled to the platform.

[0011] An additional embodiment is directed to a method for installing a centrifuge in centrifuge drawer. The method includes applying a loading tool to a centrifuge. The loading tool includes a plurality of jacks and a plurality of wheels. The centrifuge is lifted by extending the plurality of jacks. The centrifuge is rolled to a position over centrifuge drawer using the plurality of wheels. The plurality of jacks is retracted until the centrifuge is supported by the centrifuge drawer. The loading tool is then removed from the centrifuge.

[0012] In a first embodiment directed to a tubular holder of a centrifuge adapter, a first end of the tubular holder is coupled to the centrifuge adapter and a second end of the tubular holder has an opening configured to receive a bolt. The tubular holder includes a first vertical groove on the interior of the tubular holder. The first vertical groove terminates at the opening of the tubular holder. The tubular holder also includes a second vertical groove on the interior of the tubular holder. The second vertical groove terminates at the opening of the tubular holder. The tubular holder also includes a first horizontal groove of the tubular holder. The first horizontal groove connects with the first vertical groove such that a first pin can enter the tubular holder via the first vertical groove and the first pin can travel from the first vertical groove into the first horizontal groove. The tubular holder also includes a second horizontal groove of the tubular holder. The second horizontal groove connects with the first vertical groove such that a second pin can enter the tubular holder via the second vertical groove and the second pin can travel from the second vertical groove into the second horizontal groove. The first pin and the second pin are coupled to the bolt and the bolt is coupled to a robotic arm.

[0013] In a second embodiment directed to a tubular holder of a centrifuge adapter a first end of the tubular holder is coupled to the centrifuge adapter and a second end of the tubular holder has an opening configured to receive a bolt. A first pin and a second are coupled to the bolt. The opening has a keyhole shape configured to match a cross-sectional profile of the bolt having the first pin and the second pin. The tubular holder includes a first vertical groove on the interior of the tubular holder. A first end of the first vertical groove terminates at the opening of the tubular holder and a second end of the first vertical groove terminates at a shelf. A first end of the second vertical groove terminates at the opening of the tubular holder and a second end of the second vertical groove terminates at the shelf. The shelf has a first notch and a second notch. The first vertical groove is configured to receive the first pin and the second vertical groove is configured to receive the second pin when the bolt descends through the opening of the tubular holder. the first notch is configured to receive the first pin and the second notch is configured to receive the second pin after the bolt has descended such that the first pin and the second pin are below the shelf and after the bolt has rotated such that first pin aligns with the first notch and the second pin aligns with the second notch.

[0014] In another embodiment, a method for gripping a centrifuge adapter is described. A bolt coupled to the robot arm is inserted by the downward movement of a robotic arm into a tubular holder coupled to a centrifuge adapter. The robot arm rotates the bolt with respect to the tubular holder. The bolt then enters a locking position within the tubular holder. The robotic arm lifts the centrifuge adapter until the upper surface of the tubular holder contacts the lower surface of the housing of the robotic arm. The contact between the tubular holder and the robot arm damps movement of the centrifuge adapter with respect to the robot arm.

[0015] In an additional embodiment, a first embodiment of centrifuge adapter shuttle is described. One or more hooks are movably coupled to the centrifuge adapter shuttle. The hooks are configured to mate with one or more openings in a centrifuge adapter. After a centrifuge adapter is loaded onto a centrifuge adapter shuttle, the hooks are moved laterally such that the hooks overhang a ledge of the openings. In this manner, the centrifuge adapter is restrained from being lifted away from the centrifuge adapter shuttle.

[0016] In a further embodiment, a second embodiment of a centrifuge adapter shuttle is described. The centrifuge adapter shuttle includes a controller, a power supply communicatively coupled to the controller, and an electromagnet mechanically coupled to a centrifuge adapter shuttle. The electromagnet receives power from the power supply. After a centrifuge adapter is loaded onto a centrifuge adapter shuttle, power is supplied to the electromagnet such that the electromagnet electromagnetically couples to a metal bar that is coupled to the centrifuge adapter.

[0017] These and other embodiments of the technology are described in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] A further understanding of the nature and advantages of the different embodiments may be realized by reference to the following drawings.

[0019] FIG. 1 depicts a block diagram of components associated with phases of a laboratory automation system.

[0020] FIG. 2 depicts a block diagram of components associated with a pre-analytical phase of a laboratory automation system.

[0021] FIG. 3 depicts a block diagram of components associated with a double centrifugation unit.

[0022] FIG. 4 shows an illustrative shuttle used for transporting centrifuge adapters.

[0023] FIG. 5 depicts a centrifuge rotor.

[0024] FIG. 6 is a flow chart showing an illustrative example of the centrifuge system workflow.

[0025] FIG. 7 depicts an illustrative adapter swap sequence for a centrifuge.

[0026] FIG. 8 depicts an illustrative adapter loading sequence for a centrifuge.

[0027] FIG. 9 depicts an example of a Cartesian or gantry robot with three independently moveable directions x-,y-, and z-.

[0028] FIG. 10 depicts an exemplary diagram of a camera unit for sample tube detection and analysis.

[0029] FIG. 11 depicts an example of sample level detection utilizing the analysis of absorption and transmission curves at distinct wavelengths.

[0030] FIG. 12 shows an illustrative centrifuge drawer.

[0031] FIG. 13 shows an illustrative cable management device for a centrifuge drawer, according to a first embodiment.

[0032] FIGS. 14(a)-(b) show an illustrative cable management device for a centrifuge drawer, according to a second embodiment.

[0033] FIG. 15 shows an illustrative magnetic latch for a centrifuge drawer.

[0034] FIGS. 16(a)-(c) show an illustrative mechanical latch for a centrifuge drawer.

[0035] FIGS. 17 shows an illustrative compression damper for a centrifuge drawer.

[0036] FIG. 18 shows an illustrative cover for a centrifuge drawer.

[0037] FIG. 19 shows an illustrative workflow for loading a centrifuge onto a centrifuge drawer.

[0038] FIGS. 20(a)-(b) show an illustrative centrifuge adapter gripper, according to a first embodiment.

[0039] FIGS. 21(a)-(b) show an illustrative centrifuge adapter gripper, according to a second embodiment.

[0040] FIGS. 22(a)-(c) show an illustrative centrifuge adapter lift-up prevention device, according to a first embodiment.

[0041] FIG. 23 shows an illustrative centrifuge adapter lift-up prevention device, according to a second embodiment.

[0042] FIG. 24 depicts a block diagram of an exemplary computer apparatus.

DETAILED DESCRIPTION

[0043] Embodiments of the present technology relate to an analytical medical laboratory system and method for processing medical specimens. These embodiments, as will be described in more detail below, are advantageous because they provide, among other advantages, greater speed, accuracy, efficiency, and prevention of contamination. As discussed above, many conventional laboratory systems may have a process that uses standalone units throughout the lab, requiring that specimens be manually transported between each standalone unit, while others may connect some of the units with a conveyance system to move the specimens from unit to unit. Additionally, as discussed above, sample tube sizes and equipment from different manufacturers may be constraints in conventional laboratory systems.

[0044] The laboratory system can operate a controlled process using a central controller or scheduler. By keeping the samples under the control of an intelligent scheduler, the system may provide efficient usage of every instrument. The system can maintain a consistent minimal turnaround time and maximize the throughput of the entire system by maintaining control of the process and only delivering samples to instruments when those instruments are ready and available.

[0045] In embodiments of the invention, a sample can be contained in a specimen container and processed by a laboratory automation system. A "specimen container," also referred to as a "sample container," "sample tube," and "tube," may have any suitable shape or form. In some embodiments, the specimen container may be in the form of a sample tube. An exemplary specimen container may be a sample tube with a closed bottom end and an open top end. Some sample tubes have an aspect ratio of 3:1 or greater. Specimen containers may be made of any suitable material including plastic, glass, etc. A cap that is structured to cover and attach to the open end of the sample tube body may be used with a sample tube.

[0046] In embodiments of the invention, one or more specimen containers may be inserted into a "sample carrier" (also referred to as a "carrier" or a "sample container holder") for transport. A sample carrier may hold the one or more specimen containers in an upright position and provide stability as the carrier is transported along a conveyance system. In some embodiments, a sample carrier may be a puck or a cylindrical receptacle configured to receive a single specimen container. The sample carrier may have vertical slits to allow the contents of a specimen container to be viewed and analyzed. In some cases, the sample carrier may be in the form of a sample tube rack with an array of recesses for receiving specimen containers.

[0047] The laboratory system may further utilize one or more robotic gripper units mounted on robotic arms. Each robotic arm unit can have a robotic gripper for gripping sample tubes and may be equipped with one or more means for detecting information about sample tubes. The terms "gripper" and "robotic gripper" are used interchangeably herein. The means for detecting information about a sample tube may include a first imaging device, such as a camera, for identifying a sample tube among a plurality of sample tubes in a rack. The identified sample tube is gripped by the gripper. The means for detecting information about sample tubes may further include a second imaging device to obtain an image of the gripped sample tube. The level of liquid in the sample tube may be determined from the image obtained by the second imaging device or from a transmission measurement using emitter and receiver units coupled to the robotic arm unit. In comparison with prior art systems, which have a camera mounted on a track and thus require all sample tubes to be on the track before the tubes can be identified, the laboratory system described herein can identify a sample tube before it is placed on a conveyer track. As a result, samples that do not need to be transported on the conveyer are not placed on the conveyer merely for the purpose of sample tube identification. Further, urgent samples can have a prioritized placement on the conveyer track.

[0048] Use of a plurality of robotic gripper units in the laboratory system can also increase sample processing efficiency. An input module gripper can identify a sample tube and make data measurements as described above. After the input module gripper delivers the sample tube to a distribution area, a distribution area gripper (e.g., a first specimen container gripper) can deliver a sample tube to a subsequent module such as a centrifuge module or conveyor. For example, the distribution area gripper may load sample tubes into a centrifuge adapter. In the centrifuge module, a centrifuge tube gripper (e.g., a second specimen container gripper) can be used to, e.g., transport sample tubes, place sample tubes in centrifuge adapters, and/or unload sample tubes from centrifuge adapters. A centrifuge adapter gripper can be used to transport centrifuge adapters. The use of multiple grippers may increase processing efficiency relative to prior art systems that use a single gripper to transport sample tubes and centrifuge adapters.

[0049] FIG. 1 depicts one embodiment of a medical laboratory system for processing patient samples. The laboratory system includes components associated with association phase 102, pre-analytical phase 104, analytical phase 106, and post-analytical phase 108.

[0050] The pre-analytical phase 104 can include preparing patient samples for analysis. During the pre-analytical phase 104, the patient and test information can be deciphered, the process for analysis can be planned, quality checks may be performed, the sample may be separated into its constituent components (e.g., centrifuged), the sample may be divided into multiple specimen containers (e.g., aliquotted), and/or the sample can be delivered to one or more analyzers and/or racks. The pre-analytical phase 104 can manage the flow of samples to different instruments and different analyzers within the lab system. This process management may permit the system to operate efficiently and with minimal instruments. Additionally, scheduling that occurs during the pre-analytical phase 104 enables efficient processing of samples.

[0051] Embodiments of the system can identify the patient samples as quickly as possible and determine the best scheduling of each sample to provide a consistent minimal turnaround time and maximum throughput of the analytical processes. The steps and organization of those steps in the process are designed to avoid accumulation of specimen containers at the input to the system or at other stations of the system. Modules of the laboratory system can operate at a throughput speed that allows processing of samples at the maximum throughput of the upstream processes. However, in some embodiments, at the aliquoter unit, the throughput may be managed by the introduction of samples upstream and by small queues at each aliquoting station.

[0052] FIG. 2 is a more detailed depiction of the components associated with the pre-analytical phase 104. The components associated with the pre-analytical phase 104 can include modules such as input module 202, distribution area 204, centrifuge 206, decapper 208, serum indices measurement device 210, aliquoter 212, and output/sorter 214.

Input Module

[0053] The input module 202 shown in FIG. 2 is the point at which a specimen container is introduced to the laboratory system. Racks of tubes and/or individual tubes can be loaded onto one of several lanes 216, which may be manually operated drawers and/or automated devices. In FIG. 2, five lanes 216 are depicted. However, the lab system can have any number of lanes 216. The lanes 216 can be prioritized according to automated or user-established scheduling. In some embodiments, the highest priority lane (short turnaround time or "STAT") may have a fixed position for accepting a group of individual tubes from the user. Once tubes are loaded in the STAT lane, they become the next tubes processed. Other lanes can be assigned different priority levels in any manner. For example, when the drawers are manually operated, assigning one priority to at least two of the drawers and another priority to at least two other drawers may allow the system to operate continuously on one drawer while the other drawer of the same priority is available to the user.

[0054] In some embodiments, while the input module 202 is processing a drawer of samples, the user may be informed that the drawer should not be opened. For example an indicator such as a light on the drawer or a lock on the drawer may be used to warn the user. This may help maintain the process integrity and maximize throughput. When processing of the contents of the first drawer is complete, the drawer may be identified to the user as available, and the system may automatically begin processing another drawer. Additionally, the samples can be transferred to and from the drawers 216 of the input module 202 using an input module gripper 228.

[0055] In some embodiments of the invention, a "region" concept can be used. A “region” can be the basic abstraction for the usage of drawers, rack holders, trays and racks. For example, a region can be a set of tube positions within a rack in one embodiment of the invention. A region can be assigned either tube characteristics (e.g., STAT, sample type, pre-spun, cap type) or a single processing instruction. In embodiments of the invention, a tube characteristic or instruction can be assigned to one or more regions, which allows for a more robust routing scheme.

Distribution Area Module

[0056] Referring again to FIG. 2, from the lanes 216 within the input module 202, one or more distribution area grippers 218 may select the highest priority tube and transport it to a fixed matrix called the distribution area 204. The distribution area 204 is capable of distributing a sample container to a designated station of the laboratory automation system. As the input module gripper 228 transfers a specimen to distribution area 204, the gripper 228 can gather information about the specimen. For example, one or more liquid levels of fluid within the specimen container may be measured, e.g., by systems associated with gripper 228. In some embodiments, the sample tube may be photographed, e.g., by systems associated with gripper 228. The information gathered in this manner can be analyzed to determine the tube’s manufacturer, diameter, height, cap color, etc. Volumes of the sample’s components can be calculated, and an estimate of the total tube weight can be made. This weight can be later used to aid in balancing the centrifuge adapters in the centrifuge module 206, as will be discussed in more detail below.

[0057] To protect the distribution area 204 from becoming filled with low priority tubes, a limit can be set on the number of tubes loaded into this area from the low priority input lanes. Moreover, the distribution area 204 may have a reserved area to ensure STAT samples have continuous access to the distribution area 204 from the STAT drawer in the input module 202.

[0058] The distribution area 204 can be the holding area which permits the system to access test information associated with the sample tube in the association phase 102 and plan the analysis process for the sample. This enables the system to schedule a sample tube’s process with respect to the other sample tubes currently on the system. Scheduling enables the efficient processing of samples based upon priority without overloading any step in the overall system, permitting the optimization of turnaround time and throughput. Furthermore, the sample's schedule can be updated throughout the process as the system's activity or availability changes, providing real time active control of the sample.

[0059] Once the schedule is planned by the distribution area module 204, a robotic gripper 218 then selects the sample tube that is the next tube to be transferred to the next module based on the priority of the tubes within the distribution area 204. The selected sample tube is transported from the distribution area 204 to the conveyance system 220, to the centrifuge module 206, or to an error area 222 based on the analysis performed by the distribution area module 204.

[0060] If the sample tube is being moved to the centrifuge module 206, the tube can be placed into the appropriate centrifuge adapter based upon the earlier weight estimation to ensure proper balance of the centrifuge rotor. In other embodiments, the tube can be placed into a centrifuge adapter based on its priority. The centrifuge adapter is the component which carries the tubes upon a shuttle from the distribution area 204 to the centrifuge whereupon a robotic gripper transfers the centrifuge adapter with the tubes to a bucket of the centrifuge.

[0061] If the distribution area module 204 determines that the sample tube does not require centrifugation the distribution area robot gripper 218 places the sample into a carrier on the conveyance system 220 with the barcode label properly aligned to the carrier at the direction of the scheduler so as not to overload downstream processes

Centrifuge Module

[0062] The sample tube may be moved from the distribution area 204 of FIG. 2 to the centrifuge module 206 when the distribution area module 204 determines that the sample requires centrifugation before analysis of the sample. Centrifuge module 206 may include one or more automated centrifuges (e.g., centrifuge 206-1 and centrifuge 206-2) and an adapter shuttle for each centrifuge (e.g., adapter shuttle 224 and adapter shuttle 225). Centrifuge module 206 may further include one or more robot grippers (e.g., robot gripper 226 and robot gripper 227). In some embodiments, a robot gripper 226 may be a centrifuge tube gripper used to remove centrifuged sample tubes from adapters 224, 225 and transport the sample tubes to conveyance system 220. A robot gripper 227 may be a centrifuge adapter gripper used to swap adapters into and out of centrifuges 206-1, 206-2.

[0063] When a sample tube is to be transported from the distribution area 204 to the centrifuge module 206, the sample tube can be loaded by the distribution area robot gripper 218 into a centrifuge adapter from the distribution area 204. The adapters may accommodate multiple tube sizes for centrifugation. The adapter may be seated on an adapter shuttle 224, 225 that moves between the distribution area 204 and the centrifuge module 206.

[0064] FIG. 3 depicts a closer view of a double centrifuge unit 304, which was described in detail with reference to FIG. 2. The centrifuge unit 304 can include two single centrifuges 206-1 and 206-2, adapter shuttle 224, and adapter shuttle 225. Each adapter shuttle can hold centrifuge adapters 1002. Centrifuge unit 304 may further include robotic grippers 226, 227.

[0065] FIG. 4 shows an illustrative shuttle 224 used for transporting centrifuge adapters 1002.

[0066] FIG. 5 shows an illustrative centrifuge rotor 500 configured to receive four centrifuge adapters 1002. Centrifuge adapters 1002 may be loaded into centrifuge buckets 502 of the centrifuge. Centrifuge adapters are configured to receive one or more sample tubes 506. The centrifuge adapters may be configured to receive different shapes and sizes of sample tubes, as illustrated by the larger sample tube 506 and the smaller sample tube 508 in adapter 1002.

[0067] When adapters 1002 loaded with sample tubes arrive at the centrifuge module 206 from the distribution area 204 via the adapter shuttles 224, 225, the adapters 1002 are loaded into an available centrifuge bucket 502. In a preferred embodiment, each centrifuge can accept multiple adapters 1002, e.g., four adapters. In some embodiments, each adapter 1002 can hold a plurality of sample tubes, such as 14 sample tubes.

[0068] Of the adapters associated with centrifuges 206-1, 206-2, a subset of the associated adapters (e.g., two adapters) may reside on each adapter shuttle. In some embodiments, the following processes may occur simultaneously: distribution area gripper 218 loads tubes into an adapter, centrifuge tube gripper 226 unloads tubes from another adapter on an adapter shuttle and moves the unloaded sample tubes to sample carriers on conveyance system 220, centrifuge adapter gripper 227 swaps adapters for a centrifuge (e.g., 206-1), and a another centrifuge (e.g., 206-2) spins an adapter set. An adapter shuttle may transfer adapters to a centrifuge when one or more of the following occurs: a centrifuge is available, an adapter filling time is expired (which may depend on the scheduled starting time for a centrifuge), or adapters for unloading are empty.

[0069] The configuration of the adapters allows for simplified delivery of sample containers to and removal of sample containers from the centrifugation buckets. Once loaded into a centrifuge bucket, the adapters can be centrifuged.

[0070] Once centrifugation is complete, centrifuge adapter gripper 227 can remove the adapters from the centrifugation bucket. The adapter shuttle can then move back to the tube loading/unloading position. With the adapter shuttle at the loading/unloading position, centrifuge tube gripper 226 may remove sample tubes from the adapters and place the tubes in carriers on the conveyance system 220 for transport to the next module. Sample tubes may be removed from adapters and placed in a temporary buffer. For example, when a downstream module is temporarily non-operational or otherwise unavailable, the sample tubes may remain in the temporary buffer. When the downstream module becomes available, the sample may be removed from the buffer and placed on conveyance system 220. If the downstream module will be unavailable for an extended period of time, the sample can be placed on conveyance system 220 to be transported to error area 222.

[0071] The timing for loading tubes into an adapter at the distribution module 204, sending the tubes in the adapter to the centrifuge module 206 via the adapter shuttle 224, loading the adapter into a centrifuge bucket, centrifuging the samples, unloading the adapter from the centrifuge bucket, and unloading the tubes from the adapter can be established such that the process is continuous, allowing for the continual centrifugation of samples as they arrive at the centrifuge module 206 from the distribution area 204. As the centrifuge completes a spin cycle, the last tube in the distribution area 204 can be loaded by the distribution area gripper 218 into an adapter, and the shuttle 224 can move the adapter to a centrifuge in the centrifuge module 206. At the same time, an automated door on the centrifuge opens and provides access to a bucket as the rotor indexes into position at the doorway.

[0072] In one embodiment, a centrifuge adapter gripper 227 in the centrifuge module 206 can remove an empty adapter from the adapter shuttle and place the empty adapter on a deck of centrifuge module 206. Subsequently, the centrifuge adapter gripper 227 can remove an adapter that is in a centrifuge bucket. The centrifuge adapter gripper 227 can move the adapter that was removed from the centrifuge bucket to the area of adapter shuttle from which the empty adapter was removed. Next, the centrifuge adapter gripper 227 selects an adapter that has been recently loaded with tubes from the distribution area 204 and deposits it into the empty bucket. While the centrifuge rotor indexes to the next bucket, a previously emptied adapter is moved to the open position on the shuttle 224 for loading with tubes from the distribution area 204 when the shuttle 224 returns to the distribution area 204.

[0073] After the final adapter is loaded into the centrifuge, the centrifuge door, which may be an automated door may be closed to allow the centrifuge cycle to begin. The empty adapter that was on the centrifuge module deck can be placed on the adapter shuttle. The adapter shuttle may move back to the distribution area 204, and a centrifuge tube gripper 226 begins to unload tubes from the adapters removed from the buckets into carriers on the conveyance system 220. As the tubes are moved from the adapter to the carrier, liquid level detection can be performed with centrifuge tube gripper 226. For example, a liquid level measurement can be performed as described in more detail below. In some embodiments, the heights of the sedimentation layers are measured and the barcode on the sample container is read and/or aligned for the carrier. If insufficient serum or plasma is present in a centrifuged sample container, the sample container may be sent to an error area located in the output module 214.

[0074] In an alternative embodiment, a shuttle can have additional space for one or more adapters. For example, the shuttle can have a number of positions for adapters that exceeds the numbers of adapters in an adapter set by one. The additional space may be located on the loading side of the shuttle. Rather than moving an empty adapter to a temporary location such as a centrifuge module deck, as described above, the adapter may be placed at the additional space on the shuttle.

[0075] If the scheduling algorithm predicts the overloading of an analyzer with samples from the centrifuge module 206, the centrifuge module gripper 226 can unload the samples and distribute the samples from the adapters to the conveyance system. In some embodiments, the full cycle time of the centrifuges can be greater than or equal to, e.g., 360 seconds. In order to ensure optimal turn-around time and throughput the centrifuges are kept, e.g., 180 seconds out of phase for a 360 seconds centrifugation cycle. In some embodiments, downstream processes do not prevent the unloading of samples from the centrifuge adapters. If all the remaining samples in an adapter are destined for unavailable process(es) and depending upon the unavailable process, sample tubes can either be moved to a buffer in the centrifuge instrument or moved to another buffer area elsewhere in the system.

[0076] The centrifuge module 206 may include an automated centrifuge controlled by a centrifuge controller. The automated centrifuge can be loaded with multiple centrifuge adapters or receptacles, each adapter receiving multiple sample tubes. The centrifuge includes a motor coupled to a spindle, a rotor assembly, a controller, a lid, and optionally, a lid drive. The centrifuge controller indexes or stops the spindle at selected positions for automated placement and removal of either tubes, adapters or buckets. The lid has a closed position and an open position, and the lid opens and closes in response to instructions from the centrifuge controller.

[0077] Various techniques may be used to balance the weight distribution among adapters that are to be loaded into a centrifuge. In some embodiments, the weight of a tube may be determined based on information stored in a database of tube weights. The weight of sample material contained in a tube may be determined based on a measured liquid level or liquid levels in a sample tube and a known density of the liquid or liquids. In another embodiment, sample tubes may be weighed by input module gripper 228 prior to being loaded into centrifuge adapters.

[0078] In another embodiment, specimen weights can be determined by one or more balances, for example, a balance located in the distribution area or a balance of a conveyor track. The balance can measure the combined weight of the sample tube and the sample contained in the tube. This may occur as the sample tubes are carried by a conveyor track. To obtain a weight of the sample, a known weight of the sample tube can be subtracted from the combined weight. The known weight can be stored in a database of known tube weights. The sample weight may be determined using a central controller associated with the laboratory system or by another controller of the system. The controller may be communicatively coupled to the database.

[0079] Alternatively, centrifuge module 206 may comprise a scale having sites for receiving and holding a plurality of adapters, and a balance controller for selectively depositing sample tubes in cavities of the adapters while correlating incremental weight changes with the locations of each deposit for equalizing weight in pairs of the adapters.

[0080] The balance controller can be implemented as a balance program within the central controller. The balance program maintains a database of sample container weights. When a container's weight is combined with the sample's weight, the balance program can determine the optimum adapter cavity in which to place it thereby maintaining a balanced rotor within a tolerance. Sample weights are the product of density estimates and the sample volumes calculated from liquid level measurements and container geometry obtained during the initial pick-up from the input. In some embodiments, balance system may also include a supply of dummy loads in buckets for limiting weight variations between buckets. The dummy loads may be weighted for limiting the weight variations to not greater than, e.g., 10 grams between members of each pair of buckets.

[0081] The centrifuge controller may operate to perform a number of functions, such as receiving and storing centrifuge spin profiles including a rotor spindle speed and duration; indexing the rotor's sample stations into an access position, spinning the rotor in accordance with the cycle profile, stopping the rotor with a predetermined sample station at the access position, etc.

[0082] If two or more centrifuges are used in the pre-analytical system, the centrifuges may be synchronized and/or kept out of phase. For example, the starting time of a spinning cycle for centrifuge 206-1 may be scheduled at a different time from a spinning cycle for centrifuge 206-2. Because centrifuges 206-1 and 206-2 do not start spinning at the same time, high priority sample tubes may be processed quickly. In some embodiments, spin cycles for the centrifuges are scheduled such that at least one centrifuge is available to process a high priority sample tube at any time.

[0083] In an exemplary embodiment, the centrifuges may be run synchronized and out of phase on a fixed timetable such that a centrifuge is available at predetermined intervals. For example, a centrifuge cycle may have a six minute duration, which can include the time required to swap adapters out of and into the centrifuge. In a system with two centrifuges, the centrifuge cycles may be out of phase such that one of the centrifuges is available every three minutes. (e.g., one of two centrifuges is available every three minutes).

Centrifuge Workflow

[0084] FIG. 6 is a flow chart showing an illustrative example of the centrifuge system workflow. When the scheduler selects a sample container for centrifugation, the tube may be loaded by the distribution area gripper 218 into the appropriate centrifuge adapter 1002 at the centrifuge load position 1004 to ensure a balanced centrifuge rotor. At operation 1424, when the sample container 506 is selected for centrifugation, the sample container 506 is transported by distribution area gripper 218 from distribution area 204 to the centrifuge adapter 1002.

[0085] As the centrifuge cycle is ending for adapters already loaded into the centrifuge 206-1 or 206-2, the newly loaded centrifuge adapters 1002 are moved to the appropriate centrifuge 206-1 or 206-2. The adapters sit on an adapter shuttle (e.g., 224 or 225) that moves from centrifuge load position 1004, between the manager unit 700 and the centrifuge unit 304, to the appropriate centrifuge 206-1 or 206-2, as indicated at operation 1426. The adapter may be loaded by a robot gripper, such as centrifuge adapter gripper 227, into a centrifuge bucket 502, as indicated at operation 1428. The sample may be centrifuged, as indicated at operation 1430. A previously emptied adapter may be moved from a shuttle (e.g., 224, 225) to a temporary location to create a vacant space in the shuttle. The temporary location may be, e.g., a temporary holding area of a centrifuge area or a dedicated buffer region. The adapter may be removed from the centrifuge (e.g., removed from a centrifugation bucket), as indicated at operation 1432, and transferred to the vacant space in the shuttle, as indicated at operation 1434. When all adapters have been swapped and the shuttle is moved to the unload position, a sample tube may be removed from the centrifuge adapter 1002 by a robot gripper, such as centrifuge tube gripper 226, as indicated at operation 1436. The sample tube may be placed by centrifuge tube gripper 226 into a carrier on conveyance system 220, as indicated at operation 1438.

[0086] Centrifuge adapters 1002 that are loaded with sample tubes may be swapped with the adapters in the centrifuge unit 206-1 or 206-2 by centrifuge adapter gripper 227. The centrifuged adapters can then be removed from the centrifuge unit 206-1 or 206-2 and placed in a vacant space in the shuttle as indicated at 1432. For example, the centrifuged adapters may be placed in specific spots on the shuttle so that when the shuttle returns to the manager unit 700, the tubes can be unloaded by centrifuge tube gripper 226 from the adapters and placed onto the conveyance system 220. The newly loaded adapters 1002 from the manager unit 700 are placed inside the centrifuge 206-1 or 206-2. After the centrifuge adapter has been loaded into the centrifuge rotor, the centrifuge rotor may index to allow loading of a subsequent uncentrifuged centrifuge adapter. An adapter which was previously emptied of its sample tubes may be moved by the centrifuge adapter gripper 227 from an unloading spot on the shuttle to a vacant spot on the shuttle. For example, for a shuttle such as the illustrative shuttle of FIG. 11(b), a first end of the shuttle 230 may be an unloading spot and a second end 232 of the shuttle may be a vacant spot. Moving the adapter to a vacant spot on the shuttle may occur simultaneously with the indexing of the centrifuge rotor. The empty adapters can then be loaded with new sample tubes in the manager unit 700. The swapping of adapters may continue until all adapters of a centrifuge rotor have been exchanged, allowing the adapter that was placed in a temporary location to be moved to the last empty spot in the shuttle for emptied adapters. Illustrative centrifuge adapter swapping sequences are described further with reference to FIG. 7.

[0087] The shuttle may return to its home position where adapters can be loaded with sample tubes by distribution gripper 218 and/or unloaded by centrifuge tube gripper 226. When samples are unloaded from the adapters and transferred to a carrier on the transport by the centrifuge tube gripper, a barcode label on the sample tube may be aligned to the carrier and a liquid level measurement may be made to ensure that the tests required for the sample can be completed. Thus, the centrifuge tube gripper 226 may have a liquid level detection functionality as described with reference to input module gripper 228. If insufficient sample material is present for further processing of the sample, the tube can be processed according to procedures established for insufficient sample material conditions. For example, the sample tube may be processed according to predefined rules which dictate the tests to complete or the sample may be sent to a Sample in Question (SIQ) rack in output module 214.

[0088] While adapters are being swapped in the centrifuge unit 304, the scheduler may direct tubes that do not require centrifugation to be moved by the distribution area gripper 218 from the distribution area 204 to the conveyance system 220, bypassing the centrifugation unit 304, as indicated at operation 1440.

Centrifuge Adapter Swap Sequence

[0089] FIG. 7 depicts an illustrative adapter swap sequence for a centrifuge according to a first embodiment. Although a single centrifuge adapter 1002 is shown in centrifuge 206, positions B, E, H and K of centrifuge 206 correspond to four centrifuge buckets that can receive centrifuge adapters 1002. A centrifuge with four centrifuge buckets is shown in FIG. 5. A previously unloaded centrifuge adapter (e.g., centrifuge adapter 1002) is moved by centrifuge adapter gripper 227 from shuttle position A to temporary holding area M (702), as shown at 704. An unloaded centrifuge adapter is a centrifuge adapter from which all sample tubes have been removed. Next, a previously centrifuged ("spun") centrifuge adapter is moved by centrifuge adapter gripper 227 from area B of centrifuge 206 to the vacant space on shuttle position A, as indicated at operation 706. Shuttle positions A, J, G, and D can be collectively referred to as first shuttle position 710. At operation 706, the centrifuge adapter 1002 is removed from a centrifuge bucket 502 of centrifuge 206. An adapter 1002 loaded with samples that have not been centrifuged is then moved by centrifuge adapter gripper 227 from shuttle position C to the area B of the centrifuge, as indicated at operation 708. Shuttle positions L, I, F and C can be collectively referred to as second shuttle position 712.

[0090] Subsequently, a previously emptied centrifuge adapter is moved by centrifuge adapter gripper 227 from shuttle position D to shuttle position C. A previously spun centrifuge adapter is moved by centrifuge adapter gripper 227 from area E of centrifuge 206 to the vacant space on shuttle position D. An adapter loaded with samples that have not been centrifuged is moved by centrifuge adapter gripper 227 from shuttle F to area E of the centrifuge 206.

[0091] The sequence continues with a previously emptied centrifuge adapter moved by centrifuge adapter gripper 227 from shuttle position G to shuttle position F. A previously spun centrifuge adapter is moved by centrifuge adapter gripper 227 from area H of centrifuge 206 to the vacant space on shuttle position G. An adapter loaded with samples that have not been centrifuged is moved by centrifuge adapter gripper 227 from shuttle I to the area H of the centrifuge 1680.

[0092] Next, a previously emptied centrifuge adapter is moved by centrifuge adapter gripper 227 from shuttle position J to shuttle position I. A previously spun centrifuge adapter is moved by centrifuge adapter gripper 227 from area K of centrifuge 206 to the vacant space on shuttle position J. An adapter loaded with samples that have not been centrifuged is moved by centrifuge adapter gripper 227 from shuttle position L to the area K of the centrifuge 206 indicated at K. The adapter that was moved to temporary holding area M is moved to the vacant space in shuttle position L, as indicated at operation 716.

[0093] In this way, spun adapters are swapped out of a centrifuge and unspun adapters are swapped into the centrifuge.

[0094] The scheduler determines the order that samples are removed from the adapters and unspun samples are removed from the distribution area. High priority samples (STAT) may be removed first. If a downstream process such as aliquoting in aliquoter unit 212 is unable to handle the flow of samples and the next centrifuge cycle is ready to begin, the samples can be removed from the adapters and placed into a buffer at the back of the centrifuge 206. In some embodiments, the lowest priority samples are removed first to allow more time for the higher priority samples to advance. The scheduler may advance samples from the buffer when downstream processes become available and according to established priorities. If a sample requires another spin cycle, the sample may remain in the adapter to be spun again.

Centrifuge Adapter Loading Sequence

[0095] FIG. 8 depicts an illustrative adapter loading sequence for a centrifuge. In order to prevent imbalance of the centrifuge rotor, centrifuge adapters 1002 may be loaded in a manner that yields a balanced centrifuge rotor. The weight of each sample tube can be measured and/or estimated from the product of measured sample volume multiplied by a known density for the sample material. In some embodiments, sample tube weights can be determined by one or more balances, for example, a balance located in the distribution area or a balance of a conveyor track that measures sample tube weights as the sample tubes are carried by a conveyor track.

[0096] The centrifuge can be loaded according to the following sequence. A first sample tube with a highest centrifugation priority can be identified by the scheduler in the distribution area 204. Adapter A1 (1708) can be loaded with the first sample tube from distribution area 204 in a position closest to the center position of adapter A1 (1708). A second sample tube with comparable weight to the first sample tube can be selected by the scheduler from distribution area 204 and loaded into a position of A3 (1712) that is the same position occupied by the first sample tube in A1(1708). A sample tube with the second highest centrifugation priority is identified by the scheduler in distribution area 204 to be the third sample tube. The third sample tube is loaded into a position in adapter A2 (1710) that is closest to the center of A2 (1710). A fourth sample tube with comparable weight to the third sample tube can be selected by the scheduler from distribution area 204 and loaded into a position of A4 (1714) that is the same position occupied by the third sample tube in A2 (1710). The process continues with filling open positions in the adapters A1-A4 (1708-1714) with a first sample tube, a second sample tube, a third sample tube and a fourth sample tube, as described above, to fill the positions indicated in green (1700), then the positions indicated in yellow (1702), then the positions indicated in blue (1704), and then the positions indicated in red (1706), until all adapters are filled. In some embodiments, if a centrifuge cycle is nearing completion (e.g., within 30 seconds of completion), the loading of adapters may halt before all adapters are filled and the centrifuge may be loaded with adapters that have not been filled to capacity.

[0097] In some embodiments, a sample tube is loaded into an adapter only if its weight is available. The sample tube weight may be determined, for example, based on a liquid level detection performed by input module gripper 228 cross referenced with a table stored in a memory of a laboratory information system (LIS). If the weight of a sample tube is not available, centrifugation may not be performed for the sample tube. For example, the sample tube may be placed in an error rack rather than being loaded into an adapter.

[0098] In an alternative embodiment, sample tubes may be loaded into adapters according to priority order. The sample tubes may be loaded according to the order described above with reference to FIG. 8. To avoid imbalance, a lower priority sample tube may be loaded in lieu of a higher priority sample tube if the higher priority tube would cause imbalance. For example, if a first (e.g., highest priority) tube is heavy and the second and third tubes (e.g., next in priority order) equal the weight of the first tube, the second and third tubes may be loaded to oppose the force of the first tube.

[0099] In some embodiments, a request for immediate centrifugation may be issued by the scheduler, in which case adapters that are not completely filled may be centrifuged. For example, if a loaded sample tube is a STAT tube or if the adapter filling time for a centrifuge is expired, the adapter may be centrifuged immediately.

Robotic Grippers

[0100] As discussed above, a robotic arm can be used to move a sample tube or any other object (e.g. a centrifuge adapter) from many different locations within the laboratory system (e.g., input robot 228, distribution robot 218, centrifuge robot 226, etc.).

[0101] The robotic arm architecture can differ in complexity dependent upon the given task. FIG. 9 depicts an example of a Cartesian or gantry robot 1970 with three independently moveable directions x-, y-, and z-. The x-axis may be defined by an x-axis rail 1972 and the y-axis may be defined by a y-axis rail 1974. The z-axis may be defined by an orientation of a robotic arm 1976 extending in the z-direction. The gantry robot 1970 comprises a robotic arm 1976, and a gripper unit 1980 operatively and physically coupled to the robotic arm 1976. More complex robotic arms may include, for example, the Selective Compliant Assembly Robot Arm

(SCARA) or the articulated robotic arm with multiple joint arms. The gripper unit 1980 comprises a gripper housing 1982 and gripper fingers 1984 extending downward from the gripper housing 1986. The gripper fingers 1984 can move inwardly towards each other to grip a sample tube 1982 and outwardly to release a sample tube 1982.

[0102] The robotic arm including the gripper unit can be additionally employed for identification and for determination of physical characteristics of the moved object. Therefore, the robotic arm can be equipped with an appropriate identification and determination means (e.g., a camera, a bar code reader, or an absorption and transmission measurement unit). The tube identification, level detection, and tube presence detection units are described in more detail below.

Sample Level Detection

[0103] In embodiments of the invention, a camera unit and analysis tool can use the 2-D image captured by the system to determine a sample volume and sample level for the sample in the sample tube.

[0104] A sample level detection unit (or assembly) and a sample tube are depicted in FIG. 10. The sample level detection unit includes a chamber 2100. A camera unit 2102 is accommodated in the chamber 2100, which has few and, if possible, no optical reflections. The camera unit 2102 can be aligned with and focused on the sample tube 2106 containing the body fluid. An illumination source 2104 may provide light to the sample tube 2106 so that the camera unit 2102 can take a picture of the sample tube 2106.

[0105] The camera unit 2102 can be a still camera, a color image camera, a video camera, a spectral camera or the like. A color image camera, for example a 3CCD video camera, may be used. The settings of the color camera, such as focusing, white balance, diaphragm setting, filling-in, can be permanently preset or adjustable. For example, they can be adjusted with the aid of image evaluation software, as in when the data reported by the image evaluation software to the control software are of reduced quality with reference to store reference data. An algorithm can be used to calculate the sample level and/or volume using known data, such as the type of sample tube used, the type of sample, etc.

[0106] As shown in FIG. 10, the camera unit 2102 can be inclined to optimize its view of the sample tube 2106. The sample tube 2106 information can be recorded with comparatively few optical reflections with the aid of this measure.

[0107] Arranged above and in the middle relative to the analysis position of the sample tube is a gripper unit 2108 that is controlled by a computer. The gripper unit 2108 grips the sample tube 2106 located in a rack of the input section and lifts it into the analysis position. The gripper unit 2108 can comprise a gripper housing 2110. The gripper unit 2108 can also have a plurality of gripper fingers 2112 which can be used to grip the sample tube 2106.

[0108] As an alternative to the liquid level detection device using a camera unit, the liquid level detection may also be accomplished by the use of another type of image acquisition device such as a device that has laser diodes with a defined wavelength and analysis algorithms to evaluate the absorption spectra. A laser diode beam can be focused on sections of the sample tube, and an absorption and transmission measurement of different wavelengths of the focused beam can be measured. The analysis algorithm can then use the measurements to provide the liquid level and volume.

[0109] FIG. 11 depicts an example of sample level detection utilizing the analysis of absorption and transmission curves at distinct wavelengths. In instances in which blood samples are provided with the sample tube container, the system may additionally be able to detect the distinct levels of serum, plasma, or blood-cake in the total level liquid.

[0110] In FIG. 11, a portion of an operable fluid sample interrogation system is depicted generally at 2256. A first source of radiation 2258 (with a second source of radiation 2272 turned off) is arranged to apply a first radiation having a first characteristic wavelength (e.g., 980 nm) to beam combiner 2260, which directs the first emitted radiation 2262 toward a location on the sample tube 2200. The first transmitted radiation 2264 is detected by a detector, such as illustrated photo diode and amplifier arrangement 2266. A signal 2268, corresponding to the intensity of first transmitted radiation 2264 can then be stored and/or manipulated in comparison structure, such as programmable integrated circuit 2270, or a computer. The second source of radiation 2272 (with the first source of radiation 2258 turned off) is arranged to apply a second radiation having a second characteristic wavelength (e.g., 1050 nm) to beam combiner 2260 at a slightly shifted position as the first emitted radiation 2262, which directs the second emitted radiation 2274 parallel to the beam path of first emitted radiation 2262 toward a slightly different location on the sample tube 2200. The second transmitted radiation 2276 is detected by the same detector, such as illustrated photo diode and amplifier arrangement 2266. A signal 2268, corresponding to the intensity of second transmitted radiation 2276 can then be stored and/or manipulated in comparison structure, such as programmable integrated circuit 2270, or a computer.

[0111] FIG. 11 further depicts a sample tube that is being measured and analyzed using the wavelength process. As shown, serum 2215 and gel 2217 are mostly transparent to visible light while red blood cells 2219 are substantially opaque. Further, gel 2217 is transparent to infrared light while red blood cells 2219 and serum 2215 are substantially opaque. Accordingly, when the sample tube 2200 has gel 2217 to separate the serum 2215 and red blood cells 2219, it is possible just using infrared light to "see through" different sections. The infrared light reading is strong when the infrared light beam passes through air 2213, drops when the infrared light beam is directed toward the serum, is relatively strong when directed toward the gel 2217, and drops again when directed toward the red blood cells 2219. This analysis performed by the analysis tool allows for the measurement of the sample level/volume of the sample.

[0112] The liquid level detection unit can be combined with any of the above-described robotic arms with or without a tube identification unit, and with or without a tube or rack presence detection unit. Further details regarding tube identification units and tube or rack presence detection units can be found in U.S. Provisional Patent Application Nos. 61/556,667, 61/616,994, and 61/680,066.

Centrifuge Drawer

[0113] FIGS. 12-19 show various systems associated with a centrifuge drawer 6800. Mounting a centrifuge on a centrifuge drawer can facilitate movement of the centrifuge for service access and can simplify re-installation of a centrifuge. As shown in FIG. 12, centrifuge drawer includes a mounting platform 6802 coupled to frame 6804 via telescoping rails 6806. A centrifuge (not shown) may be mounted on mounting platform 6802. Telescoping rails 6806 can be extended to allow the centrifuge to be withdrawn from its installed position. Telescoping rails 6806 may be locking rails such that the centrifuge can be locked in its installed position (retracted position) or locked in a fully extended position in which the centrifuge is extended away from its installed position. In this manner, the centrifuge is prevented from being moved by the drawer while a centrifuge cycle is in progress. In some embodiments, centrifuge drawer 6800 includes alignment pucks 6808 to mechanically hold the position of the centrifuge to frame 6804. Centrifuge drawer 6800 may further comprise two or more wheels 6810 coupled to frame 6804.

[0114] The centrifuge typically receives power and communications capability through cables that connect the centrifuge module power source. Centrifuge drawer 6800 may include a feature for managing cables when the drawer is extended and retracted. In some embodiments, centrifuge drawer 6800 comprises a flexible cable container such as e-chain 6812 as shown in retracted position 6812(a) and extended position 6812(b) in FIG. 13. Although e-chain 6812 is shown in both retracted and extended positions for illustrative purposes, typically centrifuge drawer 6800 would have a single e-chain 6812 that would move between positions 6812(a) and 6812(b) as the drawer is operated. E-chain 6812 may contain cables such as power and communication cables. E-chain 6812 may be constructed from a flexible material such as a flexible plastic configured to extend and retract such that cables contained within e-chain 6812 do not interfere with the operation of centrifuge drawer 6800.

[0115] In another embodiment, a cable retractor 6814 can be used to manage cables, as shown in FIGS. 14(a)-14(b). Cable retractor 6814 may use a spring loaded cable retractor 6816 coupled to frame 6804 to keep one or more cables 6818 from interfering with the operation of centrifuge drawer 6800. Spring loaded cable retractor 6816 is shown in retracted position 6816(a) and extended position 6816(b). A spring in spring loaded cable retractor 6816 includes a spring 6816(a), 6816(b) coupled to a cable associated with the centrifuge. When the drawer is extended, the spring 6816(a), 6816(b) extends, allowing the cable to extend without coming into contact with the drawer. When the drawer is retracted, the spring compresses, pulling the cable away from frame 6804.

[0116] In some embodiments, centrifuge drawer 6800 includes a movement prevention measure. Movement of the drawer while the centrifuge is in operation could cause rotor imbalance and/or collision between the rotor bucket and containment can. Centrifuge drawer 6800 may include a permanent magnet with electric override to hold the centrifuge in place. To operate the drawer (e.g., to extend the drawer), the magnetic force of the permanent magnet is overpowered by application of an electric current to the electromagnet. For example, the electromagnet current may be activated with a polarization to counteract the magnetic field of the permanent magnet.

[0117] The centrifuge drawer 6800 may include a permanent magnet with electromagnet override latch 6819 as shown in FIG. 15. The permanent magnet latch may be installed between wheels 6810 of centrifuge drawer 6800. The permanent magnet may hold the drawer in a fully retracted state when the drawer is retracted. For example, the electromagnet current may be activated with a polarization to reinforce the magnetic field of the permanent magnet. The force of the permanent magnet may be sufficient to hold centrifuge drawer in place while the centrifuge is not running. In some embodiments, the electromagnet 6819 is engaged to hold the drawer in a fully retracted state when the centrifuge is running.

[0118] Centrifuge drawer 6800 may comprise an electric rotary mechanical latch. FIG. 16(a) shows a perspective view of the mechanical latch and FIG. 16(b) shows a cross-sectional view of the mechanical latch. To extend the drawer, an electrical signal is sent from a controller to the latch and, in response, an electric motor rotates cam 6818. The controller may be a latch controller, a centrifuge drawer controller, a centrifuge controller, or another controller. The rotation of cam 6818 causes latch element 6820 to rotate about pivot 6822. Latch element 6820 may be a bar shaped to interface with latch element 6824. Latch element 6820 may also have a cable override element 6832 that will allow the drawer to be extended when power is lost in the event of a power failure. Latch element 6824 may have a first tine 6825 and a second tine 6827. The tines 6825, 6827 can restrain the movement of a striker bolt 6830 when the striker bolt is within opening 6826. Striker bolt 6830 is attached to the drawer frame 6804. The rotation of latch element 6820 around pivot 6822 causes latch element 6824 to be released. A spring (not shown), which may be a torsion spring, such as a weak torsion spring, can cause latch element 6825 to rotate clockwise when latch element 6824 is not restrained by latch element 6820. The operation of drawer 6800 to retract the drawer can also cause latch element 6824 to rotate clockwise. When latch element 6824 has rotated such that opening 6826 is no longer blocked by tine 6825 of the latch element, the striker bolt 6830 is no longer restrained and the drawer can be extended. FIG. 16(c) shows the configuration of latch elements 6820, 6824 when the latch is in an open position such that striker bolt 6830 is no longer restrained.

[0119] Latch sensor 6828 may be capable of detecting the position of the drawer. When the drawer is in a retracted position, latch sensor 6828 can send a signal to rotate cam 6818 such that

6820 is returned to the position shown in FIG. 16(b). Counterclockwise rotation of 6825 (e.g., by urging striker bolt 6830 against tine 6827 to return latch element 6824 to the position shown in FIG. 16(b). In this way, the drawer 6800 can be mechanically locked once it is retracted.

[0120] In some embodiments, centrifuge drawer 6800 comprises a damping mechanism to mitigate vibration of the frame 6804 when the drawer is being retracted to allow the centrifuge module to continue processing samples. A damping mechanism such as the compression damper 6840 shown in FIG. 17 can be used to couple frame 6804 to platform 6802 via the damper contractor 6842 such that a force exerted to retract the drawer is speed controlled compression damper 6840. The compression damper may be a gas or fluid damper. In some embodiments, the gas damper allows the centrifuge to be retracted freely until a state requiring control is reached.

[0121] FIG. 18 shows a cover for a centrifuge drawer. Cover 6850 can be removed from the centrifuge drawer 6800 to allow access to drawer frame 6804 for loading the centrifuge onto the platform 6802. Cover 6850 may include a handle 6852 to provide a user with a gripping point to extend the centrifuge.

[0122] FIG. 19 illustrates a workflow for loading a centrifuge onto drawer 6800. At 7500, centrifuge 7502 is in crate 7504. For example, the centrifuge may have been recently shipped to the laboratory. At 7508, a loading tool 7510 having may be applied to the centrifuge 7502. Loading tool 7510 may have a plurality of wheels 7520 and a plurality of jacks 7522. At 7512, the centrifuge is jacked up by extending the jacks of loading tool 7510. At this point, crate 7504 can be removed. At 7514, centrifuge 7502 can be rolled over drawer 6800 using loading tool 7510. The jacks can be retracted such that the centrifuge 7502 is supported by centrifuge drawer 6800. At 7516, loading tool 7510 is removed. At 7518, cover 6852 can be attached to drawer 6800.

Centrifuge Adapter Gripper

[0123] A robotic arm may be capable of picking up and transporting a centrifuge adapter. For example, centrifuge adapters that are loaded with sample tubes ready to be centrifuged may be transported from the distribution area 204 to the centrifuge module 206 via a shuttle 224. The centrifuge adapters are loaded into the centrifuge, after which the samples can be centrifuged.

[0124] FIG. 20(a) shows an illustrative gripper element of a centrifuge adapter gripper. Centrifuge adapter gripper 227 (not shown) may comprise a gripper element 7600 coupled to a robotic arm. Gripper element 7600 may be a bolt. The bolt 7600 may be rounded at tip 7602 to allow the bolt 7600 to be inserted into a dedicated hooking element in centrifuge adapter tubular holder 7604. The bolt 7600 may comprise lateral pins 7606 coupled to opposing sides of bolt 7600. When bolt 7600 is rotated to a locked position within tubular holder 7604, the gripper can lift up centrifuge adapter 1002.

[0125] FIG.20(b) shows tubular holder 7604, according to a first embodiment. Tubular holder 7604 may comprise vertical grooves 7608 configured to receive pins 7606 of bolt 7600. Tubular holder 7604 may also comprise horizontal grooves 7610. Each horizontal groove 7610 may connect to a vertical groove 7608. In some embodiments, horizontal groves 7610 may be slots in tubular holder 7604. When bolt 7600 is inserted into tubular holder 7604, gripper pins 7606 may be guided downward by vertical grooves 7608. Gripper 227 may rotate bolt 7600 (e.g., by 90 degrees) such that the pins 7606 follow the horizontal grooves 7610 in tubular holder 7604 until pins 7606 reach the gripping position indicated by notches 7612. In this manner, the gripper can lift and transport centrifuge adapter 1002. To release bolt 7600 from centrifuge adapter tubular holder 7604, the bolt is rotated in the opposite direction.

[0126] FIGS. 21(a)-21(b) show tubular holder 7704, according to a second embodiment. Tubular holder 7704 may have a keyhole opening 7712 configured to match the cross-sectional profile of bolt 7700 with pins 7706. When bolt 7700 is inserted into tubular holder 7704, gripper pins 7606 fit through keyhole opening 7712 and are lowered below a shelf 7708. When the pins 7706 are below shelf 7708, gripper 227 may rotate bolt 7700 (e.g., by 90 degrees) such that the pins 7706 are seated in notch 7712. In this manner, the gripper can lift and transport centrifuge adapter 1002. To release bolt 7700 from centrifuge adapter tubular holder 7704, the bolt is rotated in the opposite direction.

[0127] Various measures may be implemented to prevent the centrifuge adapter from swinging during x- and y-axis movement of centrifuge adapter gripper 227. For example, gripper 227 may be operated at the extent of its z-axis range such that the top of the adapter is pressed against the underside of the housing of gripper 227. In this manner, any motion of centrifuge adapter 1002 with respect to gripper may be damped. In some embodiments, one or more springs may be used to prevent vibrations from the gripper housing from causing swinging of the centrifuge adapter.

[0128] In some embodiments, a robotic arm may be a combined gripper capable of gripping sample tubes as well as adapters 1002 used in the centrifuge module 206. One or more centrifuge area grippers may perform several functions, including picking up sample tubes at an input area 202, transporting sample tubes to a loading position 1004 for an empty centrifuge bucket, placing sample tubes in a free position of the centrifuge adapter, choosing a completely (or incompletely) filled centrifuge adapter, transporting the centrifuge adapter to an available centrifuge, placing the centrifuge adapter in a free position of the centrifuge rotor, choosing a centrifuged adapter, transporting a centrifuged adapter to an unloading position for a centrifuged adapter, picking up centrifuged sample tubes in the centrifuged adapter, etc.

[0129] In another embodiment, a single sample tube gripper can be applied to a telescopic robotic arm. The sample tube gripper unit may be moved down into the centrifuge body using the telescopic robotic arm. The sample tube gripper robot may then grip the centrifuge buckets with its standard gripper unit.

[0130] In another embodiment, a centrifuge bucket gripper unit can be applied to the telescopic robotic arm in addition to a standard sample tube gripper.

Centrifuge Adapter Lift-Up Prevention

[0131] A sticky label or stuck specimen tube may cause a centrifuge adapter 1002 to become airborne when centrifuge tube gripper 226 removes a sample tube from an adapter. Various lift-up prevention devices to prevent adapters 1002 from becoming airborne are described below. Typically, a lift-up prevention device is activated only when sample tubes are being loaded into and unloaded from adapters, allowing the adapters to move freely when adapters are being moved.

[0132] FIGS. 22(a)-(c) show an illustrative hook lift-up prevention device. In some embodiments, an adapter has a mechanical locking feature. For example, adapter 1002, shown in FIG. 22(a), may comprise an opening 7902. Shuttle 224, shown in FIG. 22(b), may have hook 7906 configured to be inserted into opening 7902. The hook is configured to be inserted into opening 7902 and to hold adapter 1002 to shuttle 224 when hook 7906 is inserted into opening 7902 of adapter 1002.

[0133] When the shuttle is moved to a position at which tubes can be unloaded from an adapter 1002, hook 7906 is inserted through opening 7902 and, subsequently, adapter 1002 is shifted such that hook 7906 overhangs a ledge in opening 7902 to prevent adapter 1002 from lifting off of shuttle 224, as shown in FIG. 22(c). When adapter 1002 is shifted into the adapter swapping position, the hook mechanism may be disengaged.

[0134] FIG. 23 shows an illustrative magnetic lift-up prevention device. In some embodiments, a ferromagnetic object, such as metal object 8000 (e.g., a steel bar) may be coupled to adapter 1002. For example, steel bar 8000 may be coupled to underside of adapter 1002 that rests on shuttle 224. When the shuttle is in an unloading position, stationary electromagnet (not shown) under steel bar 8000 may be powered in order to create a magnetic field to attract steel bar 8000 to the stationary electromagnet. The electromagnet may receive power from a power supply coupled to a controller in response to a signal sent to the power supply from the controller. The controller may be a centrifuge adapter shuttle controller or another controller. In this manner, adapter 1002 can be held in place during unloading. When unloading of adapter 1002 is complete, power to the stationary electromagnet can be discontinued to allow adapter 1002 to be moved. The magnetic lift-up prevention approach advantageously requires no mechanical parts and can be quickly activated and de-activated.

Computer Apparatus

[0135] The various participants and elements described herein with reference to the figures may operate one or more computer apparatuses to facilitate the functions described herein. Any of the elements in the above description, including any servers, processors, or databases, may use any suitable number of subsystems to facilitate the functions described herein, such as, e.g., functions for operating and/or controlling the functional units and modules of the laboratory automation system, transportation systems, the scheduler, the central controller, centrifuge controller, balance controller, etc.

[0136] Examples of such subsystems or components are shown in FIG.24. The subsystems shown in FIG. 84 are interconnected via a system bus 8405. Additional subsystems such as a printer 8404, keyboard 8408, fixed disk 8409 (or other memory comprising computer readable media), monitor 8406, which is coupled to display adapter 8412, and others are shown. Peripherals and input/output (I/O) devices, which couple to I/O controller 8401 (which can be a processor or other suitable controller), can be connected to the computer system by any number of means known in the art, such as serial port 8414. For example, serial port 8414 or external interface 8411 can be used to connect the computer apparatus to a wide area network such as the Internet, a mouse input device, or a scanner. The interconnection via system bus allows the central processor 8403 to communicate with each subsystem and to control the execution of instructions from system memory 8402 or the fixed disk 8409, as well as the exchange of information between subsystems. The system memory 8402 and/or the fixed disk 8409 may embody a computer readable medium.

[0137] Embodiments of the technology are not limited to the above-described embodiments. Specific details regarding some of the above-described aspects are provided above. The specific details of the specific aspects may be combined in any suitable manner without departing from the spirit and scope of embodiments of the technology. For example, any features of any two or more specific embodiments as described above, can be combined in any suitable manner without departing from the spirit and scope of the invention.

[0138] It should be understood that the present technology as described above can be implemented in the form of control logic using computer software (stored in a tangible physical medium) in a modular or integrated manner. Furthermore, the present technology may be implemented in the form and/or combination of any image processing. Based on the disclosure and teachings provided herein, a person of ordinary skill in the art will know and appreciate other ways and/or methods to implement the present technology using hardware and a combination of hardware and software

[0139] Any of the software components or functions described in this application, may be implemented as software code to be executed by a processor using any suitable computer language such as, for example, Java, C++ or Perl using, for example, conventional or object-oriented techniques. The software code may be stored as a series of instructions, or commands on a computer readable medium, such as a random access memory (RAM), a read only memory (ROM), a magnetic medium such as a hard-drive or a floppy disk, or an optical medium such as a CD-ROM. Any such computer readable medium may reside on or within a single computational apparatus, and may be present on or within different computational apparatuses within a system or network.

[0140] The above description is illustrative and is not restrictive. Many variations of the technology will become apparent to those skilled in the art upon review of the disclosure. The scope of the technology should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the pending claims along with their full scope or equivalents.

[0141] One or more features from any embodiment may be combined with one or more features of any other embodiment without departing from the scope of the technology.

[0142] A recitation of "a", "an" or "the" is intended to mean "one or more" unless specifically indicated to the contrary.

[0143] All patents, patent applications, publications, and descriptions mentioned above are herein incorporated by reference in their entirety for all purposes. None is admitted to be prior art.

WHAT IS CLAIMED IS:

1. A method comprising:

loading, by a first specimen container gripper, a plurality of specimen containers into a centrifuge adapter, wherein the first specimen container gripper sequentially loads single specimen containers of the plurality of specimen containers into the centrifuge adapter until the plurality of specimen containers are loaded;

transporting, by an adapter shuttle, the centrifuge adapter to a centrifuge area;

transporting, by a centrifuge adapter gripper, the centrifuge adapter into a centrifuge;

centrifuging, by a centrifuge, the centrifuge adapter; and

transporting, by the centrifuge adapter gripper, the centrifuge adapter from the centrifuge to an adapter shuttle; and

unloading, by a second specimen container gripper, the plurality of specimen containers from the centrifuge adapter, wherein the second specimen container gripper sequentially unloads single specimen containers of the plurality of specimen containers until the plurality of specimen containers are unloaded.

2. The method of claim 1, wherein a weight of one or more specimen containers of the plurality of specimen containers is determined prior to loading, by a first specimen container gripper, the plurality of specimen containers into a centrifuge adapter.

3. The method of claim 2, wherein the weight of the one or more specimen containers is determined by a gripper configured to transport specimen containers to an area from which the first specimen container gripper grips the plurality of specimen containers.

4. The method of claim 2, wherein the weight of the one or more specimen containers is determined by a balance of a conveyor track.

5. The method of claim 1, wherein the plurality of specimen containers are loaded by the first specimen container gripper into the centrifuge adapter in an sequential order based on priority level of the plurality of specimen containers.

6. The method of claim 1, wherein the plurality of specimen containers are loaded by the first specimen container gripper into the centrifuge adapter in an sequential order based on weight of the plurality of specimen containers.

7. The method of claim 1, wherein the second specimen container gripper is used to determine a quantity of one or more liquids in the specimen container.

8. The method of claim 1, further comprising a second centrifuge, wherein the two centrifuges are run out of phase with one another.

9. A system comprising:

a first specimen container gripper configured to load a specimen container into a centrifuge adapter;

an adapter shuttle configured to transport the centrifuge adapter to a centrifuge area;

a centrifuge adapter gripper configured to load the centrifuge adapter into a centrifuge; and

a second specimen container gripper configured to unload a specimen container from the centrifuge adapter.

10. A method for replacing a set of centrifuged adapters with a set of uncentrifuged adapters, the method comprising:

transporting, by a centrifuge adapter gripper, a centrifuge adapter from which all specimen containers have been removed to a temporary holding area;

transporting, by the centrifuge adapter gripper, a second centrifuge adapter from a centrifuge to a first shuttle position, wherein the second centrifuge adapter contains previously centrifuged sample containers;

transporting, by the centrifuge adapter gripper, a third centrifuge adapter from a second shuttle position to a centrifuge, wherein the third centrifuge adapter contains sample containers that have not been centrifuged; and transporting, by the centrifuge adapter gripper, a fourth centrifuge adapter from a temporary holding area to a second shuttle position, wherein the fourth centrifuge adapter contains sample containers that have not been centrifuged.

11. A method for loading specimen containers into a set of centrifuge adapters, the method comprising:

loading, by a specimen container gripper, a first specimen container that is first in a sequential order into a first position of a first centrifuge adapter, wherein the first position of the first centrifuge adapter is one of a first set of positions that are within a first distance from the center of the first centrifuge adapter;

loading, by the specimen container gripper, a second specimen container that is second in the sequential order into a first position of a second centrifuge adapter, wherein the first position of the second centrifuge adapter is in a first set of positions that are within a first distance from the center of the second centrifuge adapter;

loading, by the specimen container gripper, a third specimen container that is third in the sequential order into a first position of a third centrifuge adapter, wherein the first position of the third centrifuge adapter is in a first set of positions that are within a first distance from the center of the third centrifuge adapter;

loading, by the specimen container gripper, a fourth specimen container that is fourth in the sequential order into a first position of a fourth centrifuge adapter, wherein the first position of the fourth centrifuge adapter is in a first set of positions that within a first distance from the center of the fourth centrifuge adapter;

wherein when all of the first set of positions that are within a first distance from the center of the first centrifuge adapter are filled, all of the first set of positions that are within a first distance from the center of the second centrifuge adapter are filled, all of the first set of positions that are within a first distance from the third centrifuge adapter are filled, and all of the first set of positions that are within a first distance from the center of the fourth centrifuge adapter are filled:

loading, by a specimen container gripper, a fifth specimen container into a second position of a first centrifuge adapter, wherein the second position of the first centrifuge adapter is one of a second set of positions that are not within a first distance from the center of the first centrifuge adapter, wherein the fifth specimen container follows a previously loaded specimen container in the sequential order;

loading, by a specimen container gripper, a sixth specimen container into a second position of a second centrifuge adapter, wherein the second position of the second centrifuge adapter is one of a second set of positions that are not within a first distance from the center of the second centrifuge adapter, wherein the sixth specimen container follows a previously loaded specimen container in the sequential order;

loading, by a specimen container gripper, a seventh specimen container into a second position of a third centrifuge adapter, wherein the second position of the third centrifuge adapter is one of a second set of positions that are not within a first distance from the center of the third centrifuge adapter, wherein the seventh specimen container follows a previously loaded specimen container in the sequential order; and

loading, by a specimen container gripper, an eighth specimen container into a second position of a fourth centrifuge adapter, wherein the second position of the fourth centrifuge adapter is one of a second set of positions that are not within a first distance from the center of the fourth centrifuge adapter, wherein the eighth specimen container follows a previously loaded specimen container in the sequential order.

12. The method of claim 11, wherein the sequential order is based on priority level of the plurality of specimen containers.

13. The method of claim 12, wherein a lower priority sample tube may be loaded in lieu of a higher priority sample tube if the higher priority tube has a weight that exceeds the weight of the lower priority tube by a predetermined amount.

14. The method of claim 11, wherein the sequential order is based on weight of the plurality of specimen containers.

15. The method of claim 14, wherein weight is determined by a specimen container gripper.

16. The method of claim 11, wherein when a cycle for a centrifuge is within a predetermined period of time from completion, loading is halted.

17. A centrifuge drawer, comprising:

a platform coupled to a frame via telescoping rails, the platform configured to support a centrifuge; and

a latch coupled to the platform.

18. The centrifuge drawer of claim 17, wherein the latch includes:

a permanent magnet; and

an electromagnet;

wherein the permanent magnet is configured to anchor the drawer in an extended position or in a retracted position when the centrifuge is not spinning;

wherein current is applied to the electromagnet in a first direction to reinforce the magnetic field of the permanent magnet when the centrifuge is spinning; and

wherein the current is applied to the electromagnet in a second direction to counteract the magnetic field of the permanent magnet when the drawer is operated.

19. The centrifuge drawer of claim 17, wherein the latch includes:

an electric motor communicatively coupled to a controller,

a cam mechanically coupled to the electric motor, wherein the electric motor is configured to rotate the cam in response to receiving a signal from a controller;

a lever in contact with the cam, wherein the rotation of the cam causes the lever to pivot;

a latch element; wherein the latch element is caused to pivot by the rotation of the lever such that a tine of the latch element is rotated to release position, wherein a striker bolt of the centrifuge drawer can be removed from the latch when the latch element is in the release posiiton.

20. The centrifuge drawer of claim 17, further comprising a cable container coupled to the frame, the cable container configured to contain one or more cables of the centrifuge, wherein the cable container includes a flexible material configured to extend when the drawer is extended and compress when the drawer is retracted.

21. The centrifuge drawer of claim 17, further comprising a spring loaded cable retractor coupled to the frame, wherein the spring loaded cable retractor includes a spring that is coupled to one or more cables of the centrifuge, wherein the spring is configured to extend when the drawer is extended and compress when the drawer is retracted.

22. A method for installing a centrifuge in centrifuge drawer, the method comprising:

applying a loading tool to a centrifuge, wherein the loading tool includes a plurality of jacks and a plurality of wheels;

lifting the centrifuge by extending the plurality of jacks;

rolling the centrifuge to a position over centrifuge drawer using the plurality of wheels;

retracting the plurality of jacks until the centrifuge is supported by the centrifuge drawer; and

removing the loading tool from the centrifuge.

23. A centrifuge adapter, comprising:

a tubular holder, wherein a first end of the tubular holder is coupled to the centrifuge adapter and a second end of the tubular holder has an opening configured to receive a bolt, the tubular holder including:

a first vertical groove on the interior of the tubular holder, the first vertical groove terminating at the opening of the tubular holder;

a second vertical groove on the interior of the tubular holder, the second vertical groove terminating at the opening of the tubular holder;

a first horizontal groove of the tubular holder, wherein the first horizontal groove connects with the first vertical groove such that a first pin can enter the tubular holder via the first vertical groove and the first pin can travel from the first vertical groove into the first horizontal groove;

a second horizontal groove of the tubular holder, wherein the second horizontal groove connects with the first vertical groove such that a second pin can enter the tubular holder via the second vertical groove and the second pin can travel from the second vertical groove into the second horizontal groove;

wherein the first pin and the second pin are coupled to the bolt; and

wherein the bolt is coupled to a robotic arm.

24 . A centrifuge adapter, comprising:

a tubular holder, wherein a first end of the tubular holder is coupled to the centrifuge adapter and a second end of the tubular holder has an opening configured to receive a bolt;

wherein a first pin and a second are coupled to the bolt;

wherein the opening has a keyhole shape configured to match a cross-sectional profile of the bolt having the first pin and the second pin;

wherein the tubular holder includes:

a first vertical groove on the interior of the tubular holder, wherein a first end of the first vertical groove terminates at the opening of the tubular holder and a second end of the first vertical groove terminates at a shelf;

a second vertical groove on the interior of the tubular holder, wherein a first end of the second vertical groove terminates at the opening of the tubular holder and a second end of the second vertical groove terminates at the shelf;

wherein the shelf has a first notch and a second notch;

wherein the first vertical groove is configured to receive the first pin and the second vertical groove is configured to receive the second pin when the bolt descends through the opening of the tubular holder; and

wherein the first notch is configured to receive the first pin and the second notch is configured to receive the second pin after the bolt has descended such that the first pin and the second pin are below the shelf and after the bolt has rotated such that first pin aligns with the first notch and the second pin aligns with the second notch.

25. A method for gripping a centrifuge adapter, the method comprising:

inserting, by the downward movement of a robotic arm, a bolt coupled to the robot arm into a tubular holder coupled to a centrifuge adapter;

rotating, by the robot arm, the bolt with respect to the tubular holder, wherein the bolt enters a locking position within the tubular holder; and

lifting, by the upward movement of the robotic arm, the centrifuge adapter, wherein the lifting continues until the upper surface of the tubular holder contacts the lower surface of the housing of the robotic arm, wherein the contact between the tubular holder and the robot arm damps movement of the centrifuge adapter with respect to the robot arm.

26. A centrifuge adapter shuttle, comprising:

one or more hooks movably coupled to the centrifuge adapter shuttle, wherein the hooks are configured to mate with one or more openings in a centrifuge adapter; and

wherein after a centrifuge adapter is loaded onto a centrifuge adapter shuttle, the hooks are moved laterally such that the hooks overhang a ledge of the openings such that the centrifuge adapter is restrained from being lifted away from the centrifuge adapter shuttle.

27. A centrifuge adapter shuttle, comprising:

a controller;

a power supply communicatively coupled to the controller;

an electromagnet mechanically coupled to a centrifuge adapter shuttle, the electromagnet receives power from the power supply; and

wherein after a centrifuge adapter is loaded onto a centrifuge adapter shuttle, power is supplied to the electromagnet such that the electromagnet electromagnetically couples to a metal bar that is coupled to the centrifuge adapter.

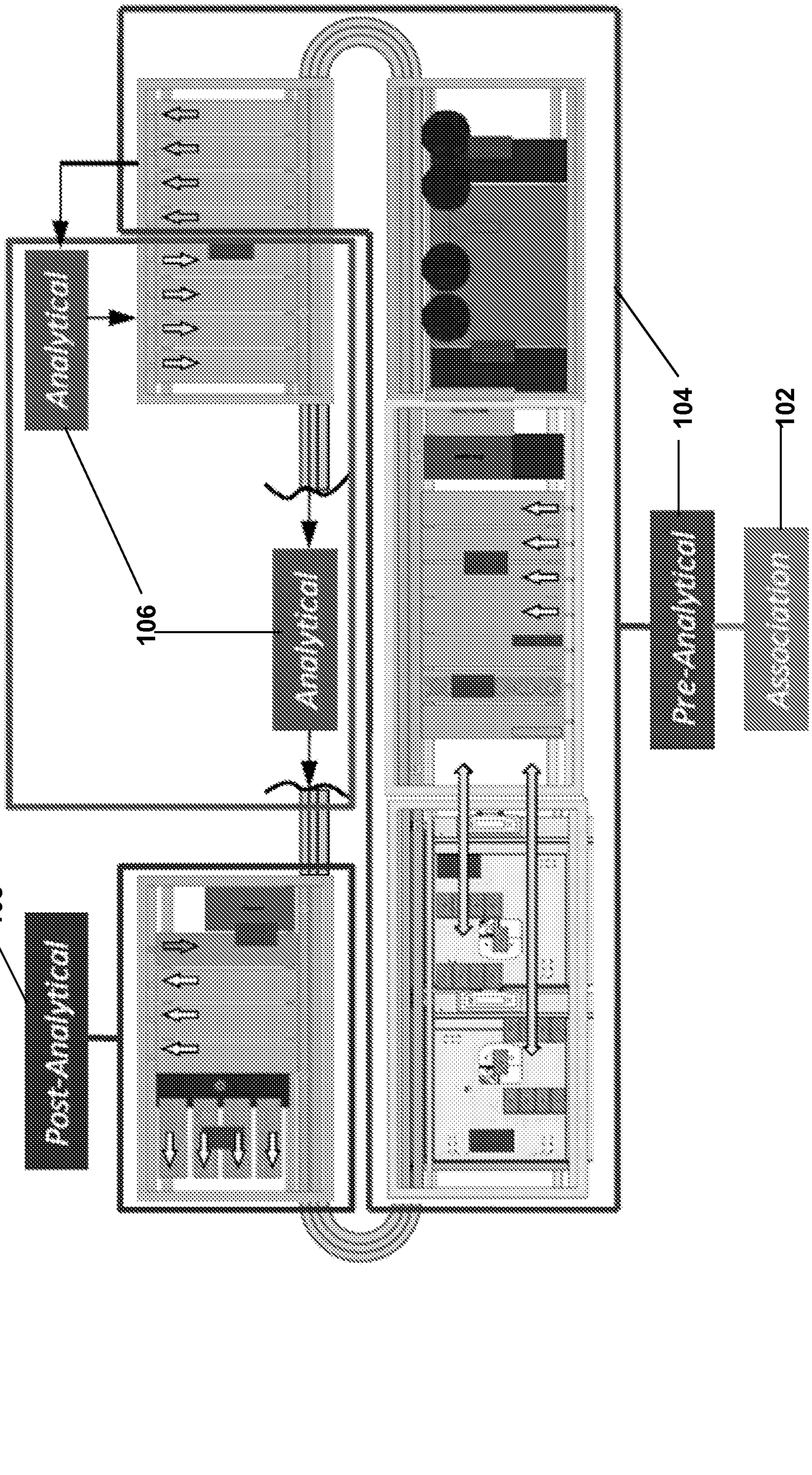
Analytical
Analytical
106
108
Post-Analytical
104
Pre-Analytical
102
Association

FIG. 1

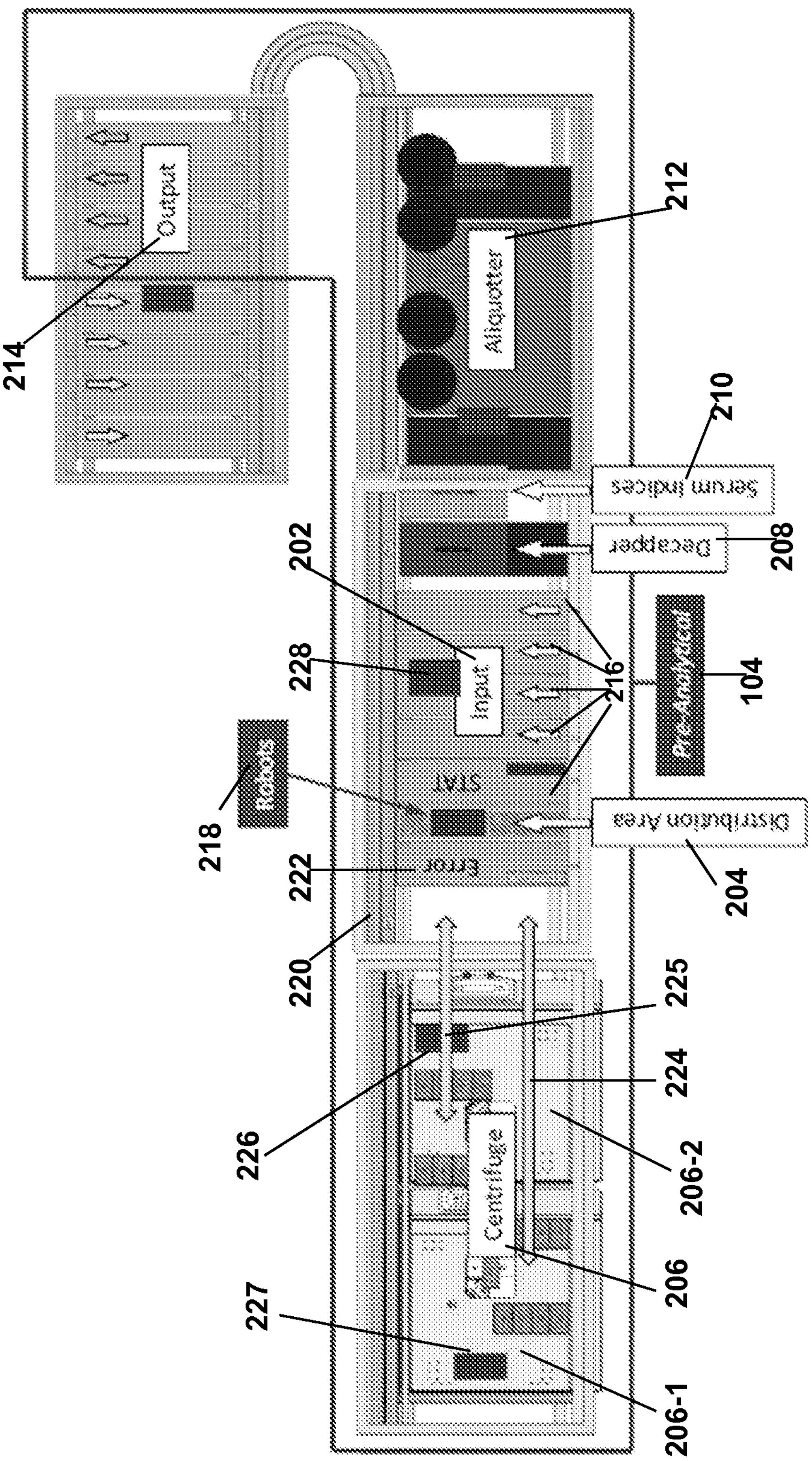
Output
214
Aliquotter
212
Serum Indices
210
Decapper
208
202
228
Input
216
Pre-Analytical
104
Robots
218
STAT
Distribution Area
204
Error
222
220
225
224
226
Centrifuge
206-2
206
227
206-1

FIG. 2

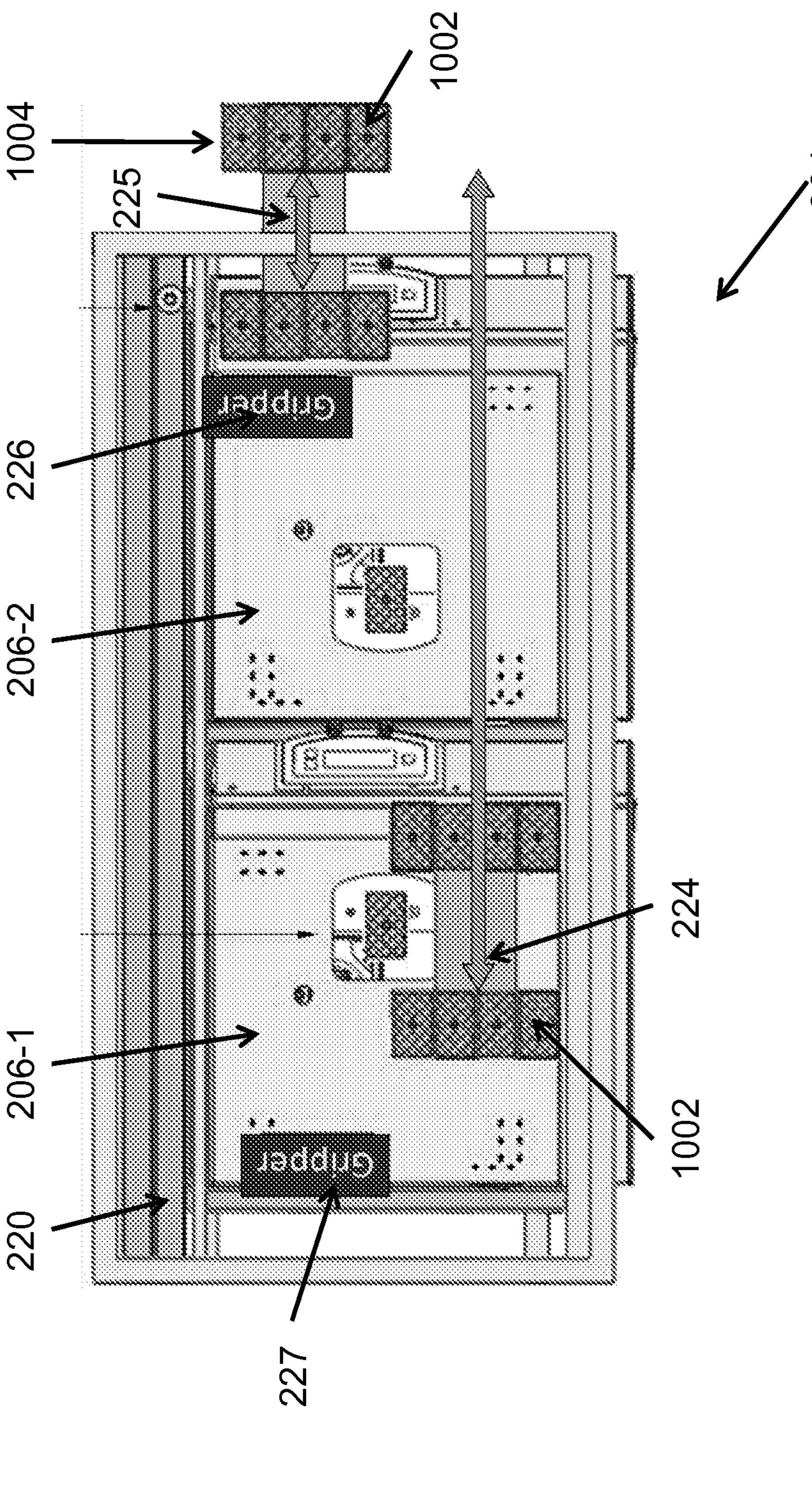
1004
1002
225
304
226
Gripper
206-2
206-1
224
1002
220
Gripper
227

FIG. 3

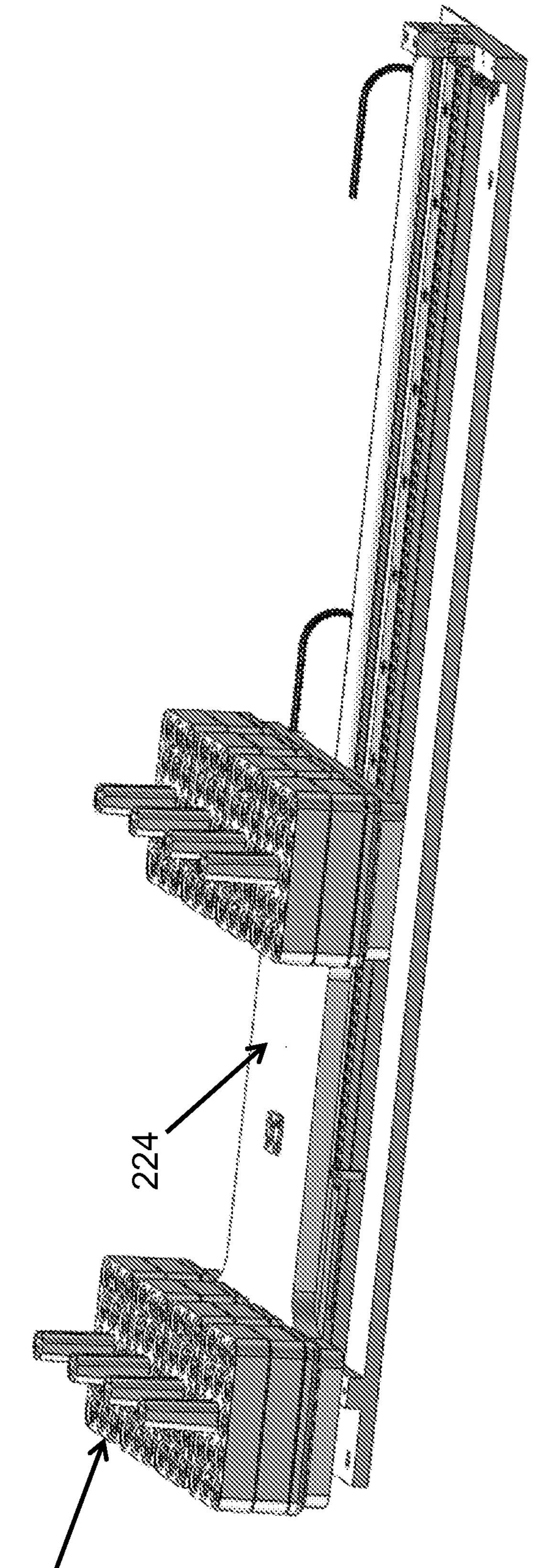

FIG. 4

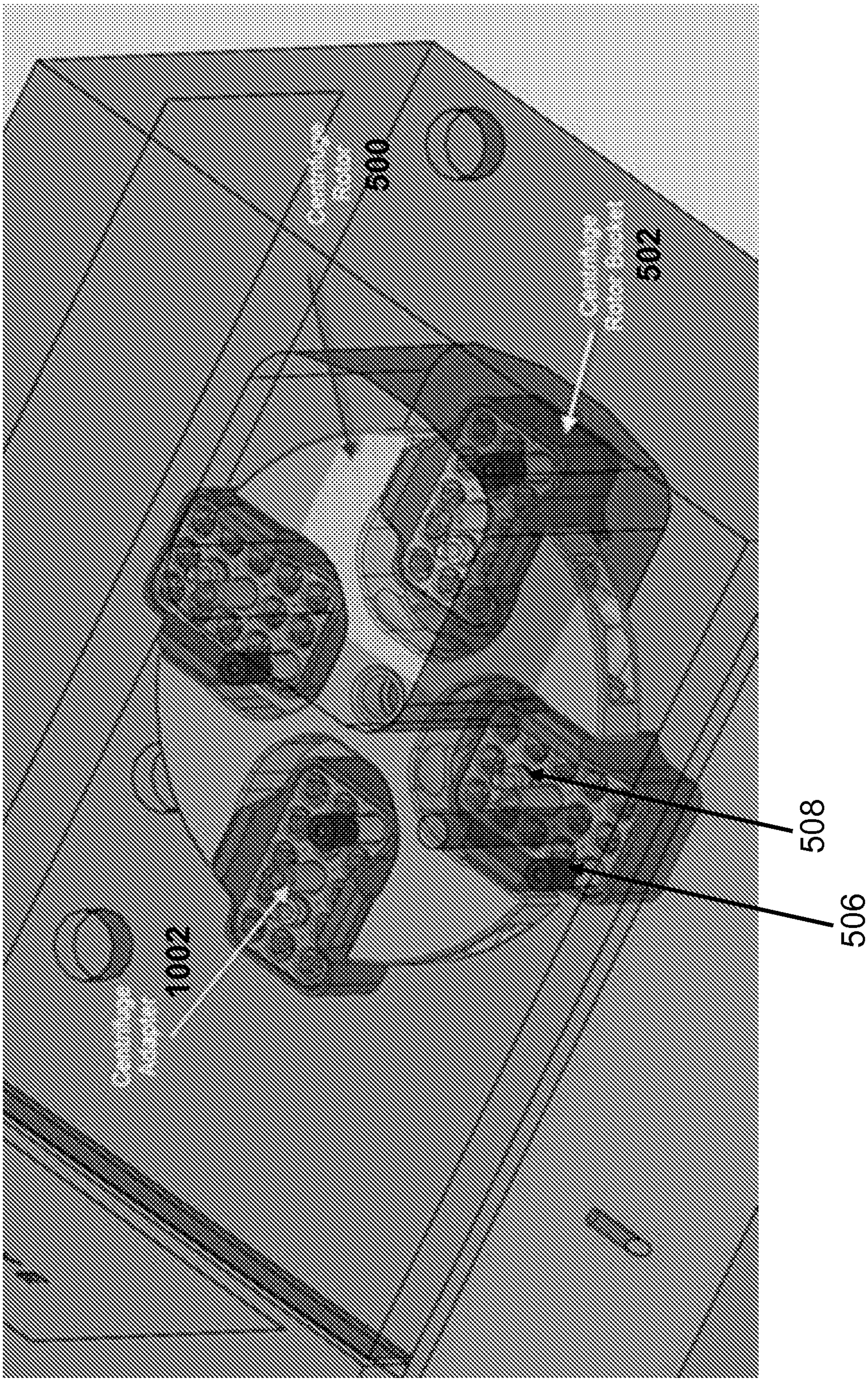

FIG. 5

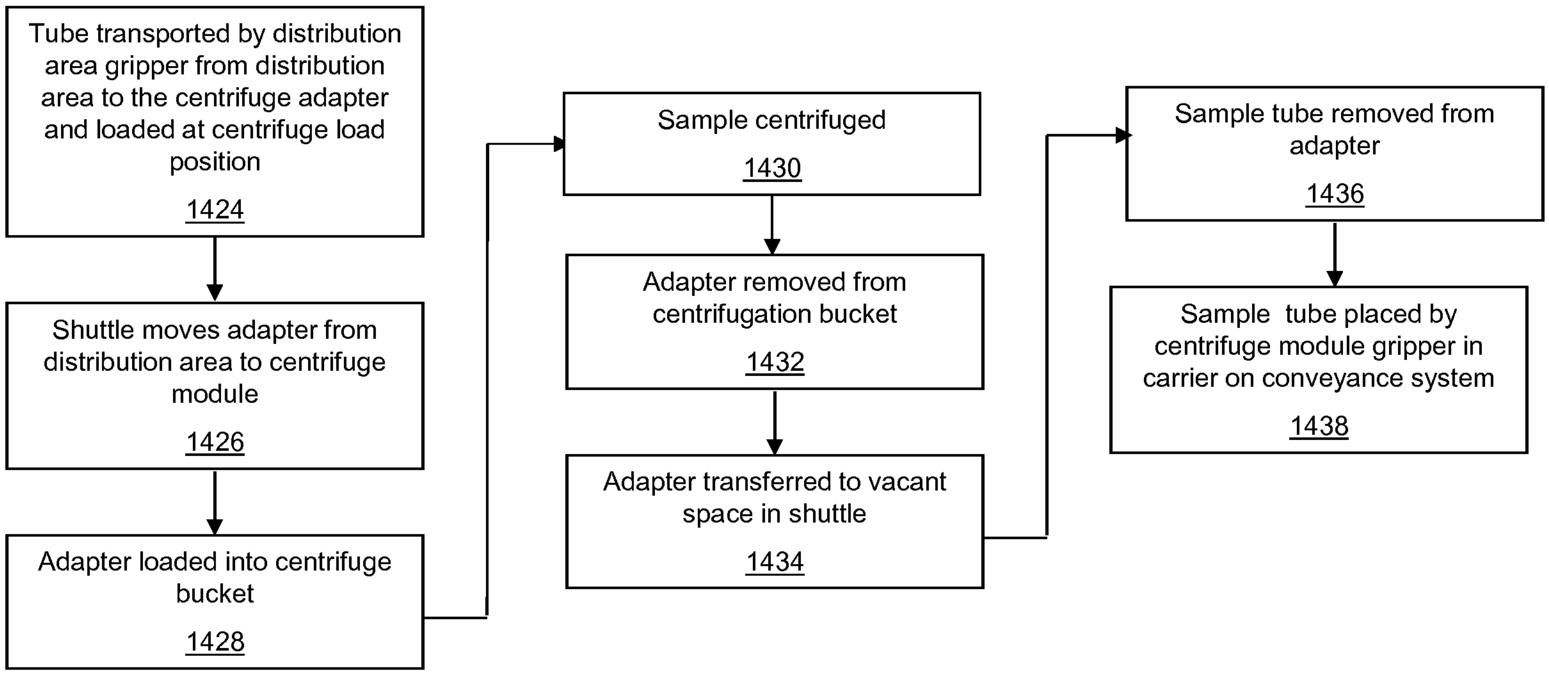
Tube transported by distribution area gripper from distribution area to the centrifuge adapter and loaded at centrifuge load position
1424
Shuttle moves adapter from distribution area to centrifuge module
1426
Adapter loaded into centrifuge bucket
1428
Sample centrifuged
1430
Adapter removed from centrifugation bucket
1432
Adapter transferred to vacant space in shuttle
1434
Sample tube removed from adapter
1436
Sample tube placed by centrifuge module gripper in carrier on conveyance system
1438

FIG. 6

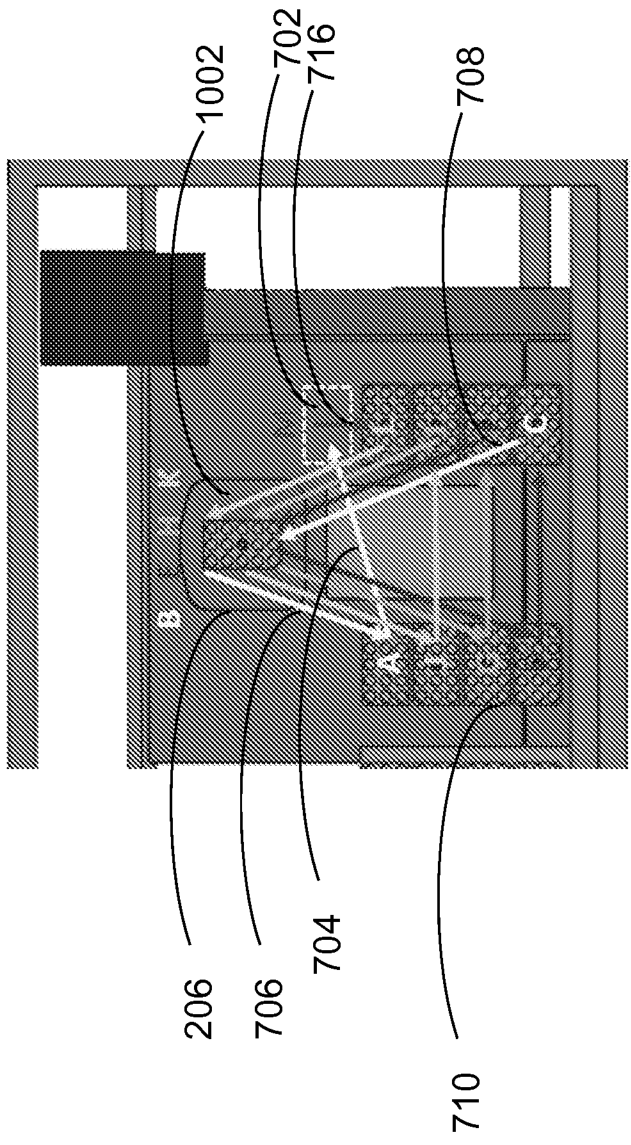

FIG. 7

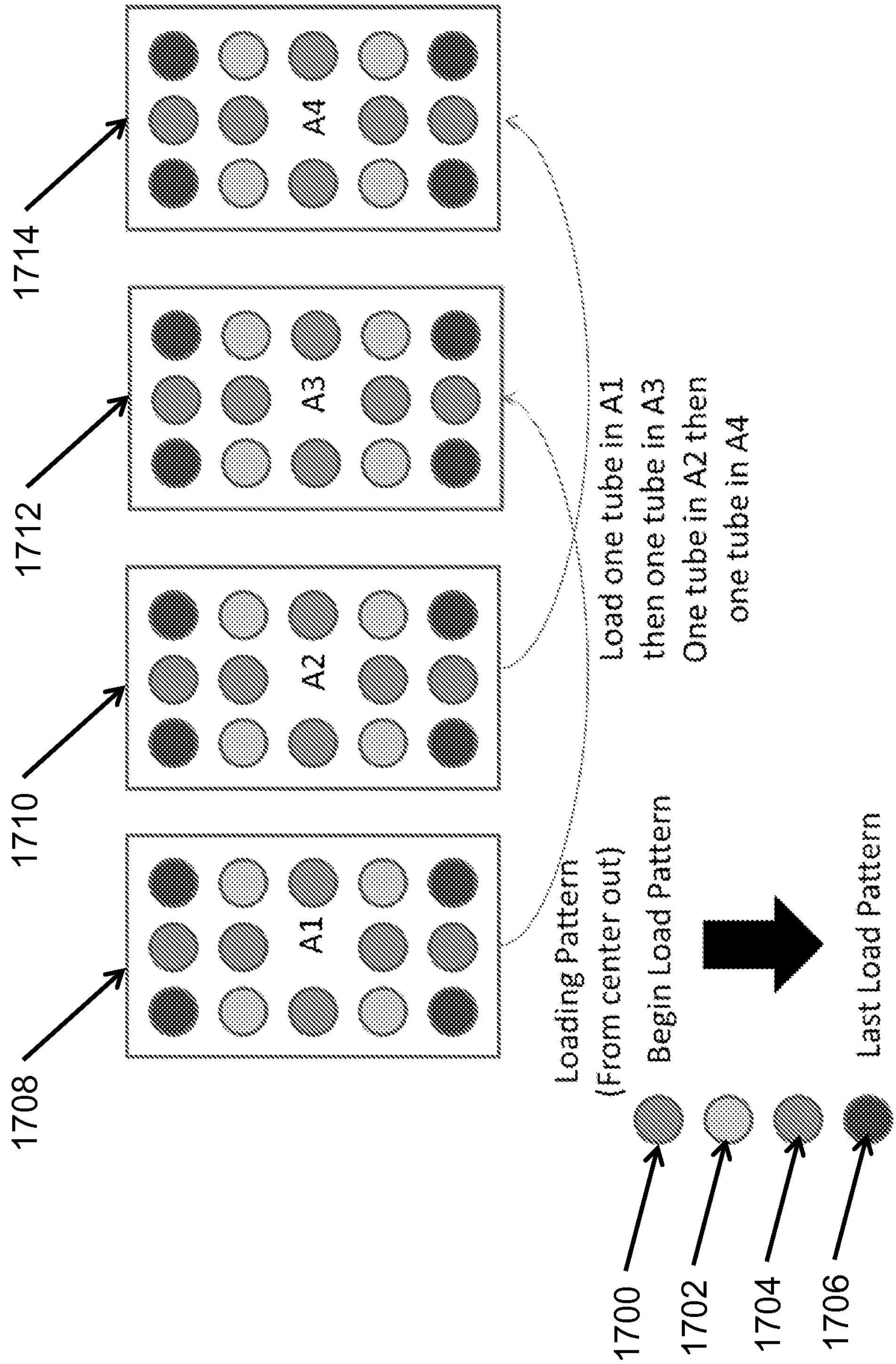
1708
1710
1712
1714
A1
A2
A3
A4
Load one tube in A1
then one tube in A3
One tube in A2 then
one tube in A4
Loading Pattern
(From center out)
Begin Load Pattern
Last Load Pattern
1700
1702
1704
1706

FIG. 8

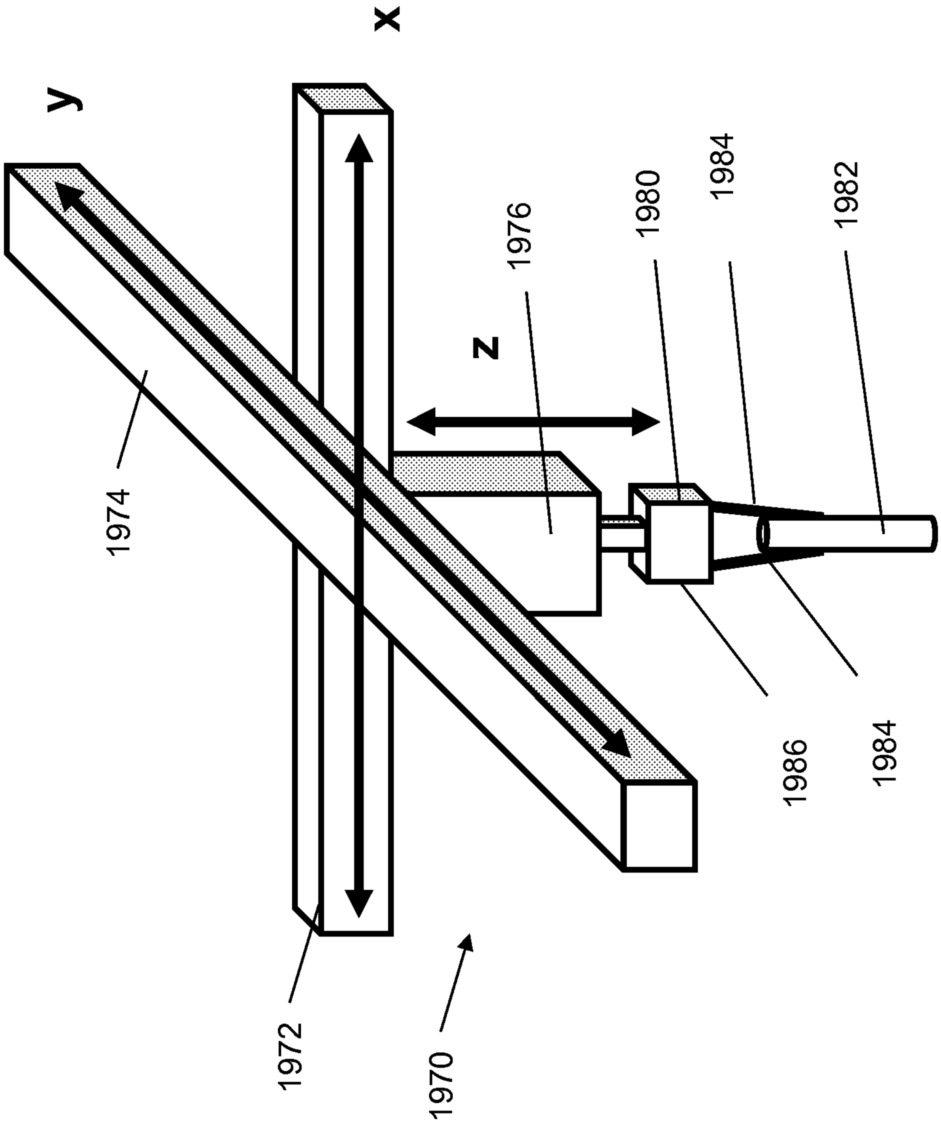

FIG. 9

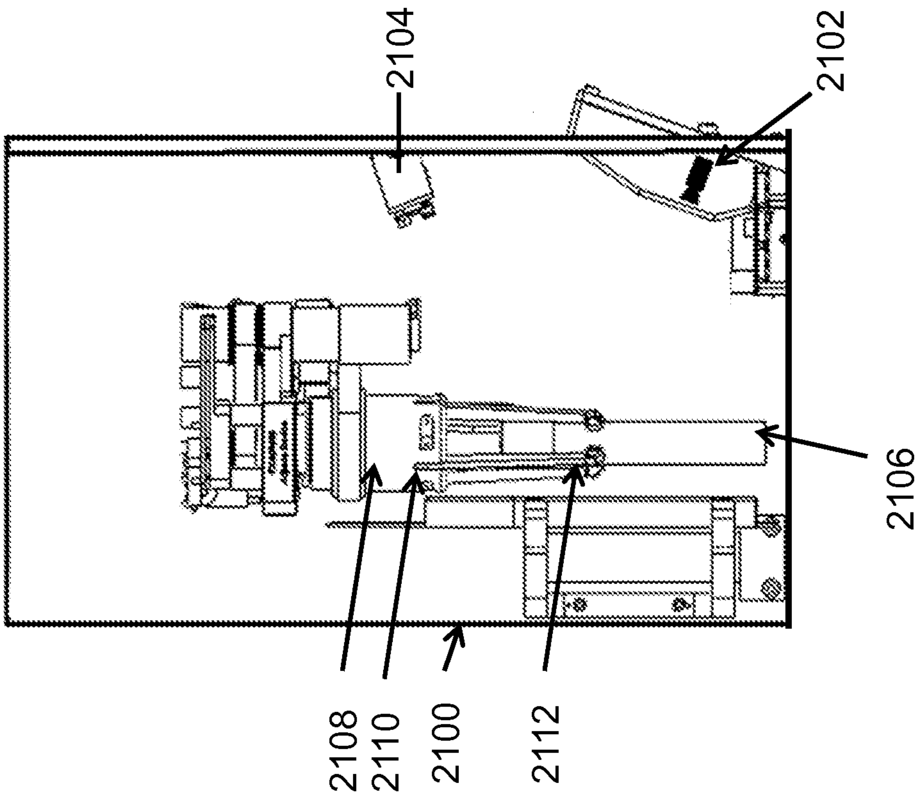

FIG. 10

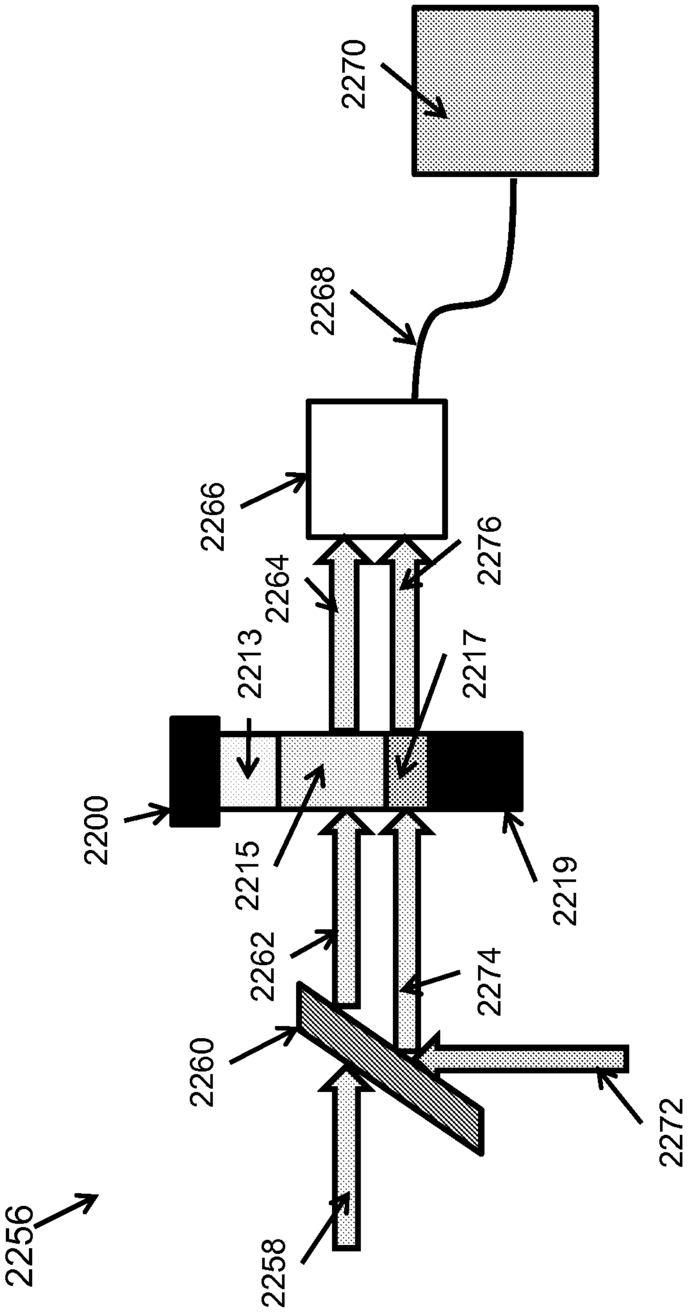
2270
2268
2266
2264
2276
2213
2217
2200
2215
2219
2262
2274
2260
2272
2256
2258

FIG. 11

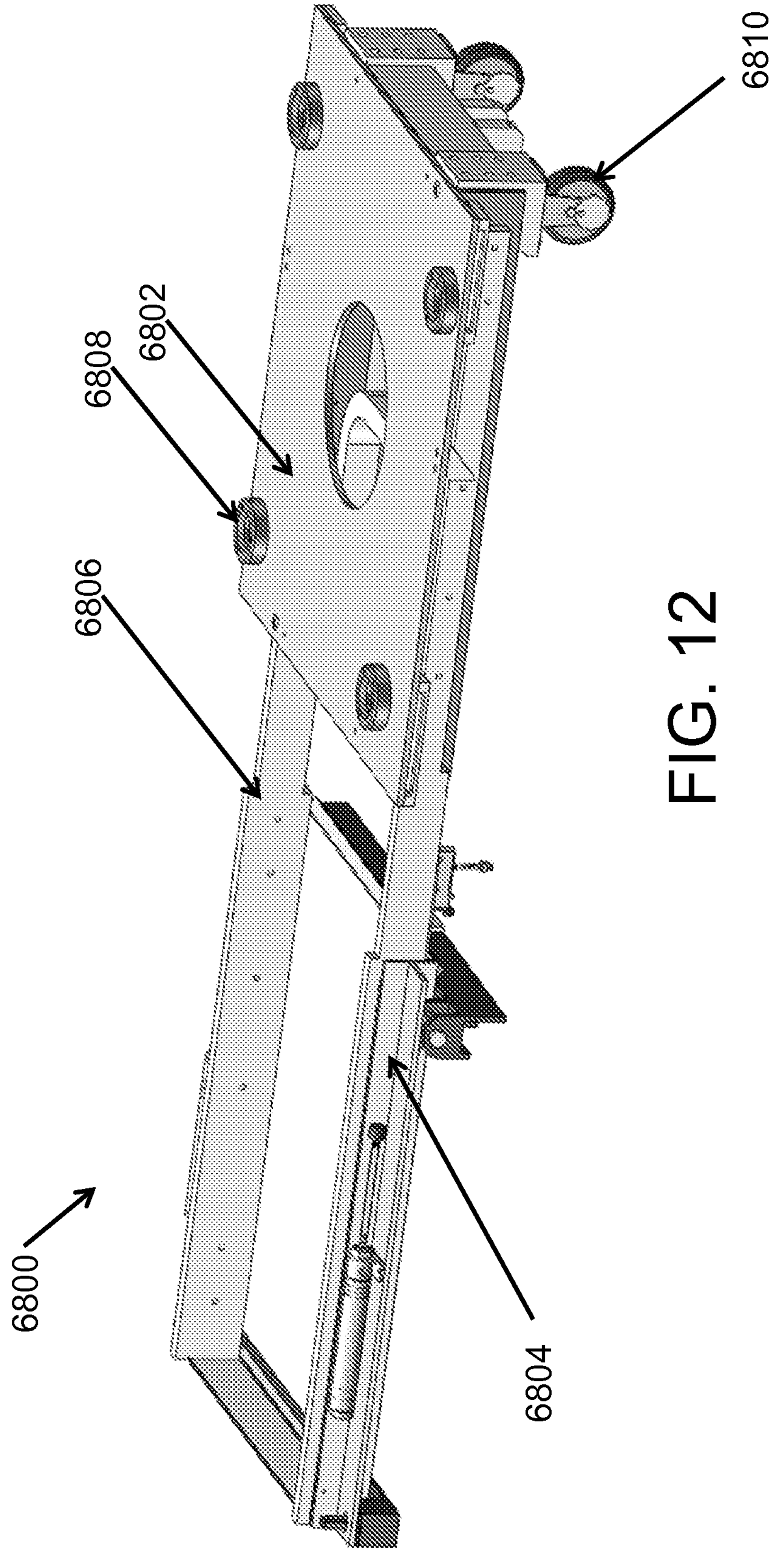

FIG. 12

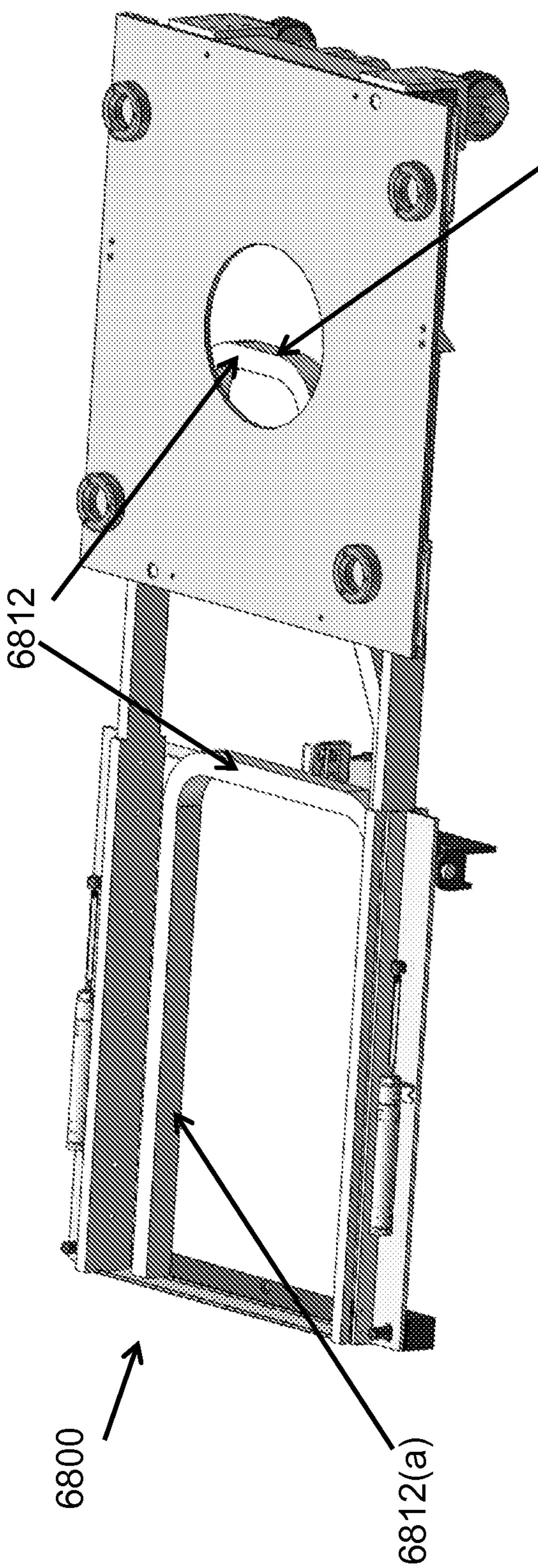

FIG. 13

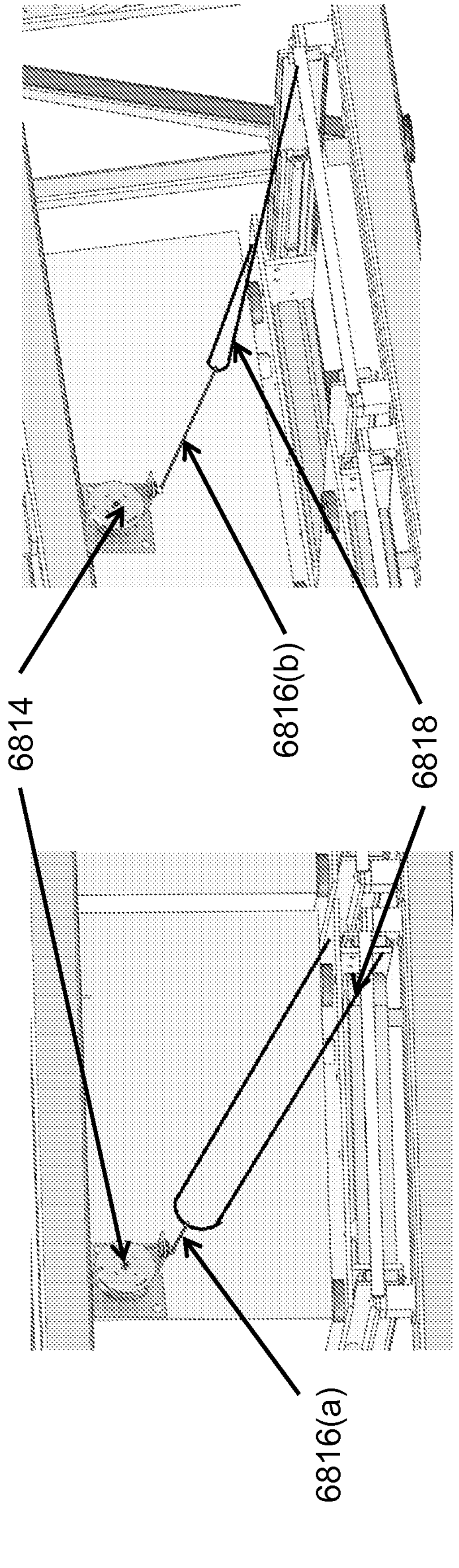

FIG. 14(a)

FIG. 14(b)

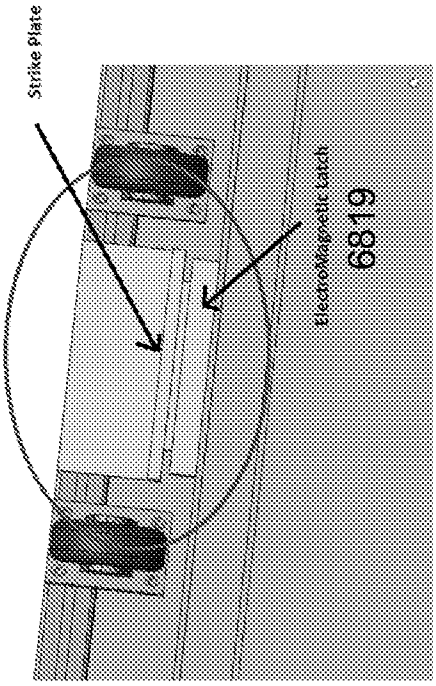

FIG. 15

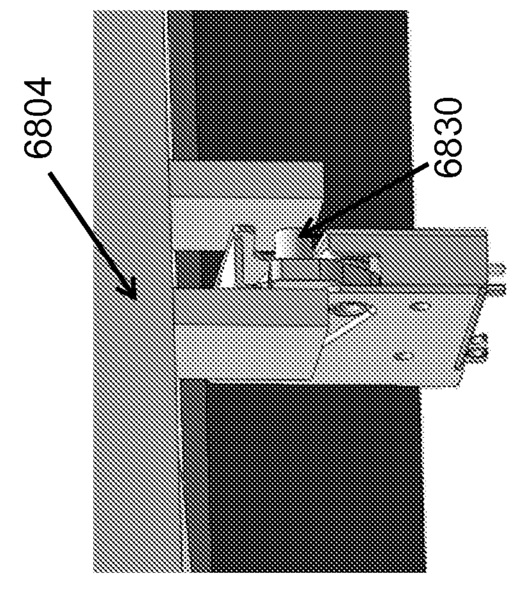

FIG. 16(a)

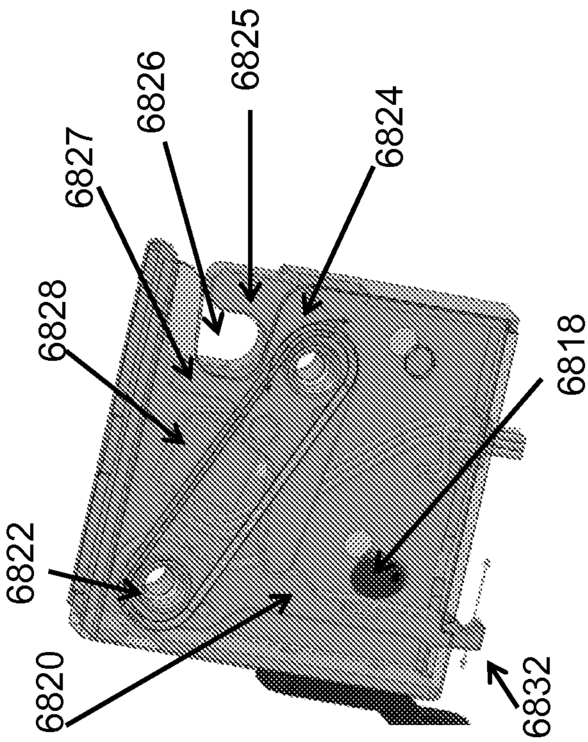

FIG. 16(b)

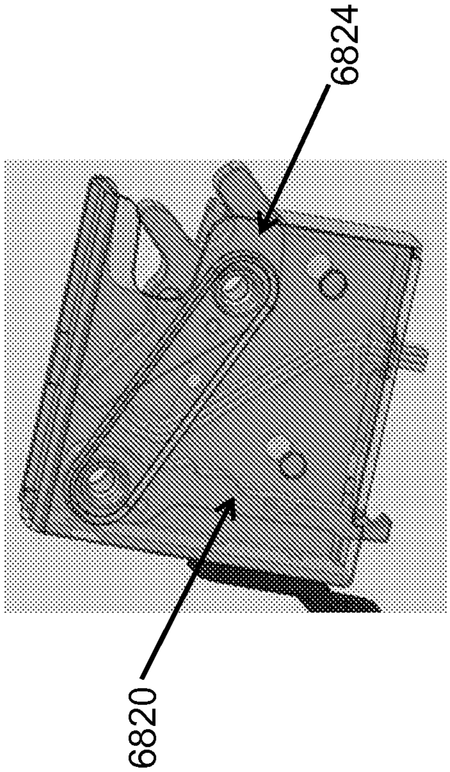

FIG. 16(c)

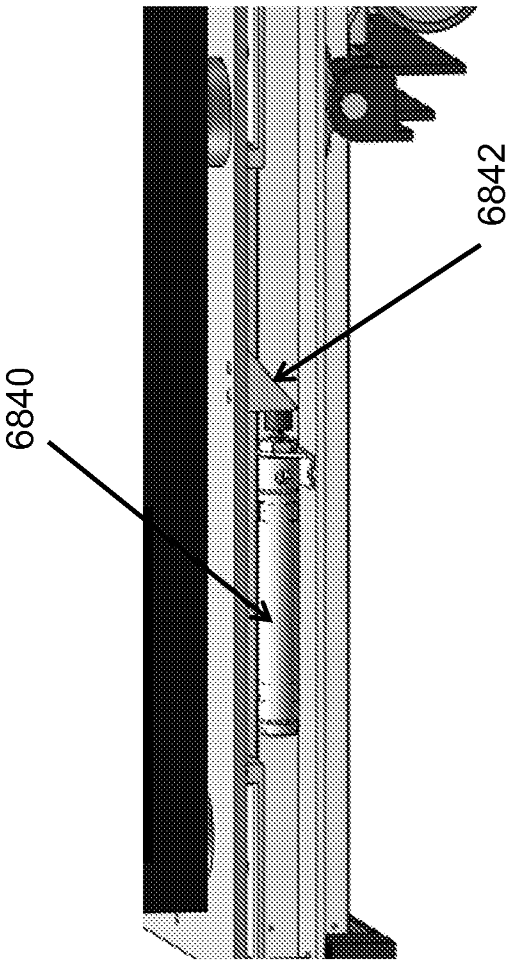

FIG. 17

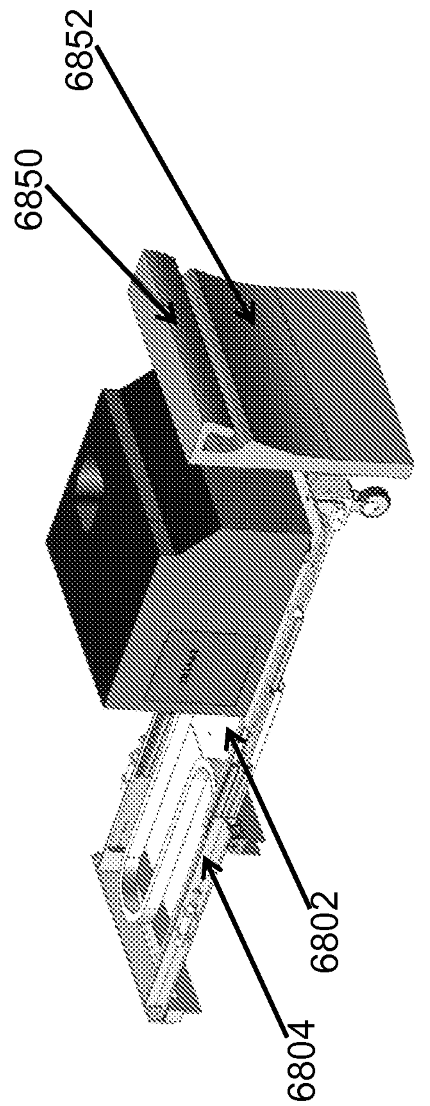

FIG. 18

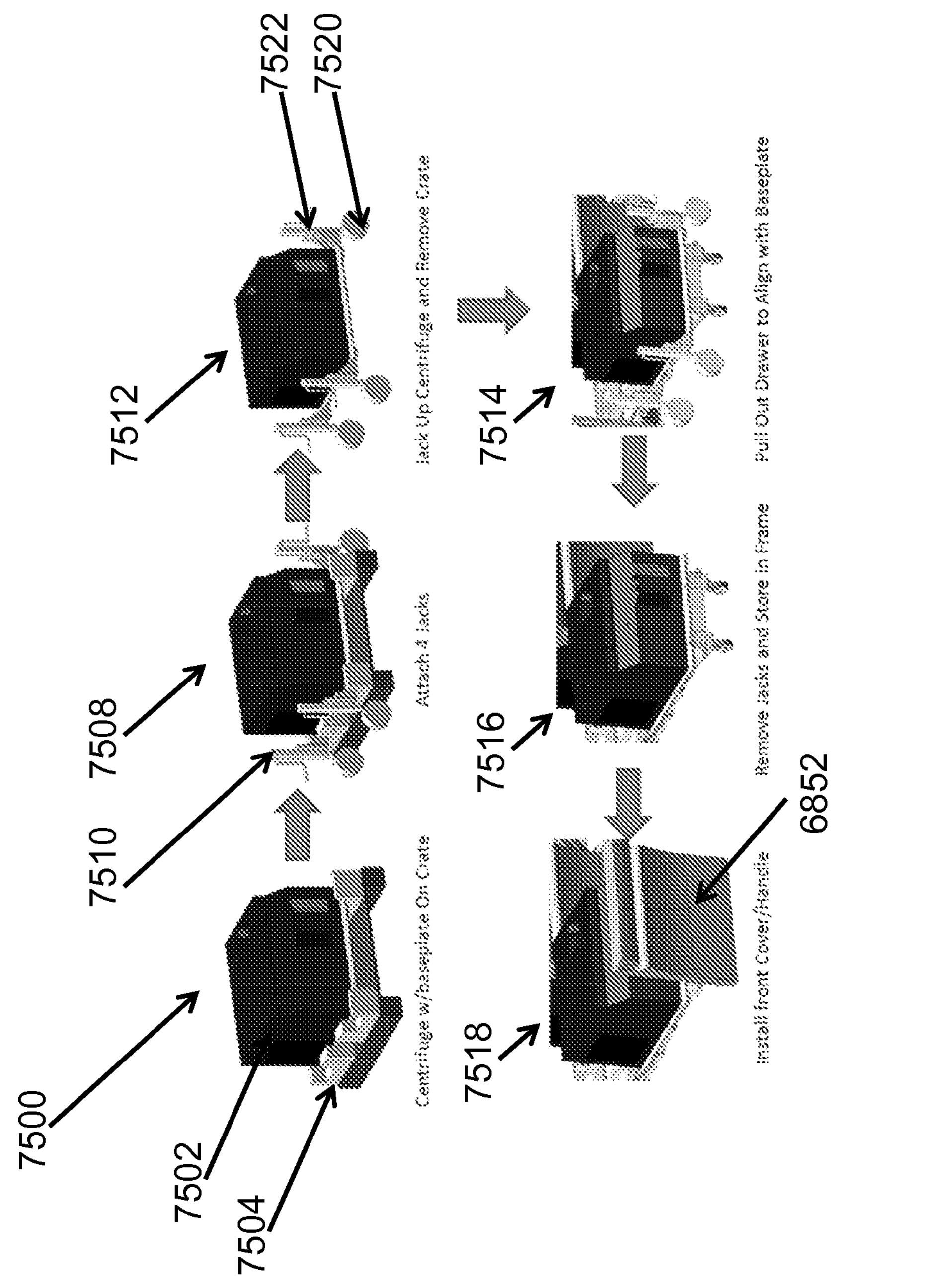
7500
7502
7504
7510
7508
7512
7522
7520
7514
7516
7518
6852
Centrifuge w/baseplate On Crate
Attach 4 Jacks
Jack Up Centrifuge and Remove Crate
Pull Out Drawer to Align with Baseplate
Remove Jacks and Store in Frame
Install Front Cover/Handle

FIG. 19

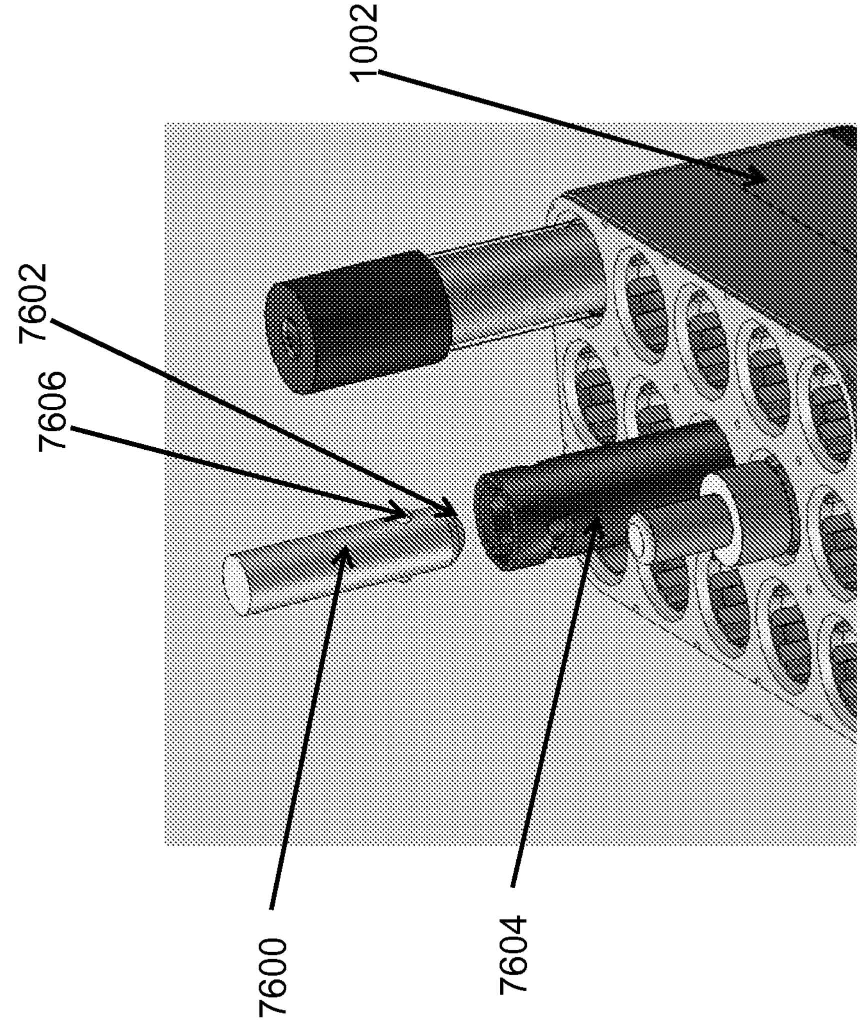

FIG. 20(a)

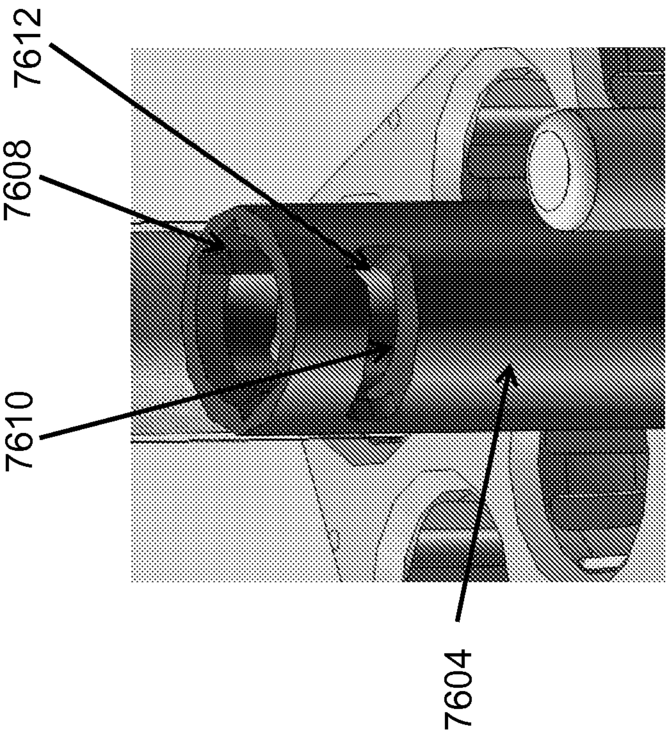

FIG. 20(b)

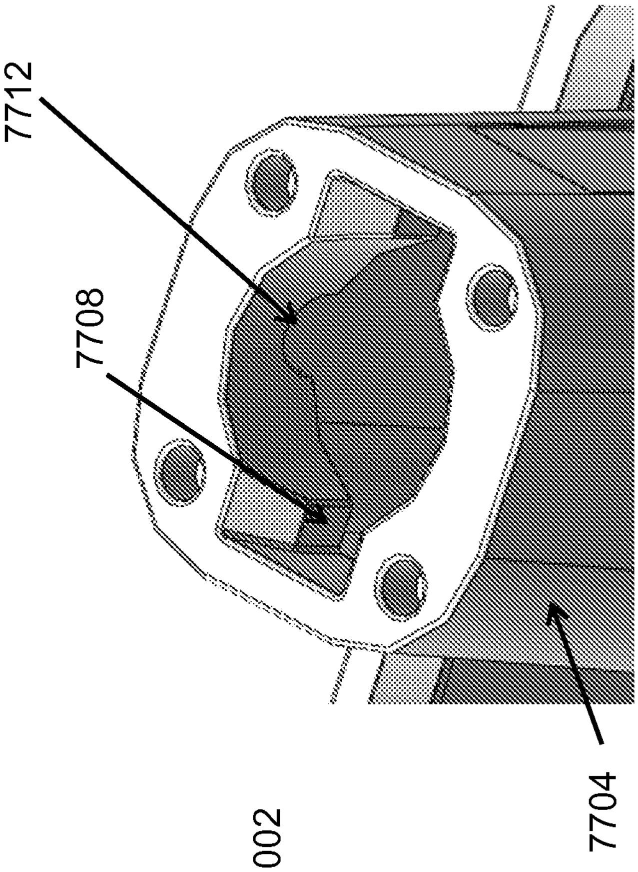

FIG. 21(b)

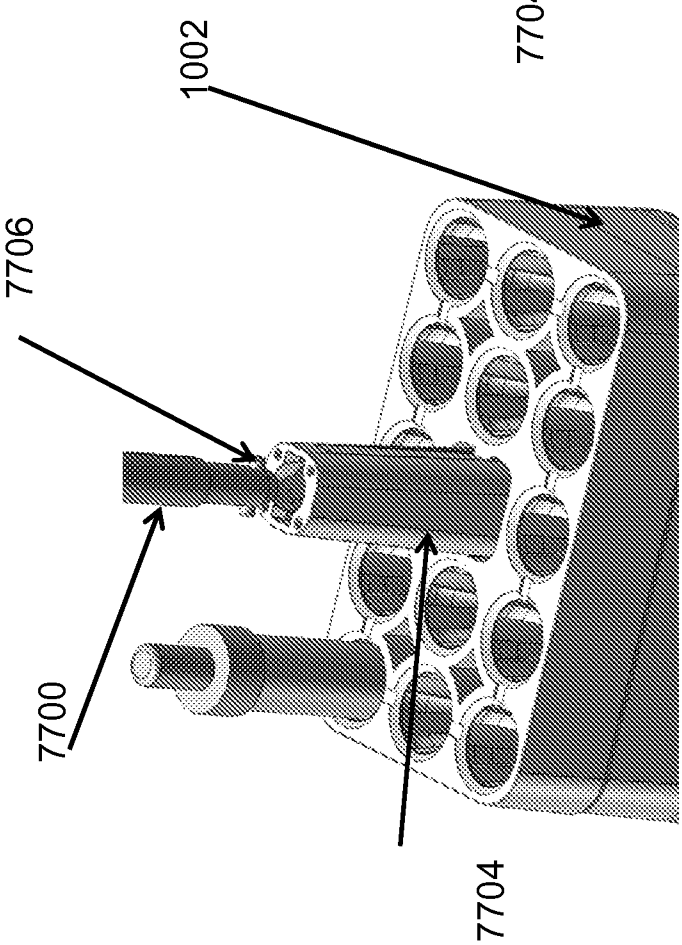

FIG. 21(a)

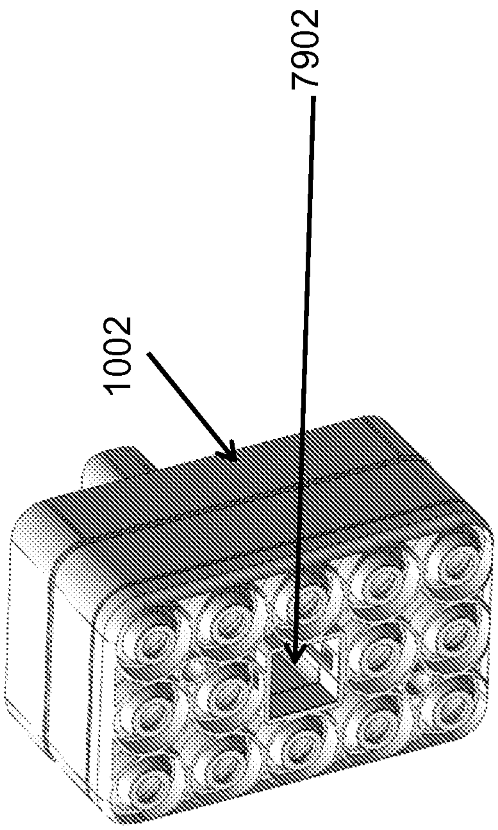

FIG. 22(a)

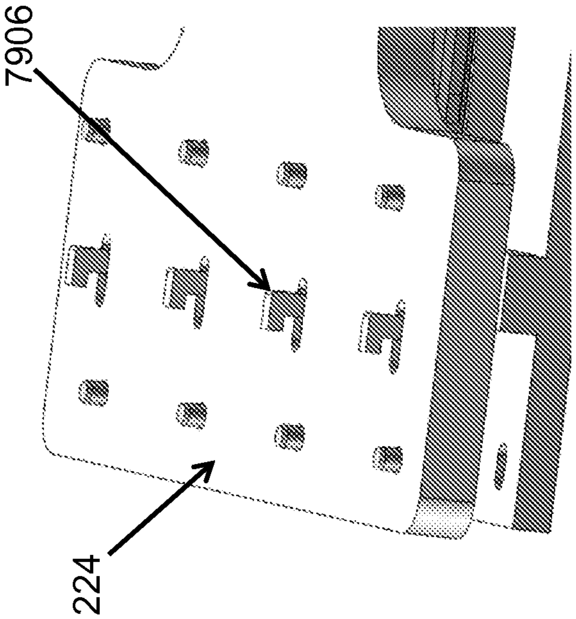

FIG. 22(b)

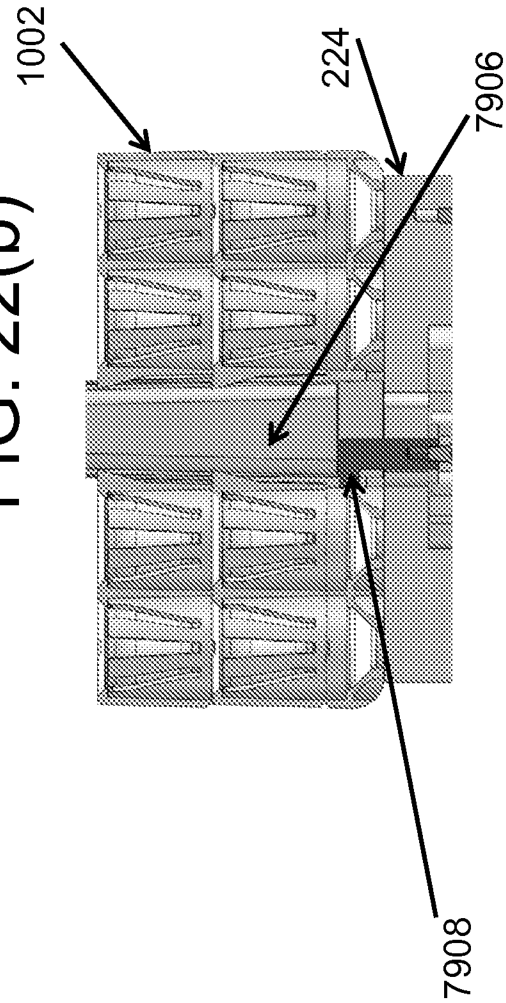

FIG. 22(c)

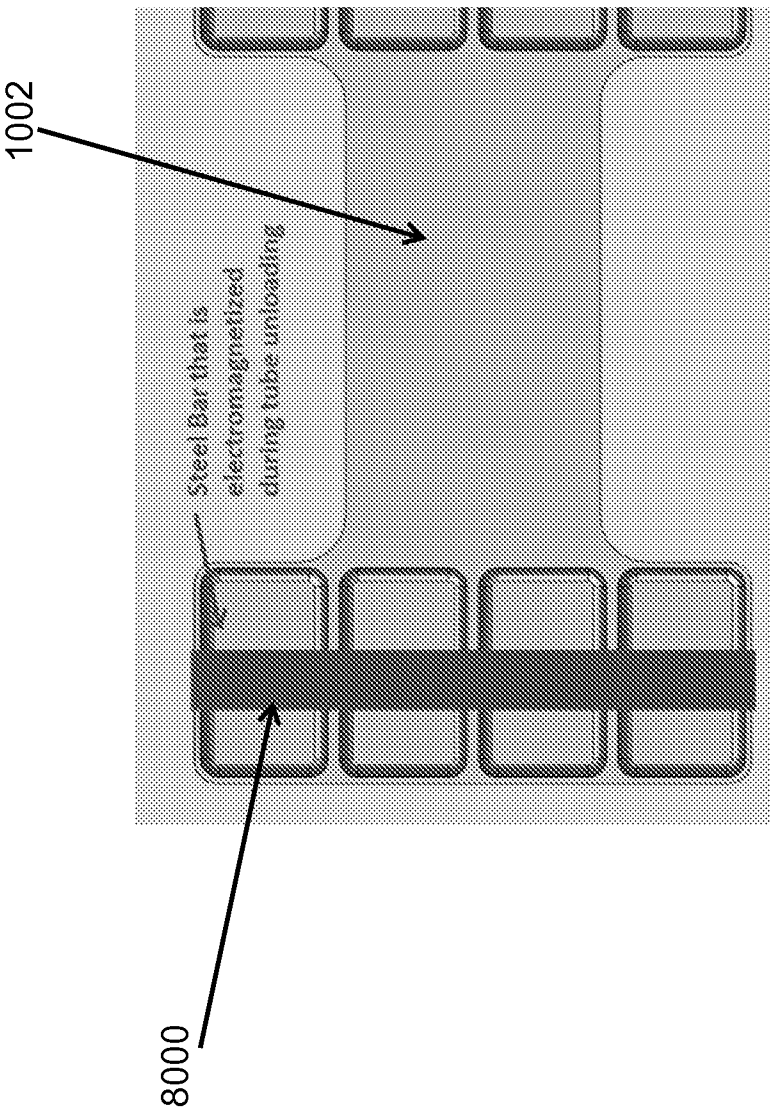
1002
Steel Bar that is
electromagnetized
during tube unloading
8000

FIG. 23

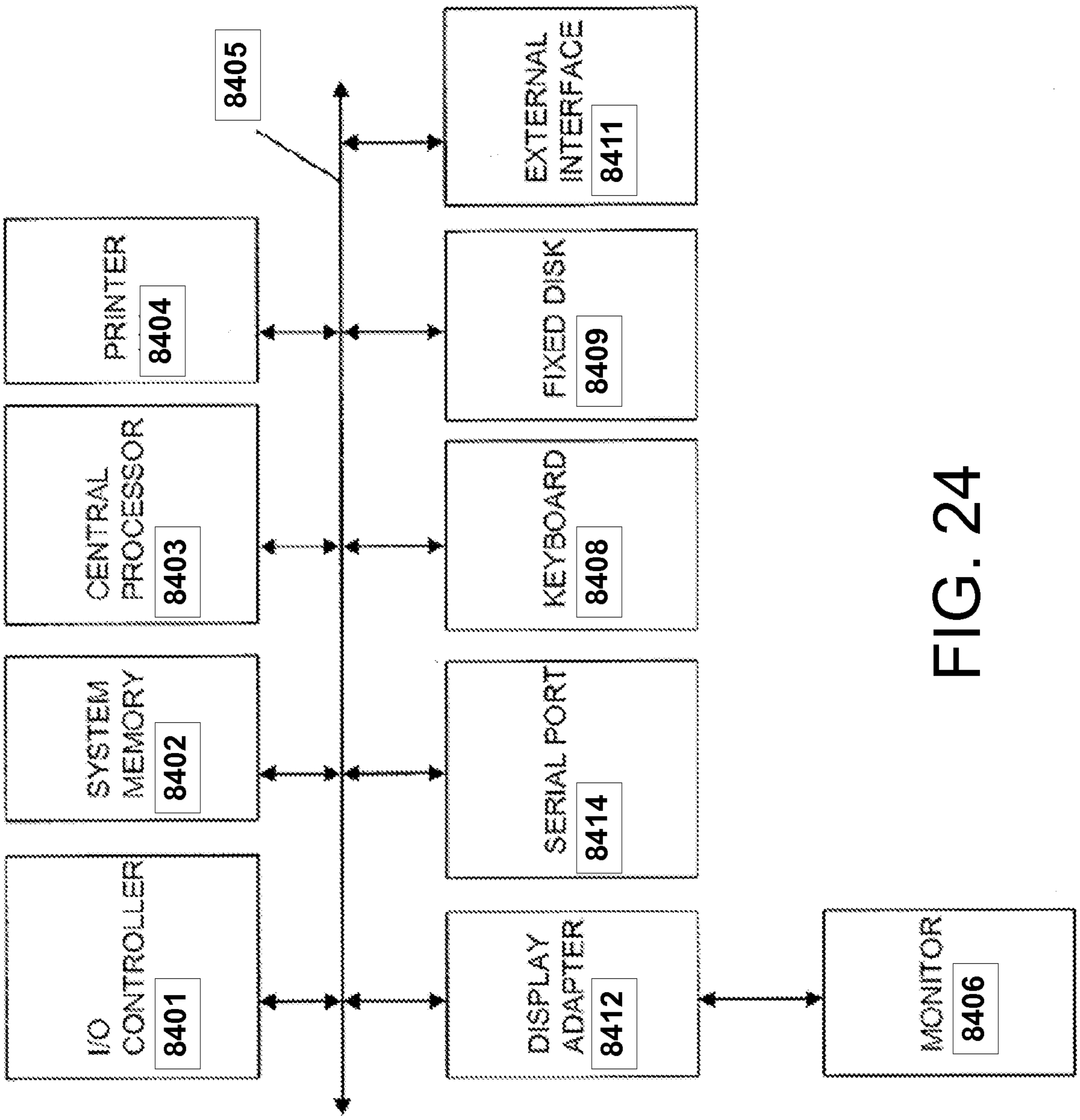
8405
I/O CONTROLLER 8401
SYSTEM MEMORY 8402
CENTRAL PROCESSOR 8403
PRINTER 8404
DISPLAY ADAPTER 8412
SERIAL PORT 8414
KEYBOARD 8408
FIXED DISK 8409
EXTERNAL INTERFACE 8411
MONITOR 8406

FIG. 24