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COORDINATED CONVEYERS IN AN AUTOMATED SYSTEM

Abstract

Coordinated conveyors in an automated system. A system comprises a plurality of conveyors, which each comprise a plurality of segments, and one or more stations. An instruction is received to perform an operation that requires at least one station to process at least a first item held by a first segment of a first conveyor and a second item held by a second segment of a second conveyor. In response to the instruction, one or both of the first and second conveyors are moved, such that the first segment and the second segment are aligned at the station. After alignment, one or more instruments of the station process the first item and the second item.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation application of U.S. patent application Ser. No. 18/244,841, filed on Sep. 11, 2023, which is a continuation application of U.S. patent application Ser. No. 16/578,108, filed on Sep. 20, 2019, which claims priority to U.S. Provisional Patent App. No. 62/742,830, filed on Oct. 8, 2018, which are all hereby incorporated herein by reference as if set forth in full.

BACKGROUND
Field of the Invention
[0002] The embodiments described herein are generally directed to automation, and, more particularly, to the coordination of a plurality of conveyors within an automated system.
Description of the Related Art
[0003] Many automated systems utilize complex robotics to move items within the system. Such robotics generally require multiple mechanical systems that perform complex movement in at least three dimensions. In addition, items must generally be moved between different areas within the automated system (e.g., by robotic grippers) that are responsible for different processes.
[0004] As one example of a system in which automation would be useful, before a blood transfusion can be performed, both the donor and patient blood must undergo extensive diagnostic testing in laboratories. The required diagnostic tests can be divided into two distinct classes: (1) immunohematology (IH) tests for red-blood cell antigens and antibodies; and (2) tests for viral and other infectious-disease markers to exclude donor blood that may transmit infectious diseases.
[0005] More than a century of research has identified and named about thirty clinically significant red-blood-cell antigens and corresponding antibodies that can cause transfusion reactions of varying degrees. This is the field of IH, in which tests either identify blood groups of patients or donor red-blood cells, or detect the presence and determine the identity of red-blood-cell antibodies in blood samples. IH pre-transfusion testing requires that specific procedures be performed, including, for example, antigen typing, antibody identification, and cross-matching, to ensure that transfusion blood is compatible with the patient.
[0006] Donors must also be screened for risk of infectious disease. This involves testing donor blood samples for infectious-disease antigens and antibodies. Infectious diseases, currently required to be tested by immunological methods, are Cytomegalovirus (CMV), syphilis, hepatitis B (HBV) (comprising HBV surface antigen and core antibody), hepatitis C (HCV), human immunodeficiency virus (HIV) (comprising HIV types 1 and 2), human T-lymphotropic antibodies (HTLV), Chagas disease, Zika, and West Nile virus. In addition, minipool nucleic acid testing (NAT) is mandated for the presence of certain viruses in donor samples, including HIV, HBV, HCV, and West Nile virus. Presently, such tests are not done on automated IH systems, but could be upon

advent of a pathogen-screening red-blood-cell reagent.
[0007] Column agglutination technology (CAT) has emerged as the standard for pre-transfusion blood testing, replacing nearly all competitive methods. Conventional CAT utilizes gel cards with six to eight wells. Because of the gel card's historical strengths, efforts in automating IH testing have been designed around the gel card. This has required very elaborate, expensive, and slow robotic systems.
[0008] Specifically, complex robotics are required to move standard gel cards within automated IH systems. For example, if a particular test is ordered by the laboratory information system (LIS), the automated system must retrieve a specific gel card from an inventory deck and move it to the testing deck. This generally requires controlling a robotic gripper to find the specific gel card in the inventory deck and load it into a carrier, which is then moved to an elevator, which moves the carrier to the testing deck. A robotic gripper extracts the specific gel card, barcodes it, and pierces the appropriate microwell seals. At that point, the testing process, which also involves complex robotics, is initiated on the microwells of the gel card. To avoid waste, if some of the microwells of the gel card remain unused, the transportation process is reversed, such that the gel card with unused microwells is returned to the inventory deck.
[0009] In view of the above, what is needed is an alternative to the complex transportation robotics required by automated IH and other systems.
SUMMARY
[0010] Accordingly, systems, methods, and non-transitory computer-readable media are disclosed for providing and coordinating a plurality of conveyers within an automated system. In an embodiment, a system comprises a plurality of conveyors, wherein each of the plurality of conveyors comprises a plurality of segments configured to hold at least one item; one or more stations, wherein each of the one or more stations comprises one or more instruments; at least one hardware processor; and one or more software modules configured to, when executed by the at least one hardware processor, receive an instruction to perform an operation that requires at least one of the one or more stations to process at least a first item held by a first segment of a first one of the plurality of conveyors and a second item held by a second segment of a second one of the plurality of conveyors, in response to receiving the instruction, control one or both of the first conveyor and the second conveyor to move, such that the first segment and the second segment are aligned at the at least one station, and after the first segment and the second segment have been aligned at the at least one station, control the one or more instruments of the at least one station to process the first item and the second item. The at least one hardware processor may be configured to independently control each of the plurality of conveyors to move each of the plurality of conveyors independently from any of the other plurality of conveyors.
[0011] The plurality of conveyors may comprise a plurality of concentric circular carousel conveyor that rotate around a common point. The plurality of segments may be on a top surface of each of the plurality of concentric circular carousel conveyors, and the top surface of each of the plurality of concentric circular carousel conveyors may be within a same plane as the top surface of each of the other plurality of concentric circular carousel conveyors. Each of the plurality of concentric circular carousel conveyors may have a different radius, and in plan view, all but one of the plurality of concentric circular carousel conveyors may be nested within another one of the plurality of concentric circular carousel conveyors. Each of the plurality of conveyors may be configured to rotate in two directions, and the one or more software modules may be configured to, when executed by the at least one hardware processor: determine in which of the two directions to rotate at least one of the first conveyor and the second conveyor so as to minimize movement; and control the at least one of the first conveyor and the second conveyor to rotate in the determined direction. At least one of the plurality of concentric circular carousel conveyors may be configured to hold test cells for blood testing, and the one or more software modules may be configured to, when executed by the at least one hardware processor, control the at least one concentric circular

carousel conveyor to spin as a centrifuge (e.g., spinning at 1,500 revolutions per minute or greater, or between 1,500 and 4,000 revolutions per minute). At least one of the plurality of concentric circular carousel conveyors may be configured to hold test cells for blood testing, and the one or more software modules may be configured to, when executed by the at least one hardware processor, control the at least one concentric circular carousel conveyor to spin so as to agitate the test cells held by the at least one concentric circular carousel conveyor. Each of the one or more stations may comprise a bridge extending, along a radial line of the plurality of concentric circular carousel conveyors, over each of the plurality of concentric circular carousel conveyors. The one or more instruments of the at least one station may comprise a pipettor configured to move along an underside of the bridge above the plurality of concentric circular carousel conveyors, and the one or more software modules may be configured to, when executed by the at least one processor, control the pipettor to move to any one of a plurality of positions above the plurality of concentric circular carousel conveyors.

[0012] The plurality of concentric circular carousel conveyors may comprise the first conveyor, the second conveyor, and a third conveyor, wherein the first conveyor is configured to hold test cells, the second conveyor is configured to hold reagent containers, and the third conveyor is configured to hold specimen containers, and wherein the one or more software modules are configured to, when executed by the at least one hardware processor: while the first conveyor and the second conveyor are aligned at the at least one station, control the pipettor to move over a reagent container on the second segment of the second conveyor, aspirate an amount of reagent from the reagent container on the second segment, move over a test cell on the first segment of the first conveyor, and dispense the amount of reagent into the test cell on the first segment; and, while the first conveyor and the third conveyor are aligned at the at least one station, control the pipettor to move over a specimen container on a third segment of the third conveyor, aspirate an amount of specimen from the specimen container, prepare a sample from the specimen, move over the test cell on the first segment, and dispense the sample into the test cell on the first segment. The first conveyor may be nested within the second conveyor, and the second conveyor may be nested within the third conveyor. One or more of the first conveyor, the second conveyor, or the third conveyor may comprise two or more concentric circular carousel conveyors that can rotate independently. Preparing a sample from the specimen may comprise: moving over a specimen-processing vessel; dispensing the amount of specimen into the specimen-processing vessel to be mixed with one or more fluids to form the sample; and aspirating an amount of the sample from the specimen-processing vessel. The one or more software modules may be configured to, when executed by the at least one hardware processor, control the pipettor to: move over a wash buffer containing wash fluid; aspirate wash fluid from the wash buffer to clean the pipettor; and, after cleaning the pipettor, dispense the wash fluid into a disposal buffer. Each test cell may comprise one or more L-shaped microwells, wherein each microwell comprises a receptacle portion and a well portion, wherein the well portion is configured to rest horizontally on a top surface of the first conveyor, and wherein the receptacle portion comprises an opening that is accessible to the pipettor while the well portion is resting horizontally on the top surface of the first conveyor. Each test cell may comprise a plurality of L-shaped microwells arranged in an annulus sector, which is attachable to and detachable from the top surface of the first conveyor, such that, when then annulus sector is attached to the top surface of the first conveyor, the plurality of L-shaped microwells longitudinally extend along a radial line of the plurality of concentric circular carousel conveyors, and wherein a peripheral curve of the annulus sector matches a peripheral curve of top surface of the first conveyor. The test cells may comprise an immunohematology or infectious-disease assay. The first conveyor may comprise a thermoelectric heating component that heats a top surface of the first conveyor on which the test cells are held so as to incubate the test cells, wherein the one or more software modules, when executed by the at least one processor, control the thermoelectric heating component to heat the top surface of the first conveyor for a determined amount of time.

[0013] One or more of the plurality of conveyors may comprise a thermoelectric cooling component that cools a top surface of the one or more conveyors on which items are held. Each of the plurality of conveyors may be configured to stop at each of a plurality of indexed positions. The one or more software modules may be configured to, when executed by the at least one hardware processor, move the plurality of conveyors to align any combination of segments, across the plurality of conveyors, at each of the one or more stations.
[0014] The one or more instruments of at least one of the one or more stations may comprise a reader device configured to read a characteristic of a third item on a segment of at least one of the plurality of conveyors. The reader device may comprise a camera configured to capture an image of a machine-readable indicia on the third item, and the one or more software modules may be configured to, when executed by the at least one hardware processor: identify the third item from the image; identify the segment of the at least one conveyor on which the third item is held; and map an identifier of the third item to an identifier of the identified segment. The identifier of the identified segment may comprise C-coordinates that uniquely identify a location on the at least one conveyor on which the third item is held, and the one or more software modules may be configured to, when executed by the at least one hardware processor, map the C-coordinates to G-coordinates that uniquely identify a location of the identified segment within an automated system. The third item may comprise a microwell, the reader device may comprise a camera configured to capture an image of the microwell, and the one or more software modules may be configured to, when executed by the at least one hardware processor analyze the image of the microwell to determine a test result. The camera may be configured to capture the image of the microwell while the microwell is spinning on the conveyor on which the microwell is held.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0015] The details of the present invention, both as to its structure and operation, may be gleaned in part by study of the accompanying drawings, in which like reference numerals refer to like parts, and in which:
[0016] FIG. **1** is a top-down view of an exemplary system of conveyors, in which one or more of the processes described herein, may be implemented, according to embodiments;
[0017] FIG. **2** illustrates an example processing system, by which one or more of the processed described herein, may be executed, according to an embodiment;
[0018] FIGS. **3**A and **3**B illustrate top-down and side cross-sectional views, respectively, of an exemplary system of conveyors, according to an embodiment;
[0019] FIGS. **4**A and **4**B illustrate an example of how the movements of conveyors may be coordinated, according to an embodiment;
[0020] FIGS. **5**A-**5**C illustrate examples of test cells to be used on a carousel conveyor, according to an embodiment; and
[0021] FIG. **6** illustrates the use of a conveyance system in a process for pre-transfusion IH testing, according to an embodiment.
DETAILED DESCRIPTION
[0022] In an embodiment, systems and methods are disclosed for providing and using one or more coordinated conveyors within an automated system. After reading this description, it will become apparent to one skilled in the art how to implement the invention in various alternative embodiments and alternative applications. However, although various embodiments of the present invention will be described herein, it is understood that these embodiments are presented by way of example and illustration only, and not limitation. As such, this detailed description of various embodiments should not be construed to limit the scope or breadth of the present invention as set

forth in the appended claims.

1. System Overview

1.1. Overview of Conveyors

[0023] For ease of understanding, movement within the system will be described herein in terms of an X, Y, and Z coordinate system. With respect to figures providing a top-down view, the Z axis extends orthogonally through the page, whereas the X and Y axes are within the plane of the page and orthogonal to each other.

[0024] FIG. **1** is a top-down view of an exemplary system of conveyors, according to an embodiment. In the illustrated embodiment, each conveyor **110** in system **100** is circular in plan view. However, one or more, including all, of conveyors **110** may instead be elliptical, linear, square, rectangular, or any other shape in plan view. In addition, one or more of conveyors **110** may be inclined, may rotate vertically instead of horizontally, may be positioned at an angle, and/or the like.

[0025] The plurality of conveyors **110** are illustrated as concentric to each other in plan view, with conveyor **110**A nested within or surrounded by conveyor **110**B, which in turn is nested within or surrounded by conveyor **110**C, and so on and so forth. In an embodiment, the top surface of each conveyor **110** lies within the same X-Y plane as the top surface of every other conveyor **110**. However, other configurations are possible. For example, the top surfaces of two or more, including all, of conveyors **110** may lie within different X-Y planes. In this case, two or more of conveyors **110**, whose top surfaces lie in different planes, may overlap in plan view. In one embodiment, all of conveyors **110** may be of the same radius with their top surfaces lying in different X-Y planes that are all orthogonal to the Z axis. In other words, conveyors **110** may be stacked along the Z axis.

[0026] In the illustrated embodiment, conveyors **110** are spaced equidistantly apart from each other. However, in an alternative embodiment, the distances between conveyors **110** may vary within the X-Y plane and/or along the Z axis.

[0027] The number of conveyors **110** within system **100** will generally depend on how conveyors **110** are used within system **100**. Thus, the number of conveyors **110** may be one, two, three, four, or any integer N, as illustrated in FIG. **1**.

[0028] In the illustrated embodiment, in which circular conveyors **110** are used, conveyors **110** may be referred to as “carousels.” Each carousel conveyor **110** rotates around the Z axis and, when concentric, rotates around the same point as every other carousel conveyor **110**. In a preferred embodiment, each carousel conveyor **110** can rotate in both rotational directions (e.g., clockwise and counterclockwise in plan view).

[0029] In an embodiment, each conveyor **110** may be driven by its own motor, such as a stepper motor, Geneva drive, rack and pinion, or the like, under the control of a processing system described elsewhere herein. Each carousel conveyor **110** may comprise a carousel that rotates on a fixed circular base and is driven by a separate or on-board motor (e.g., on a circular track).

[0030] In an embodiment, each carousel conveyor **110** may rotate independently from any other carousel conveyor **110**, in terms of direction and/or speed, and in parallel. For example, carousel conveyor **110**A may rotate in one direction as carousel conveyor **110**B rotates in the opposite direction or is stationary. Additionally or alternatively, carousel conveyor **110**A may rotate at a different speed than carousel conveyor **110**B.

[0031] The movement (e.g., rotation) of each conveyor **110** may be independently controlled by one or more processing devices described elsewhere herein. The processing device(s) may be programmed to coordinate movements of conveyors **110** to perform complex logistics in a wide variety of applications.

[0032] In an embodiment, one or more of carousel conveyors **110** may be configured to rotate with enough speed (e.g., radians per second) to serve as a centrifuge. For example, a centrifugal carousel conveyor **110** may be capable of spinning at greater than two-thousand revolutions per minute

(RPM). In addition, the centrifugal carousel conveyor **110** may be able to move at much slower speeds when performing normal conveyance operations (e.g., to align a particular one of its segments with one or more segments on other conveyors **110**). In other words, the centrifugal carousel conveyor **110** may be configured to act in either a normal mode or a centrifugal mode, as determined by a processing system.

[0033] Alternatively or additionally, one or more of conveyors **110** may be configured to act as an agitator. Agitation may comprise a carousel conveyor **110** rotating at a greater speed than during normal conveyance operations, but at a slower speed than a centrifuge. The agitation could also comprise a conveyor **110** alternating the direction of movement (e.g., direction of rotation for a carousel conveyor **110**) in order to rock the items on the conveyor **110**. In this case, the agitating conveyor **110** may accelerate in one direction, decelerate to a stop, accelerate in the opposite direction, decelerate to a stop, and so on and so forth. It should be understood that in the case of a carousel conveyor **110**, the carousel conveyor **110** may function as both a centrifuge (at high RPM) and an agitator (at low RPM and/or with alternating rotational directions).

[0034] Each conveyor **110** may be configured to hold items of any size, shape, and type. In some implementations, the same conveyor **110** may be configured to hold items of different sizes, shapes, and/or types. However, in the primary embodiment discussed herein, each conveyor **110** holds items of the same size, shape, and type.

[0035] A conveyor **110** may be configured to move an item at a particular position on the conveyor **110** to a particular location associated with a station. In an embodiment, a conveyor **110** is configured to move an item at a particular position on the conveyor **110** to a location associated with any one of a plurality of stations. In either case, a station may comprise one or more instruments for performing some operation (e.g., collection, aspiration, deposition, imaging, detection, measurement, manipulation, assembly, grouping, packaging, etc.) on the item. A station may perform a single joint operation or simultaneous common operations on aligned items from multiple conveyors **110**.

[0036] In an embodiment which utilizes multiple stations, each station may perform a same or different operation in parallel. For example, a first pipetting station (e.g., on one side of conveyance system **100**) may prepare a test along a first radial line of conveyance system **100**, while a second pipetting station (e.g., on the same or opposite side of conveyance system **100**) simultaneously prepares a test along a second radial line of conveyance system **100**. As another example, a pipetting station may prepare a test using one subset of conveyors **110**, while a reading station may simultaneously read machine-readable indicia on items on the same subset or a different subset of conveyors **110**. As yet another example, a plurality of reading stations may image test results in parallel, so that the data may interpreted or otherwise processed in parallel, to thereby increase throughput.

[0037] Items may be positioned on conveyors **110** or housed within conveyors **110** in any manner that is appropriate for the intended use of conveyance system **100**. For example, items may rest on a top surface of a conveyor **110**. Alternatively, items may be housed within individual drawers of a conveyor **110**.

[0038] As discussed throughout, the movements of conveyors **110** may be coordinated under the control of a processing system. However, because conveyors **110** are independently controllable, each conveyor **110** may also be moved on its own in both directions. This enables random access of any portion on any conveyor **110**, including any item or set of contiguous items that may be held by that portion. For example, in response to an instruction that identifies an item to be accessed (e.g., issued by another component or system, an operator via a graphical user interface, etc.), the processing system may determine the location of the item on a conveyor **110** (e.g., by mapping an identifier of the item to a place identifier discussed elsewhere herein), and move the conveyor **110** so that the location of the item is accessible (e.g., at an access panel of the automated system, by a robotic pushing or gripping system, etc.). As another example, in response to an instruction that identifies a portion (e.g., segment) of a conveyor **110** to be accessed (e.g., issued by another component or system, an operator via a graphical user interface, etc.), the processing system may determine the location of the portion of the conveyor **110**, and move the conveyor **110** so that the location of the portion is accessible (e.g., at an access panel of the automated system, by a robotic pushing or gripping system, etc.). In this manner, an item can be stowed on or removed from the accessible portion of conveyor **110**.

[0039] It should be understood that conveyance system **100** may be made compatible with any external systems. Examples of such external systems including, without limitation, LIS, remote operating systems, dashboard systems, quality control systems, alarm systems, inventory management systems (e.g., which manage specimens and/or reagents, and may perform automatic reordering), and/or the like.

1.2. Example Processing Device

[0040] FIG. **2** is a block diagram illustrating an example processing system **200** that may be used in connection with various embodiments described herein. For example, processing system **200** may be used as or in conjunction with one or more of the functions, processes, or methods described herein, to control conveyors **110** and/or stations within conveyance system **100**, analyze and/or report test results in an automated IH system, and/or the like. System **200** can be a server, conventional personal computer, or any other processor-enabled device. Other computer systems and/or architectures may be also used, as will be clear to those skilled in the art.

[0041] In an embodiment, system **200** controls one or more motors that drive conveyors **110**. For example, system **200** may drive an actuator of a motor to activate and deactivate the motor, change the direction of rotation of the motor, change the speed of the motor, and/or the like. An automated system, comprising conveyance system **100**, may comprise a separate system **200** for each conveyor **110** and/or a single system **200** that controls two or more, including potentially all, of conveyors **110**.

[0042] In addition, system **200** may communicate with one or more stations to control the stations and/or receive, analyze, and/or report data sensed by the stations. For example, system **200** may send instructions that control one or more instruments (e.g., pipettor, camera, NFC chip, radio frequency identification (RFID) interrogator, or other sensor, etc.) of a station to the station. System **200** may also receive data (e.g., image data, signal data, etc.) collected by one or more instruments of a station. This received data may be analyzed, interpreted, or otherwise processed by system **200** for reporting purposes.

[0043] System **200** may also communicate with a LIS or other system that is external to the automated system. System **200** may communicate with this external system, for example, via an application programming interface (API) and/or over at least one network. System **200** may receive instructions from the external system (e.g., from the LIS to run one or more tests on one or more specimens), and report test results to the external system.

[0044] System **200** preferably includes one or more processors, such as processor **210**. Additional processors may be provided, such as an auxiliary processor to manage input/output, an auxiliary processor to perform floating-point mathematical operations, a special-purpose microprocessor having an architecture suitable for fast execution of signal-processing algorithms (e.g., digital-signal processor), a slave processor subordinate to the main processing system (e.g., back-end processor), an additional microprocessor or controller for dual or multiple processor systems, and/or a coprocessor. Such auxiliary processors may be discrete processors or may be integrated with processor **210**. Examples of processors which may be used with system **200** include, without limitation, the Pentium® processor, Core i7® processor, and Xeon® processor, all of which are available from Intel Corporation of Santa Clara, California.

[0045] Processor **210** is preferably connected to a communication bus **205**. Communication bus **205** may include a data channel for facilitating information transfer between storage and other peripheral components of system **200**. Furthermore, communication bus **205** may provide a set of signals used for communication with processor **210**, including a data bus, address bus, and/or control bus (not shown). Communication bus **205** may comprise any standard or non-standard bus architecture such as, for example, bus architectures compliant with industry standard architecture (ISA), extended industry standard architecture (EISA), Micro Channel Architecture (MCA), peripheral component interconnect (PCI) local bus, standards promulgated by the Institute of Electrical and Electronics Engineers (IEEE) including IEEE 488 general-purpose interface bus (GPIB), IEEE 696/S-100, and/or the like.

[0046] System **200** preferably includes a main memory **215** and may also include a secondary memory **220**. Main memory **215** provides storage of instructions and data for programs executing on processor **210**, such as one or more of the functions and/or modules discussed herein. It should be understood that programs stored in the memory and executed by processor **210** may be written and/or compiled according to any suitable language, including without limitation C/C++, Java, JavaScript, Perl, Visual Basic, .NET, and the like. Main memory **215** is typically semiconductor-based memory such as dynamic random access memory (DRAM) and/or static random access memory (SRAM). Other semiconductor-based memory types include, for example, synchronous dynamic random access memory (SDRAM), Rambus dynamic random access memory (RDRAM), ferroelectric random access memory (FRAM), and the like, including read only memory (ROM).

[0047] Secondary memory **220** may optionally include an internal medium **225** and/or a removable medium **230**. Removable medium **230** is read from and/or written to in any well-known manner. Removable storage medium **230** may be, for example, a magnetic tape drive, a compact disc (CD) drive, a digital versatile disc (DVD) drive, other optical drive, a flash memory drive, and/or the like.

[0048] Secondary memory **220** is a non-transitory computer-readable medium having computer-executable code (e.g., disclosed software modules) and/or other data stored thereon. The computer software or data stored on secondary memory **220** is read into main memory **215** for execution by processor **210**.

[0049] In alternative embodiments, secondary memory **220** may include other similar means for allowing computer programs or other data or instructions to be loaded into system **200**. Such means may include, for example, a communication interface **240**, which allows software and data to be transferred from external storage medium **245** to system **200**. Examples of external storage medium **245** may include an external hard disk drive, an external optical drive, an external magneto-optical drive, and/or the like. Other examples of secondary memory **220** may include semiconductor-based memory, such as programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable read-only memory (EEPROM), and flash memory (block-oriented memory similar to EEPROM).

[0050] As mentioned above, system **200** may include a communication interface **240**. Communication interface **240** allows software and data to be transferred between system **200** and external devices (e.g. printers), networks, or other information sources. For example, computer software or executable code may be transferred to system **200** from a network server (e.g., platform **110**) via communication interface **240**. Examples of communication interface **240** include a built-in network adapter, network interface card (NIC), Personal Computer Memory Card International Association (PCMCIA) network card, card bus network adapter, wireless network adapter, Universal Serial Bus (USB) network adapter, modem, a wireless data card, a communications port, an infrared interface, an IEEE 1394 fire-wire, and any other device capable of interfacing system **200** with a network or another computing device. Communication interface **240** preferably implements industry-promulgated protocol standards, such as Ethernet IEEE 802 standards, Fiber Channel, digital subscriber line (DSL), asynchronous digital subscriber line (ADSL), frame relay, asynchronous transfer mode (ATM), integrated digital services network (ISDN), personal communications services (PCS), transmission control protocol/Internet protocol (TCP/IP), serial line Internet protocol/point to point protocol (SLIP/PPP), and so on, but may also implement customized or non-standard interface protocols as well.

[0051] Software and data transferred via communication interface **240** are generally in the form of electrical communication signals **255**. These signals **255** may be provided to communication interface **240** via a communication channel **250**. In an embodiment, communication channel **250** may be a wired or wireless network, or any variety of other communication links. Communication channel **250** carries signals **255** and can be implemented using a variety of wired or wireless communication means including wire or cable, fiber optics, conventional phone line, cellular phone link, wireless data communication link, radio frequency ("RF") link, or infrared link, just to name a few.

[0052] Computer-executable code (e.g., computer programs, including one or more software modules) is stored in main memory **215** and/or secondary memory **220**. Computer programs can also be received via communication interface **240** and stored in main memory **215** and/or secondary memory **220**. Such computer programs, when executed, enable system **200** to perform the various processes and functions described elsewhere herein.

[0053] In this description, the term "computer-readable medium" is used to refer to any non-transitory computer-readable storage media used to provide computer-executable code and/or other data to or within system **200**. Examples of such media include main memory **215**, secondary memory **220** (including internal memory **225**, removable medium **230**, and external storage medium **245**), and any peripheral device communicatively coupled with communication interface **240** (including a network information server or other network device). These non-transitory computer-readable media are means for providing executable code, programming instructions, software, and/or other data to system **200**.

[0054] In an embodiment that is implemented using software, the software may be stored on a computer-readable medium and loaded into system **200** by way of removable medium **230**, I/O interface **235**, or communication interface **240**. In such an embodiment, the software is loaded into system **200** in the form of electrical communication signals **255**. The software, when executed by processor **210**, preferably causes processor **210** to perform one or more of the processes and functions described elsewhere herein.

[0055] In an embodiment, I/O interface **235** provides an interface between one or more components of system **200** and one or more input and/or output devices. Example input devices include, without limitation, sensors, keyboards, touch screens or other touch-sensitive devices, biometric sensing devices, computer mice, trackballs, pen-based pointing devices, and/or the like. Examples of output devices include, without limitation, other processing devices, cathode ray tubes (CRTs), plasma displays, light-emitting diode (LED) displays, liquid crystal displays (LCDs), printers, vacuum fluorescent displays (VFDs), surface-conduction electron-emitter displays (SEDs), field emission displays (FEDs), and/or the like. In some cases, an input and output device may be combined, such as in the case of a touch panel display (e.g., in a smartphone, tablet, or other mobile device).

[0056] System **200** may also include optional wireless communication components that facilitate wireless communication over a voice network and/or a data network. The wireless communication components comprise an antenna system **270**, a radio system **265**, and a baseband system **260**. In system **200**, radio frequency (RF) signals are transmitted and received over the air by antenna system **270** under the management of radio system **265**.

[0057] In an embodiment, antenna system **270** may comprise one or more antennae and one or more multiplexors (not shown) that perform a switching function to provide antenna system **270** with transmit and receive signal paths. In the receive path, received RF signals can be coupled from a multiplexor to a low noise amplifier (not shown) that amplifies the received RF signal and sends the amplified signal to radio system **265**.

[0058] In an alternative embodiment, radio system **265** may comprise one or more radios that are configured to communicate over various frequencies. In an embodiment, radio system **265** may combine a demodulator (not shown) and modulator (not shown) in one integrated circuit (IC). The demodulator and modulator can also be separate components. In the incoming path, the demodulator strips away the RF carrier signal leaving a baseband receive audio signal, which is sent from radio system **265** to baseband system **260**.

[0059] If the received signal contains audio information, then baseband system **260** decodes the signal and converts it to an analog signal. Then the signal is amplified and sent to a speaker. Baseband system **260** also receives analog audio signals from a microphone. These analog audio signals are converted to digital signals and encoded by baseband system **260**. Baseband system **260** also encodes the digital signals for transmission and generates a baseband transmit audio signal that is routed to the modulator portion of radio system **265**. The modulator mixes the baseband transmit audio signal with an RF carrier signal, generating an RF transmit signal that is routed to antenna system **270** and may pass through a power amplifier (not shown). The power amplifier amplifies the RF transmit signal and routes it to antenna system **270**, where the signal is switched to the antenna port for transmission.

[0060] Baseband system **260** is also communicatively coupled with processor **210**, which may be a central processing unit (CPU). Processor **210** has access to data storage areas **215** and **220**. Processor **210** is preferably configured to execute instructions (i.e., computer programs, comprising one or more software modules, etc.) that can be stored in main memory **215** or secondary memory **220**. Computer programs can also be received from baseband processor **260** and stored in main memory **210** or in secondary memory **220**, or executed upon receipt. Such computer programs, when executed, enable system **200** to perform the various processes and functions of the disclosed embodiments.

1.3. Example Conveyor System

[0061] FIG. **3**A is a top-down view and FIG. **3**B is a side cross-sectional view of an exemplary system of conveyors, according to an embodiment. This embodiment of conveyance system **100** may be used, for example, within an automated blood-testing system. For the purposes of illustration, conveyance system **100** will be described primarily in the context of pre-transfusion blood testing of donor blood (e.g., serological disease-screening tests for hepatitis, HIV, etc.). However, this example is not limiting, and it will be readily apparent to a person of skill in the art how to adapt the described embodiments to other blood-testing—and more generally, chemical-testing—processes (e.g., coagulation studies, chemistries, serum enzymes, prothrombin time (PT) tests, partial thromboplastin time (PTT) tests, etc.).

[0062] In the illustrated example, conveyance system **100** comprises four concentric circular carousel conveyors **110**A, **110**B, **110**C, and **110**D, whose top surfaces are all in the same X-Y plane, and which are all configured to rotate around the Z axis, independently of each other, under the control of one or more processing systems **200**. It should be understood that the number of concentric circular carousel conveyors **110** may be decreased or increased to any number, and that four is simply used as one non-limiting example.

[0063] As illustrated in FIG. **3**B, each of carousel conveyors **110**A, **110**B, **110**C, and **110**D may be independently driven by drives **150**A, **150**B, **150**C, and **150**D, respectively. Each drive **150** may comprise a motor (e.g., stepper motor, Geneva drive, rack and pinion, etc.) that rotates the respective carousel conveyor **110** on a circular track. For example, the motor may rotate a belt that frictionally grips a circumference of a portion of the respective carousel conveyor **110** to impart rotation to the carousel conveyor **110**. The motor may be configured to rotate at a plurality of different speeds and/or in two different directions.

[0064] In an embodiment, conveyance system **100** comprises one or more bridges **120** positioned along a radial line that extends outward from the center of carousel conveyors **110**. Bridge **120** is one example of a station discussed elsewhere herein. The station may also comprise an apparatus **130** for performing certain bridge-related operations external to conveyors **110** (e.g., cleaning a pipettor tip).

[0065] Each bridge **120** may be stationary, but, in an alternative embodiment, could be configured to move. In an embodiment, each bridge **120** comprises one or more instruments **140** on its underside, between bridge **120** and conveyors **110**. Instrument(s) **140** may be movable between two or more, including potentially all, of positions **122**A-**122**E. For example, instrument **140** may be configured to slide along the underside of bridge **120** between any of positions **122**A-**122**E. Alternatively, instrument(s) **140** may be permanently fixed at one or more, including potentially all, of positions **122**A-**122**E. In either case, there may be a plurality of bridges **120**, each positioned along a different radial line that extends outward from the center of carousel conveyors **110**. Each of the plurality of bridges **120** may comprise the same or different configurations of one or more movable and/or fixed instruments **140**.

[0066] Instrument(s) **140** may comprise one or more sensors. The sensor(s) may comprise a camera capable of imaging in the visible light spectrum, the infrared light spectrum, the ultraviolet light spectrum, and/or the like. Additionally or alternatively, the sensor(s) may comprise any other type of reading or detection device that is configured to image, measure, recognize, characterize, or otherwise sense some feature of an item on a conveyor **110** beneath the device.

[0067] In an embodiment that utilizes a camera as instrument(s) **140**, the camera may be configured to observe multiple items (e.g., test cells) simultaneously. This may be implemented using depth-of-field software and/or zoom parameters (e.g., up to microscopic resolution), such that a sufficient number of pixels, as required by analysis software (e.g., image processing algorithms), are available for each target (e.g., hemagglutinating red-blood cells) in the image data to be recognized. The camera may be configured to record continuous video (e.g., image frames) or multiple still images, for example, of test cells, to be used for interpreting test results. The camera may record the video or still images from above or below the items being imaged. As an example, one or more of the cameras may be stationary dual-lens megapixel cameras that employ onboard or remote image recognition and/or classification (e.g., via artificial intelligence using neural networks, etc.), electronic or optical zooming, depth-of-field technology, and/or the like. Notably, the imaging can be performed without moving any items off of conveyors **110**.

[0068] Alternatively or additionally, instrument(s) **140** may comprise a pipettor, which is capable of sliding along the underside of bridge **120** between any of positions **122**A-**122**E. The pipettor may be oriented so that its tip faces conveyors **110** and may be configured to raise (i.e., move towards bridge **120** to increase the distance between the pipettor tip and conveyors **110**) and lower (i.e., move towards conveyors **110** to decrease the distance between the pipettor tip and conveyors **110**).

[0069] In an embodiment, each conveyor **110** may be divided into segments. For example, carousel conveyors **110** may be logically segmented into wedges (e.g., annulus sectors, circular arc segments, crescents, etc.). Similarly, linear conveyors **110** may be divided into rectangles. Each conveyor **110** may be configured so that, when the conveyor **110** stops, a center of each segment must be aligned with one of a plurality of indexed positions. In other words, when a conveyor **110** is stationary, the center of every segment must be at an indexed position, and cannot be between indexed positions. Thus, if processing system **200** stops a conveyor **110** before its segment centers are aligned with the indexed positions, conveyor **110** may continue to move the minimum amount necessary for its segment centers to align with the indexed positions prior to stopping. In the case of a carousel conveyor **110**, the carousel conveyor **110** would only be able to move by a multiple of a fixed radian amount, and in the case of a linear conveyor **110**, the linear conveyor **110** would only be able to move by a multiple of a fixed distance.

[0070] The centers of the segments, as well as the indexed positions, may be equidistantly spaced, and the number of segments may equal the number of indexed positions in a given conveyor **110**. In an embodiment, the indexed positions represent a position of the respective conveyor **110** at which at least one of the segments is properly accessible by an instrument **140** (e.g., on bridge **120**). Each conveyor **110** may have the same number of indexed positions as every other conveyor **110** or a different number of indexed positions than one or more other conveyors **110**. Similarly, each conveyor **110** may be divided into the same number of segments as every other conveyor **110** or a different number of segments than one or more other conveyors **110**, depending on the intended usage. In an alternative embodiment, indexed positions may be omitted. In such an embodiment, processing system **200** may control each conveyor **110** to move to any position and by any rotational or linear distance.

[0071] Advantageously, since the automated or robotic movements in conveyance system **100** are short and direct and implemented by the same mechanism (e.g., indexing and spinning of carousel conveyors **110**), the automated system may utilize a minimalist and inexpensive design. For example, all movements of conveyor **110** may be performed by the same, easily controllable mechanisms (e.g., drive **150**, which may comprise a stepper motor, Geneva drive, rack and pinion, etc.), and are direct, one-dimensional, quick, and short (e.g., a fraction of a centimeter). This can remove 90% of the robotic mechanisms employed by current, expensive systems, while increasing throughput rate.

[0072] In an embodiment, each segment of a conveyor **110** may be individually movable. For example, each segment may be configured to be shunted out of its respective conveyor **110** (e.g., vertically, horizontally, etc.). When a segment has been shunted out of its respective conveyor **110**, other segments of the conveyor **110** may be configured to move into or through the shunted segment's position within conveyor **110**, and then the shunted segment may be moved back into conveyor **110**. This enables segments to pass each other within conveyor **110**.

[0073] In addition, in an embodiment, when two segments of two adjacent conveyors **110** are aligned, an item on one segment of one conveyor **110** may be pushed or otherwise transferred to the adjacent segment on the other conveyor **110**. This transfer may be implemented by a robotic pusher that is configured to extend across the segment holding the item to push the item across to the adjacent segment and then retract, or a robotic gripper that is configured to grip the item and pull it across to the adjacent segment. In such an embodiment, the adjacent conveyors **110** may be substantially flush with each other such that there is no spacing or little spacing between the adjacent conveyors **110**.

[0074] In an embodiment, one or more of conveyors **110** may be temperature-controlled. In such an embodiment, the surface temperature of segments of the conveyor **110** or the entire conveyor **110** may be controlled using, for example, thermoelectric heating and/or cooling. Different segments of the same conveyor **110** may be individually controlled, for example, to be different temperatures than each other. Alternatively or additionally, portions of the encompassing automated system may be temperature-controlled. In such an embodiment, processing system **200** may move one or more segments of one or more conveyors **110** into these temperature-controlled portions, to control the temperature of items being held by those segments. In either case, the temperature of the temperature-controlled conveyors **110** or temperature-controlled portions of the automated system may be adjusted under control of processing system **200**.

1.4. Place Identification

[0075] In an embodiment, each item within the automated system is associated with a place identification (PID). Each PID may comprise a set of one or more coordinates that identify a position of an item within the automated system. In some cases, the PID may be the sole identifier of items within conveyance system **100**. In an embodiment, the PID comprises both a C-coordinate and a G-coordinate.

[0076] Each C-coordinate may identify a fixed location on a conveyor **110** or other holding component of the automated system, such as a fixed storage shelf from which items are moved to a conveyor **110** and/or to which items are moved from a conveyor **110**. The C-coordinate may comprise coordinates (e.g., Cartesian X-Y coordinates in two-dimensional Euclidean space) about a fixed origin point on the holding component's surface (e.g., the top surface of a conveyor **110**). For instance, as discussed above, each conveyor **110** may be divided into a plurality of segments. Each of these plurality of segments for each conveyor **110** may be permanently associated with a unique C-coordinate that uniquely identifies the segment's position within the holding components of the automated system. As long as an item is positioned on a particular holding component (e.g., a particular segment of conveyor **110**), there is no need to continue tracking the item via reading methods (e.g., barcode readers), since the location of the item may be fixed at its associated C-coordinate (e.g., the C-coordinate of the particular segment of conveyor **110** on which it is being held) for the duration of its processing. Thus, advantageously, since items are processed in place, once an item's position has been identified once (e.g., by reading its associated barcode or other machine-readable indicia at a particular C-coordinate), it does not need to be identified again.

[0077] As mentioned above, each C-coordinate may comprise X and Y coordinates, representing a unique position on a conveyor **110**. With respect to a circular carousel conveyor **110**, the X axis may be defined as coextensive with the circular profile of conveyor **110**, and the Y axis may be defined as a radial line extending outward from the center of the circular profile of conveyor **110**. Thus, each item on carousel conveyor **110** may be assigned an X coordinate that identifies the item's location on the circular X axis of carousel conveyor **110**, and a Y coordinate that identifies the item's position on a radial line extending through the X coordinate.

[0078] A separate C-coordinate system may be utilized for each conveyor **100** or other holding component in the automated system. In such an embodiment with N−1 holding components (e.g., including conveyors **110**), the PID could be N-dimensional. Specifically, the PID could comprise a G-coordinate, plus a C-coordinate for each of the N−1 holding components. However, in this case, only one C-coordinate would ever be valid at a time (the others can be null), since an item can only be held by one holding component at a time, and therefore, have only one C-coordinate at a time. Alternatively, all of the holding components could be defined in a single, shared Euclidean space, especially in the case in which the top surfaces of all of the holding components are within the same plane (e.g., in an embodiment with concentric circular carousel conveyors **110**). In such an embodiment, the value of the C-coordinate itself will identify on which holding component an item is being held.

[0079] Each G-coordinate may comprise real-world Global Positioning System (GPS) coordinates (e.g., latitude and longitude, and optionally elevation) or similar coordinates defined for a particular space (e.g., housing of the automated system, manufacturing floor, etc.). The Euclidean space of the C-coordinate system may be superimposed on an underlying ground Euclidean space of the G-coordinate system (e.g., underlying conveyors **110** and other holding components of the automated system). Both Euclidean spaces may have the exact same dimensions, and the Euclidean space of the C-coordinate system may directly relate to the ground Euclidean space of the G-coordinate system about a fixed origin point on the ground Euclidean space beneath conveyors **110**.

[0080] In an embodiment, the C-coordinate and G-coordinate systems may be polar coordinate systems around a fixed center pole. This may be especially convenient in embodiments which utilize circular carousel conveyors **110**. In a polar coordinate system, each point on a plane is determined by a distance from a reference point and an angle from a reference direction. Thus, each location in the polar coordinate system is a vector, which enables application of any equation in matrix algebra.

[0081] As discussed above, C-coordinates of items on moving surfaces, such as the top surfaces of conveyors **110**, may move over time. However, because of the relationship between the C-coordinate system and the G-coordinate system, points in the C-coordinate system may be tied to fixed points in the G-coordinate system. Thus, a full PID may be defined as the combination of a C-coordinate, which identifies a location on a holding component of the automated system, and a G-coordinate, which identifies a location within the automated system.

[0082] In this manner, an item can be associated with a PID so that its exact location throughout the automated system can be tracked by processing system **200**. In other words, the exact location of an item within an automated system can be identified using its assigned PID. Processing system **200** tracks the PIDs of all items within the automated system at all times, and may control their movements without human intervention. For instance, processing system **200** may control conveyors **110** and/or other devices (e.g., a robotic gripper) to fetch an item or set of items from a source PID (e.g., a shelf), move it onto a conveyor **110**, convey the item(s) on the conveyor **110** (during which time the PID may be continually updated to reflect its changing G-coordinate, while its C-coordinate remains fixed), and deliver the item(s) of the conveyor **110** to a destination PID (e.g., another shelf). The movement of items between holding components (e.g., conveyors **110**, shelves, etc.) may be observed by cameras, which may be monitored and/or controlled by artificial intelligence (AI).

[0083] In an embodiment, processing system **200** may utilize an optical or mechanical system to continually determine the G-coordinate of a given C-coordinate based on the relationship of the fixed origin point of the C-coordinate system to the G-coordinate system. In other words, processing system **200** can determine the exact position of a conveyor **110**—and therefore, items on the conveyor **110**—at any given moment. Accordingly, processing system **200** may calculate the G-coordinate of any item on a conveyor **110**, regardless of whether conveyor **110** is stopped or in motion. This enables processing system **200** to control the G-coordinate of any item, for example, by moving the item from one G-coordinate to another G-coordinate using one or more conveyors **110**.

[0084] Relational databases may be used to track items via their PIDs. Specifically, each item may be associated in a relational database with a PID. The PID may be used as an index or key into the relational database of items. The items may be associated with other data as well, such as an item identifier, one or more item descriptors (e.g., type, price, etc.), and/or the like. A relational database may persistently record every movement of an item. For example, a row may be stored in a movement table that identifies the item that was moved, the PID of the source of the movement, the PID of the destination of the movement, the time of the movement, and/or the like. This history of movements can be used for a variety of applications, including auditing, debugging, calculating royalties for use of conveyance system **100**, and/or the like.

[0085] As mentioned elsewhere herein, in an embodiment, conveyance system **100** enables random access of any item or set of contiguous items or segment on any conveyor **110**. For example, each segment may be individually addressed by PID. Processing system **200** may receive an instruction for random access to an item or segment. The instruction may comprise an identifier of the item and/or the C-coordinate or full PID of the segment, and may be received from another component of the automated system, from an external system, from an operator via a graphical user interface of the automated system, and/or the like. If the instruction comprises an identifier of the item, processing system **200** may map the identifier to a C-coordinate or full PID that identifies the segment and conveyor **110** on which the item is located. Otherwise, if the instruction comprises the C-coordinate or full PID, this C-coordinate or PID readily identifies the segment and conveyor **110** to be randomly accessed to processing system **200**. In either case, once the segment has been identified, processing system **200** may then control the conveyor **110**, comprising the segment, to move the segment into a position in which it may be accessed. For example, the access position may be a position that is accessible through an opening for loading and unloading of items, a position that is accessible to another robotic system (e.g., pusher or gripper), and/or the like.

[0086] In this manner, any segment and/or item within conveyance system **100** can be randomly accessed. This ability to randomly access segments allows an item to be quickly unloaded from or loaded onto any segment of any conveyor **110**, and enables high-volume items (e.g., frequently used items) to be stowed on conveyors **110** near each other. It can also facilitate the archiving of unexpired samples (e.g., at a blood bank). For example, a tested sample may be stowed on a conveyor **110**, and then subsequently tested again (e.g., a few days later) for ongoing transfusions, in so-called “reflex” testing (i.e., tests indicated by events or new results). In addition, processing system **200** may utilize random access of segments of conveyors **110** to automatically re-sort items on conveyors **110**, for example, to optimize placement of those items within the automated system.

1.5. Example Coordination of Carousels

[0087] FIGS. **4**A and **4**B illustrate an example of how the movements of conveyors **110** may be coordinated, according to an embodiment. The illustrated conveyance system **100** comprises four carousel conveyors **110**A. Each carousel conveyor **110** is divided into wedges **112**, for example, with each wedge **112** being represented by a different PID.

[0088] In the illustrated example, processing system **100** determines that it must align the wedges **112**, that have been assigned C-coordinates A**1**, B**1**, C**1**, and D**1**, into a radial line underneath bridge **120**, so that they may all be accessed for an operation using one or more instruments on bridge **120**. As shown in FIGS. **4**A and **4**B, A**1** on conveyor **110**A is rotated clockwise by three indexed positions, B**1** on conveyor **110**B is rotated counterclockwise by fifteen indexed positions, C**1** on conveyor **110**C is rotated counterclockwise by seven indexed positions, and D**1** on conveyor **110**D is rotated clockwise by four indexed positions, to align A**1**, B**1**, C**1**, and D**1**, on carousels **110**A-**110**D, in the same radial line under bridge **120**. Consequently, A**1** is under position **122**A of bridge **120**, B**1** is under position **122**B of bridge **120**, C**1** is under position **122**C of bridge **120**, and D**1** is under position **122**D of bridge **120**. Accordingly, all of the wedges **122**, identified by A**1**, B**1**, C**1**, and D**1**, are accessible by the instrument(s) of bridge **120**, as shown in FIG. **4**B.

[0089] In the example of FIGS. **4**A and **4**B, carousel conveyors **110** are capable of rotating in either direction. Thus, processing system **200** may select a direction of rotation for each of conveyors **110** that is most efficient for that particular conveyor **110**. Efficiency may be defined as the least amount of movement, in which case processing system **200** may select a direction of rotation that requires the least amount of rotation to move a particular wedge **112** to its destination indexed position. However, in an alternative system **100**, carousel conveyors **110** may only rotate in a single direction, or a different definition of efficiency may be used.

[0090] Notably, conveyors **110** may be controlled to align any combination of segments **112**, across conveyors **110**, in a radial line with each other (e.g., under bridge **120**). Thus, processing system **200** may coordinate conveyors **110** to align segments **112**, thereby aligning the particular items being held on those segments **112**, in order to execute a particular task on the aligned items (e.g., using instrument(s) **140** on bridge **120**). In this case, each conveyor **110** may convey a set of items that are all related to the same step in an overall task, such that, when segments **112** are aligned, all of the items needed for all of the steps of the task are available on a radial line across conveyors **110**. For example, referring to FIG. **4**B, an item for a first step of the task may be located at A**1** and accessible at position **122**A to an instrument **140**, an item for a second step of the task may be located at B**1** and accessible at position **122**B to an instrument **140**, and item for a third step of the task may be located at C**1** and accessible at position **122**C to an instrument **140**, and an item for a fourth step of the task may be located at D**1** and accessible at position **122**D to an instrument **140**. Using larger numbers of segments, millions or billions of different combinations of items can be quickly radially aligned serially or in parallel.

1.6. Immunohematology

[0091] In an embodiment, the conveyance system **100** in FIG. **3**, comprising four concentric carousel conveyors **110**, may be configured to perform pre-transfusion blood testing (e.g., for viral and other infectious disease markers). While the concentric carousel conveyors **110**A-**110**D are shown and described below in a particular order from the center to outside of conveyance system **100**, carousel conveyors **110**A-**110**D may be provided in a different order. Furthermore, conveyance system **100** may comprise fewer or more concentric carousel conveyors **110** than shown.

[0092] A first carousel conveyor **110**A may hold test cells (e.g., 100 to 10,000 test cells) of various shapes and sizes, as required by the particular tests to be performed. The test cells may comprise an assay, such as an IH assay (e.g., for red-blood cell antigens and antibodies), an infectious disease assay, or an assay for other clinical diagnostic tests. The test cells may comprise clip-on racks (e.g., crescent-shaped racks), which may, but do not have to, fill the entire top surface of first carousel conveyor **110**A. Each rack may comprise concentric curved lines of test cells. The racks of test

cells may clip on and off first carousel conveyor **110**A and be disposable.
[0093] The tests cells may comprise IH or infectious-disease assays. Such assays may be forward-typing, reverse-typing, Rh-typing, antibody-screening, antibody-identifying, red-blood-cell-phenotyping, AHG-testing, viral-marking, and/or the like. Viral-marking antigens may comprise CMV, HBV (surface antigen and core antibody), HCV, HIV (type 1 and 2), HTLV, Chagas disease, Zika virus, and West Nile virus.
[0094] In an embodiment, the test cells for pre-transfusion blood testing may comprise one or more fluid zones. The top fluid zone may be for incubating plasma and/or serum and red-blood cells.
[0095] FIGS. **5**A-**5**C illustrate examples of test cells to be used on a carousel conveyor **110**, according to an embodiment. Conventional gel cards have a plurality (e.g., six or eight) of vertical microwells. In contrast, FIG. **5**A illustrates a horizontal microwell, according to an embodiment. Microwell **500** comprises a receptacle portion **510** (e.g., where plasma and red blood cells can incubate), with an opening or access port for receiving a pipette tip, connected to a horizontal well portion **520**. Each microwell **500** may be an L-shaped lateral flow assay that lies horizontally and radially, with the access port facing up to receive fluids from above. This enables the microwell **500** to be centrifuged in place and read from above or below. Each microwell **500** may be 25 millimeters (mm) long, and may sit substantially flush on the top surface of first carousel conveyor **110**A.
[0096] As illustrated in FIG. **5**B, these microwells **500** may be arranged in a line **550** (e.g., of six, eight, or ten microwells **500** each). In IH, it is routine to run a panel of ten tests on a sample, requiring pipetting red-blood cells into five microwells and plasma into five microwells. Thus, in a preferred embodiment, each line **550** may comprise ten microwells **500**.
[0097] Furthermore, as illustrated in FIG. **5**C, these lines **550** of microwells may be combined into racks **560** (e.g., of six, eight, or ten lines **550** each) and held (e.g., clipped on) the top surface of a carousel conveyor **110**. Racks **560** may be arranged on the top surface of a carousel conveyor **110** with the opening of receptacle portion **510** on each microwell **500** facing upward. Notably, each line **550** of microwells **500** may correspond to a radial line extending outward from conveyance system **100**. In addition, each microwell **500** may be arranged such that its receptable portion **510** is closer to the inner edge of carousel conveyor **110**, while its well portion **520** is closer to the outer edge of carousel conveyor **110**, to thereby enable lateral centrifugation. Racks **560** may be arranged, and angled with respect to each other, in annulus sectors, to substantially cover the entire top surface of carousel conveyor **110**. As an example, each annulus sector on first carousel conveyor **110**A may be 100 centimeters (cm) long and 25 cm wide, and hold 300 test cells in each of 10 concentric perimeter rings, providing up to 3,000 available disposable test cells per annulus sector. As another example, each annulus-sector-shaped rack **560** may comprise one-hundred radial lines **550** with ten microwells **500** in each line **550**, providing 1,000 available test cells per annulus sector.
[0098] As used racks **560** are removed from first carousel conveyor **110**A, new, clean, disposable racks **560** may be placed on first carousel conveyor **110**A in their places. The removal and/or placement of racks **560** may be performed manually or automatically. As tests are scheduled by the automated IH system, racks **560** may be prepared with sufficient lead time to perform the scheduled tests, for example, by adding reagents to the number of microwells **500** that will be used during the tests. Alternatively, racks **560** may be manufactured with reagents in place. Advantageously, the capability of onboard, in-place preparation of microwells **500** provides greater flexibility in test menus, lowers the cost of disposables, eliminates the problem of wasted wells, enables simpler and less expensive manufacturing of test cells, with simpler shipping and quality control processes and fewer recalls, and simpler inventory management.
[0099] The illustrated configuration of microwells **500** enables first carousel conveyor **110**A to be effectively used as a centrifuge on microwells **500**. This is advantageous, since the microwells **500** do not need to be moved to a separate centrifuge device. In other words, they can be both tested

and centrifuged, in the same place, on carousel conveyor **110**A, eliminating the need for complex robotics to move the test cells into and out of a separate centrifuge. Carousel conveyors **110** may be configured to spin at one or more centrifugal speeds, as required for the specific test being performed (e.g., apheresis for CAT testing). For example, to run gel tests, antibody and red-blood cells may be added to a microwell **500** on carousel conveyor **110**A, and then carousel conveyor **110**A may be spun at a set speed for a set time to deliver a measured amount of centrifugal force that moves agglutinated or non-agglutinated red-blood cells toward the closed end of well portion **520**. Test results can be read out by a camera or other reader device that is positioned above or below the well portion **520** of the microwell **500** (e.g., at position **122**A on a bridge **120**). Advantageously, the same standard, established, validated, FDA-approved CAT tests (e.g., protein flotation or simwash method for red-blood cell washing) can be performed, without modification or development, in this improved manner. It should be understood that not all testing may require centrifugation (e.g., homogenous "passive" IH testing). In these cases, first carousel conveyor **110**A is simply not used in its centrifugation mode.

[0100] In the manner described above, hundreds or thousands of fresh microwells **500** (e.g., for CAT testing) can be positioned and immediately accessible for testing (e.g., on a testing deck of an automated IH system), providing a simpler, faster, and less expensive way to automate CAT testing. Advantageously, microwells **500** start in place and stay in place during the entire testing process. Instead of conventional six to eight-well vertical gel cards, which have to be tilted to horizontal in bucket centrifuges, embodiments of the disclosed microwells **500** can be spun in place in large numbers. In other words, first carousel conveyor **110**A can rotate to indexed positions for loading, reading, and pipetting, remain stationary for incubation, and spin as a centrifuge or agitator. No loading of gel cards into and out of a centrifuge is required. This eliminates the need for robotics to retrieve, tilt, or otherwise move test cells, and which generally requires a complex gripper mechanism and long, slow, three-dimensional traversals. Accordingly, throughput can be increased by ten times or greater. To further shorten processing time, microwells **500** may be read (e.g., stroboscopically on a sub-second timescale) while first carousel conveyor **110**A is still spinning as a centrifuge. Alternatively, microwells **500** may be read while first carousel conveyor **110**A is stationary. While this may reduce complexity within the system, it may also decrease the throughput rate of the automated system.

[0101] As discussed elsewhere herein, a carousel conveyor **110** may act as an agitator, in addition to a conveyor. For example, first carousel conveyor **110**A may spin lightly after reagent (e.g., Anti-Human Globulin (AHG) reagent) has been added to a microwell **500** and before any tests are performed. This light spinning can force the reagent into the correct position at the end of well portion **520**, eliminating the problem of "splash and bubble" that plagues current CAT testing. The correctness of the placement of the reagent, during or after agitation, may be validated by an automated reading station, prior to further processing (e.g., adding a sample, incubation, etc.).

[0102] A second carousel conveyor **110**B may hold one or more rings of reagent containers. The reagent containers may be designed to be installed and removed individually or as racks (e.g., crescent racks) of multiple reagent containers. In an embodiment, a station may be provided at which reagent containers may be installed and/or accessed (e.g., read) on a segment of second carousel conveyor **110**B that is accessible to the station, when second carousel conveyor **110**B is stationary.

[0103] A third carousel conveyor **110**C may hold one or more rings of sample or specimen containers (e.g., vacutainers containing blood from donors or patients). Preferably, third carousel conveyor **110**C is more peripheral than and surrounds first carousel conveyor **110**A and second carousel conveyor **110**B, but this is not a requirement of conveyance system **100**. The specimen containers may be designed to be installed and removed individually or as racks (e.g., crescent racks) of multiple specimen containers. In an embodiment, a station may be provided at which specimen containers may be installed and/or accessed on a segment of third carousel conveyor

110C that is accessible to the station, when third carousel conveyor **110**C is stationary.
[0104] A fourth carousel conveyor **110**D may hold a ring of vessels for processing specimens, such as making dilutions or cell suspensions. Alternatively, the specimen-processing vessels may be held on the third carousel conveyor **110**C, along with the specimen containers, for example, on a radial line with the specimen container that the vessel will be used to process. In this case, the specimen-processing vessels are preferably farther from the center of conveyors **110** than the specimen containers, but may alternatively be closer to the center of conveyors **110** than the specimen containers. The specimen-processing vessels may be designed to be installed and removed individually or as racks (e.g., crescent racks) of specimen-processing vessels. In an embodiment, a station may be provided at which specimen-processing vessels may be installed and/or accessed on a segment of fourth carousel conveyor **110**D that is accessible to the station, when fourth carousel conveyor **110**D is stationary.
[0105] In the described embodiment, conveyance system **100** also comprises at least one automated pipetting station, which may be implemented as a bridge **120** that extends orthogonally over all of concentric carousel conveyors **110**A-**110**D on a radial line. Thus, a segment from each of first through fourth carousel conveyors **110**A-**110**D may be radially aligned under bridge **120**, while all of carousel conveyors **110**A-**110**D are stopped. During this radial alignment, a pipettor is configured to move radially on bridge **120**, and is capable of stopping at each of positions **122**A-**122**D to perform an operation at the underlying segment. The pipetting system may comprise one or more pipettors and/or a single channel or multi-channel pipettor, peristaltic or other types of pumps, pipettors in different orientations, and/or the like. At position **122**A, the pipettor has access to at least one test cell on first carousel conveyor **110**A, and preferably can make small steps along the radial line of bridge **120** to access a plurality of test cells in a radial line on first carousel conveyor **110**A. Similarly, at position **122**B, the pipettor has access to at least one reagent on second carousel conveyor **110**B. Similarly, at position **122**C, the pipettor has access to at least one specimen container on third carousel conveyor **110**C. Similarly, at position **122**D, the pipettor has access to at least one specimen-processing vessel on fourth carousel conveyor **110**D (or third carousel conveyor **110**C). Notably, any combination of test cell, reagent container, specimen container, and specimen-processing vessel can be obtained by rotating carousel conveyors **110**A-**110**D relative to each other. Thus, the pipettor may aspirate from or dispense into any container on conveyors **110** via rotation of conveyors **110** and radial and vertical movement of the pipettor, under control of processing system **200**. In this manner, any specimen sample may be mixed with any reagent in any test cell within conveyance system **100**.
[0106] In an embodiment, the automated pipetting station may also comprise automated tip cleaning. For example, at position **122**E, the pipettor may have access to a cleaning mechanism (e.g., implemented in apparatus **130**), such as a stationary wash buffer. The pipettor may access the cleaning mechanism when appropriate to clean the tip of the pipettor. For example, whenever the pipettor needs to wash itself, the pipettor may slide along bridge **120** to a position above the wash buffer (e.g., position **122**E), lower the pipettor tip into the wash buffer, aspirate washing fluid to perform self-cleaning, and then dispense the washing fluid (e.g., above a disposal buffer). Alternatively or additionally, the pipettor may have access to cell-suspension and/or dilution-making mechanisms (e.g., implemented in apparatus **130**) at position **122**E.
[0107] In an embodiment, conveyance system **100** may comprise a plurality of automated pipetting stations to increase throughput. For example, system **100** may comprise ten automated pipetting stations, with each station on a separate radial line. The radial lines may be adjacent to each other. In this case, if first carousel conveyor **110**A is configured to hold ten test cells along each radial line, conveyance system **100** is able to simultaneously prepare a 10×10 batch of test cells at a time. It should be understood that the number of pipetting stations may be decreased or increased to any number, depending on the desired size and throughput rate of a particular conveyance system **100**. Notably, the addition or removal of pipetting or other stations does not require any changes to

conveyors **110**. Thus, in an embodiment, the stations may be modular components that can be purchased as need and added by an operator after manufacture (e.g., after manufacture and purchase of conveyance system **100** or the automated system).

[0108] By one estimation, a conveyance system **100** with a 10-channel pipettor and capable of reading test results during spinning, could run 200 test panels (e.g., 200 radial lines, each comprising 10 test cells, for 2,000 test cells total) per hour with a single first carousel conveyor **110**A. This far exceeds the throughput rate of even the fastest conventional CAT system. Furthermore, this throughput rate can be multiplied by adding any number of first carousel conveyors **110**A to the implementation of conveyance system **100**.

[0109] Conveyance system **100** may also comprise an automated reading station, which may be implemented as a second bridge **120** that extends orthogonally over all of concentric carousel conveyors **110**A-**110**D on a radial line. Alternatively, the automated reading station could be combined with the automated pipetting station into a single bridge **120**. The automated reading station may comprise a camera, spectrophotometer, or other sensor (e.g., fixed barcode readers configured to read barcodes on items on conveyors **110**) at one or more positions (e.g., **122**A-**122**D) to image or otherwise detect or measure parameters of items on conveyors **110**A-**110**D respectively. For example, the detection device may be a stationary video-reading device that reads and records hemagglutination in multiple test cells (e.g., an entire rack **560**) at the same time. In this manner, the automated reading station can gather data from assays represented by items on conveyors **110**. In an embodiment, the automated reading station may gather the data as carousel conveyors **110** spin, for example, using stroboscopic light. This enables early reporting, for example, in emergency transfusion situations.

[0110] In an embodiment, conveyors **110** may be sized to hold the reagent and specimen containers for the entire active inventory of a typical blood bank. Thus, all of the reagent and specimen containers may be accessible to the automated system for autonomous processes (e.g., pre-transfusion testing). In addition, this enables autonomous inventory control, automated reordering (e.g., when reagent inventory is low), and autonomous quality control.

[0111] The automated system may comprise a housing that is approximately the size of a kitchen island (e.g., six feet by six feet) with concentric carousel conveyors **110** disposed inside. The housing may provide access to concentric carousel conveyors **110** from above for convenient loading and unloading of items. For example the housing may comprise an openable and closable panel that provides top-loading access to at least a portion of carousel conveyors **110**. For safety purposes, the automated system may prevent access to conveyors **110** while conveyors **110** are moving.

[0112] The automated system may also comprise a processing system **200** that can be controlled remotely via communications over one or more networks. Thus, the automated system, including conveyors **110**, may be remotely managed via a user system (e.g., personal desktop computer, mobile device such as a smartphone or tablet computer, server, etc.). In an embodiment, more than one user may operate the automated system at a time to independently rotate different conveyors **110** and/or utilize different stations (e.g., on different sides of conveyance system **100**).

[0113] Such an automated system could replace the entire diagnostic operation (e.g., including technologists, laboratories, desks, etc.) of a hospital blood bank. The automated system could be scaled up to a larger version which is capable of handling the entire process for storing and issuing blood units for a large hospital blood bank, under the supervision of local and/or remote personnel. Alternatively, the automated system could be scaled down to a smaller version. Regardless of size, the control and analysis algorithms do not need to be altered.

[0114] As mentioned above, carousel conveyors **110**A-**110**D may be coordinated so as to radially align segments, with their associated items, at one or more stations (e.g., bridge **120**) for processing, such as pre-transfusion testing, random access testing, and/or reflex testing (e.g., based on algorithms or human direction for interpreting prior test results) in an automated blood-analysis system. The capabilities of such a system may far exceed the capabilities of current immunohematology (IH) analyzers, such as the BioRad IH1000™. For example, conventional CAT has focused on automated processing of gel cards (e.g., comprising six or eight wells) using complicated robotics. Advantageously, in an embodiment of an automated blood-analyzing system comprising conveyance system **100**, with concentric carousel conveyors **110**, the only robotic automation required is rotation of carousel conveyors **110** and movement of the pipettor for fluid handling (e.g., aspiration, aliquoting specimen samples, reagents, and other fluids, etc.). The static pipetting station and/or reading station cooperate with carousel conveyors **110** to serve each test performed by the automated blood-analyzing system.

[0115] Test cells, reagent containers, specimen containers, and/or specimen-processing vessels may be labeled with barcodes, near-field-communication (NFC) chips, RFID tags, or other machine-readable indicia that can be read by an automated reading station and which identify and/or describe the respective item. The automated reading station may read the indicia of an item at a position on carousel conveyor **110** (e.g., identified by a C-coordinate), and processing system **200** may store an association between the identifier of the item and the position (e.g., C-coordinate). Thus, processing system **200** may control a carousel conveyor **110** to deliver a particular item to a station for reading, pipetting, loading, unloading, and/or other processing.

[0116] One or more of the illustrated conveyors **110**A-**110**D may comprise a plurality of conveyors **110**. For instance, first carousel conveyor **110**A, which is described as holding test cells, could comprise a plurality (e.g., two) concentric carousel conveyors **110** that each hold test cells. This duplication of conveyors **110** that hold the same type of items can minimize dwell time. Specifically, as one of these carousel conveyors **110** is being used in one process (e.g., loading or unloading, reading, aspiration or dispensation, as a centrifuge, other testing, etc.), other ones of these carousel conveyors **110** may be used in a different process. For example, as test cells are being loaded onto one of first carousel conveyors **110**A, another one of first carousel conveyors **110**A may be spun as a centrifuge. Processing system **200** may store and execute time-sharing algorithms that control the division of operations between the plurality of same-type conveyors **110**, so as to minimize dwell time in which a process is waiting for a conveyor **110** to become available. In other words, the algorithms are programmed to minimize contention for the same-type conveyors **110**.

[0117] One or more of the illustrated conveyors **110**A-**110**D may be temperature-controlled. For example, first carousel conveyor **110**A may comprise a metal surface that is heated (e.g., thermoelectrically) to impart heat of an appropriate temperature to incubate the test cells (e.g., at the customary temperature of 37° Celsius) for a measured time (e.g., 10 minutes), under control of processing system **200**. In a linear batch process, in which radial lines **550** of test cells are steadily stepped under bridges **120**, incubation times can be controlled, for example, by providing appropriate spacing between the bridge **120** of the automated pipetting station and the bridge **120** of the next processing station. For example, if ten minutes is required for incubation and first carousel conveyor **110**A is stepped every ten seconds, the bridges **120** should be spaced apart by sixty radial lines.

[0118] Similarly, second carousel conveyor **110**B and/or third carousel conveyor **110**C may comprise a surface that is cooled to keep the reagents and/or specimens at temperatures that are appropriate for their preservation. For more precise temperature control, processing system **200** and each temperature-controlled conveyor **110** may be configured to adjust the temperature of specific segments of the conveyor **110** separately from other segments of the same conveyor **110**. Thus, in addition to centrifugation and/or agitation, a carousel conveyor **110** may also act as an incubator, thereby eliminating the need for test cells, already in place on the carousel conveyor **110**, to be robotically moved.

2. Process Overview

[0119] Embodiments of processes for controlling conveyance system **100** will now be described in detail. It should be understood that the described processes may be embodied in one or more software modules that are executed by one or more hardware processors (e.g., processor **210**) of an automated system that comprises conveyance system **100**. The described processes may be implemented as instructions represented in source code, object code, and/or machine code. These instructions may be executed directly by the hardware processor(s), or alternatively, may be executed by a virtual machine operating between the object code and the hardware processors.

[0120] Alternatively, the described processes may be implemented as a hardware component (e.g., general-purpose processor, integrated circuit (IC), application-specific integrated circuit (ASIC), digital signal processor (DSP), field-programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, etc.), combination of hardware components, or combination of hardware and software components. To clearly illustrate the interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps are described herein generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled persons can implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the invention. In addition, the grouping of functions within a component, block, module, circuit, or step is for ease of description. Specific functions or steps can be moved from one component, block, module, circuit, or step to another without departing from the invention.

[0121] Furthermore, while the processes, described herein, are illustrated with a certain arrangement and ordering of steps, each process may be implemented with fewer, more, or different steps and a different arrangement and/or ordering of steps. In addition, it should be understood that any step, which does not depend on the completion of another step, may be executed before, after, or in parallel with that other independent step, even if the steps are described or illustrated in a particular order.

[0122] For the purposes of illustration, the processes will be described herein with reference to a conveyance system **100** comprising concentric carousel conveyors **110**. However, this example is not limiting, and it will be readily apparent to a person of skill in the art how to adapt the described processes to other configurations of cooperating conveyors **110**, including different numbers of conveyors **110**, different shapes of conveyors **110** (e.g., adjacent linear conveyors **110**), vertically stacked conveyors **110**, and/or the like.

2.1. Item Loading

[0123] In an embodiment, one or more items may be labeled with machine-readable indicia (e.g., barcode, Quick Response (QR) code, alphanumeric string, NFC chip, RFID tag, etc.). At the time that these items are loaded on a conveyor **110**, processing system **200** may automatically rotate conveyor **110**, such that each segment on which an item is loaded passes through an automated reading station. The automated reading station may read the machine-readable indicia of the item on the segment of conveyor **110** that is currently accessible to the reading station (e.g., via an instrument **140**, such as a camera, barcode reader, NFC chip, RFID interrogator, etc.), to identify the item. Because processing system **200** tracks each segment of conveyor **110** (e.g., via its PID), processing system **200** can also identify which segment is currently accessible to the reading station. Thus, processing system **200** may map an identifier of that item to an identifier of the segment (e.g., the C-coordinate of the segment) of the conveyor **110** on which it has been loaded. This mapped association may be stored (e.g., in memory **215** or **220**) until the item is removed from conveyor **110**. Advantageously, this association allows the item to be identified in subsequent operations based on its position on conveyor **110**, and the position of an item on conveyor **110** to be retrieved using an identifier of the item. Each item within a rack **560** may be given a position identifier identifying its location within that rack **560** prior to rack **560** being loaded onto a conveyor **110**. Once rack **560** has been placed onto conveyor **110**, processing system **200** may compute the C-coordinate of each item within rack **560** based on the position of rack **560** on conveyor **110** and the position identifier of the item within the rack **560**.

[0124] If the automated reading station is only capable of reading the machine-readable indicia while conveyor **110** is stationary, conveyor **110** may rotate to a first indexed position, stop for a sufficient time for the automated reading station to read the machine-readable indicia, rotate to a second indexed position, stop for a sufficient time for the automated reading station to read the next machine-readable indicia, rotate to a third indexed position, and so on and so forth. In an alternative embodiment, the automated reading station may be configured to read machine-readable indicia while conveyor **110** is rotating (e.g., via stroboscopic light). In this case, conveyor **110** may simply rotate as much as necessary for all of the machine-readable indicia on conveyor **110** to be read (e.g., a full or partial revolution), at a speed at which the automated reading station is able to read the machine-readable indicia (e.g., synchronized with the stroboscopic light).

2.2. Immunohematology (IH)

[0125] FIG. **6** illustrates the use of conveyance system **100** in a process **600** for pre-transfusion IH testing, according to an embodiment. Process **600** may be implemented as one or more software modules stored and executed by processing system **200** (e.g., specifically by processor(s) **210**) to control the components of conveyance system **100**. Process **600** may occur after all utilized items have been loaded onto conveyors **110** or in parallel with the utilized items being loaded onto conveyors **110**.

[0126] In step **605**, processing system **200** determines whether any test cells need to be prepared. For example, processing system **200** may receive an instruction (e.g., via a user interface provided by the automated system) to perform one or more tests. In response to the instruction, processing system **200** may determine how many test cells need to be prepared. Then, in steps **610** and **615**, processing system **200** may iteratively prepare each test cell that needs to be prepared. If any test cells remain to be prepared (i.e., “Yes” in step **605**), process **600** proceeds to step **610**. Otherwise, if no test cells remain to be prepared (i.e., “No” in step **605**), process **600** proceeds to step **620**.

[0127] In step **610**, processing system **200** rotates one or both of first carousel conveyor **110**A, holding test cells, and second carousel conveyor **110**B, holding reagent containers, so that the next set of test cell(s) to be prepared are aligned with the appropriate reagent at the automated pipettor station. For example, processing system **200** may determine which reagent to be used in the preparation, identify a segment of second carousel conveyor **110**B that holds that reagent, and rotate carousel conveyors **110**A and/or **110**B so that the identified segment of second carousel conveyor **110**B is radially aligned with the set of test cell(s) to be prepared under bridge **120**. At this time, processing system **200** could also rotate other conveyors **110** (e.g., third carousel conveyor **110**C and/or fourth carousel conveyor **110**D) to align segments of those conveyors **110**, which will be needed for subsequent operations, with the aligned set of test cell(s) and reagent, at the automated pipettor station. Alternatively, this alignment may be done at a later time as needed.

[0128] In step **615**, processing system **200** controls the pipettor to pipette reagent from the reagent container in the aligned segment of second carousel conveyor **110**B into the set of test cell(s) in the aligned segment of first carousel conveyor **110**A. More specifically, the pipettor is moved along bridge **120** to position **122**B above the reagent container, the pipettor tip is lowered into the reagent container, an appropriate amount of reagent is aspirated into the pipettor, the pipettor tip is raised, the pipettor is moved along bridge **120** to position **122**A above a test cell, the pipettor tip is lowered into the test cell (e.g., into the opening in receptacle portion **510** of a microwell **500**), an appropriate aliquot of reagent is dispensed into the test cell, and the pipettor tip is raised. This process may be repeated multiple times for each test cell in the aligned set of test cell(s) on first carousel conveyor **110**A. However, for efficiency, the pipettor may aspirate an amount of reagent that is sufficient for multiple test cells (e.g., sufficient for 100 test cells), such that the pipettor may dispense reagent into a plurality of test cells (e.g., along a radial line under bridge **120**) without returning to the reagent container. In this case, the pipettor may step radially across the aligned segment of first carousel conveyor **110**A from one end of a line **550** of test cells to the opposite end of the line **550** of test cells (e.g., from innermost test cell to outermost test cell). The pipettor may perform self-cleaning (e.g., using a wash buffer as discussed elsewhere herein) as needed (e.g., before aspiration of any reagent).

[0129] In step **610**, if a set of test cell(s) need to be filled with a plurality of reagents (e.g., for multiplexed testing within the same microwell **500**), first carousel conveyor **110**A may be held stationary, while second carousel conveyor **110**B is stepped to the segment holding the next reagent container, over a plurality of iterations of steps **610** and **615**. On the other hand, if a plurality of sets of test cell(s) need to be filled with the same reagent, second carousel conveyor **110**B may be held stationary, while first carousel conveyor **110**A is stepped to the segment holding the next set of test cell(s), over a plurality of iterations of steps **610** and **615**.

[0130] In step **620**, processing system **200** may control first carousel conveyor **110**A to agitate the test cells, into which reagent has been dispensed, to force the reagent into the appropriate position (e.g., within well portion **520** of each microwell **500**). This agitation may comprise gently spinning first carousel conveyor **110**A at low RPM. If such agitation is not required for a particular test, step **620** may be omitted.

[0131] In step **625**, processing system **200** determines whether any specimens need to be tested. For example, processing system **200** may receive an instruction (e.g., via a user interface provided by the automated system) to perform one or more tests on one or more specimens. In response to the instruction, processing system **200** may determine the locations of specimens to be tested. Then, in steps **630** and **635**, processing system **200** may iteratively prepare each sample that needs to be prepared from the located specimens. If any specimens remain to be prepared (i.e., "Yes" in step **625**), process **600** proceeds to step **630**. Otherwise, if no specimens remain to be prepared (i.e., "No" in step **625**), process **600** proceeds to step **640**.

[0132] In step **630**, processing system **200** rotates one or both of the first carousel conveyor **110**A, holding reagent-filled test cells, and third carousel conveyor **110**C, holding specimen containers, so that a set of reagent-filled test cell(s) is aligned with the next specimen to be prepared at the automated pipettor station. For example, processing system **200** may identify a segment of third carousel conveyor **110**C that holds the next specimen, identify a segment of first carousel conveyor **110**A that holds a set of reagent-filled test cell(s) to be used for that specimen, and rotate carousel conveyors **110**A and/or **110**C so that the identified segment of third carousel conveyor **110**C is radially aligned with the set of test cell(s) to be used under bridge **120**. In an embodiment that uses fourth carousel conveyor **110**D to hold specimen-processing vessels, fourth carousel conveyor **110**D may be similarly rotated to also move a segment of fourth carousel conveyor **110**, holding the specimen-processing vessels to be used, into alignment under bridge **120**. Alternatively, as discussed elsewhere herein, specimen-processing vessels may be installed radially next to their associated specimen containers on third carousel conveyor **110**C.

[0133] In step **635**, processing system **200** controls the pipettor to pipette a sample into the set of test cell(s) in the aligned segment of first carousel conveyor **110**A. More specifically, the pipettor is moved along bridge **120** to position **122**C above the specimen container, the pipettor tip is lowered into the specimen container, an appropriate sample of the specimen is aspirated into the pipettor, the pipettor tip is raised, if necessary the sample is prepared using specimen-processing vessels, the pipettor is moved along bridge **120** to position **122**A above a test cell, the pipettor tip is lowered into the test cell (e.g., into the opening in receptacle portion **510** of a microwell **500**), an appropriate aliquot of the sample is dispensed into the test cell, and the pipettor tip is raised. This process may be repeated multiple times for each test cell in the aligned set of test cell(s) on first carousel conveyor **110**A to be used for testing the sample. However, for efficiency, the pipettor may aspirate an amount of the sample that is sufficient for multiple test cells, such that the pipettor may dispense an aliquot of the sample into a plurality of test cells (e.g., along a radial line under bridge **120**) without having to collect more of the sample. In this case, the pipettor may step radially across the aligned segment of first carousel conveyor **110**A from one end of a line **550** of test cells to the opposite end of the line **550** of test cells (e.g., from innermost test cell to outermost test cell). The pipettor may perform self-cleaning (e.g., using a wash buffer as discussed elsewhere herein) as needed (e.g., before aspiration of any sample).

[0134] As mentioned above, in some cases the sample of the specimen may be prepared using specimen-processing vessels, before being dispensed into test cells. For instance, the pipettor may dispense the sample into a specimen-processing vessel (e.g., at position **122**D under bridge **120**) to make a dilution or cell suspension using the specimen. Similarly, the pipettor may obtain (e.g., via aspiration, a connected fluid system, etc.) any other fluid(s) necessary for the dilution or cell suspension, and dispense those fluid(s) into the specimen-processing vessel. The pipettor may then aspirate the dilution or cell suspension as the sample to be dispensed into the set of test cell(s).

[0135] In step **630**, if a set of test cell(s) need to be filled with a plurality of samples, first carousel conveyor **110**A may be held stationary, while third carousel conveyor **110**C is stepped to the segment holding the next specimen container, over a plurality of iterations of steps **630** and **635**. On the other hand, if a plurality of sets of test cell(s) need to be filled with the same sample, third carousel conveyor **110**C may be held stationary, while first carousel conveyor **110**A is stepped to the segment holding the next set of test cell(s), over a plurality of iterations of steps **630** and **635**.

[0136] In step **640**, processing system **200** may control first carousel conveyor **110**A to incubate the sample-filled test cells. This incubation may comprise increasing the temperature of at least those segments of first carousel conveyor **110**A that hold the sample-filled test cells. Alternatively or additionally, this incubation may comprise rotating the segments of first carousel conveyor **110**A that hold the sample-filled test cells into a portion of conveyance system **100** that is temperature-controlled for incubation. The incubation period may be set to an appropriate time period (e.g., ten minutes). Once the incubation period ends, process **600** may proceed to step **645**. Notably, numerous test cells (e.g., 1,000 test cells) may be simultaneously incubated. In addition, agitation may be applied (e.g., by gently spinning first carousel conveyor **110**A at low RPM) to shorten the required incubation period. If incubation is not required for a particular test, step **640** may be omitted.

[0137] In step **645**, processing system **200** may control first carousel conveyor **110**A to act as a centrifuge. Specifically, processing system **200** may accelerate and spin first carousel conveyor **110**A at high RPM (e.g., greater than or equal to 1,500 RPM, 1,600 RPM, 2,000 RPM, 4,000 RPM, etc.), designed to exert an appropriate amount of centrifugal force on the test cells being held on first carousel conveyor **110**A. The precise RPM s to be used for centrifugation may depend on the size of first carousel conveyor **110**A (e.g., 4,000 RPM on an 11-inch conveyor **110**A, 1,600 RPM on a 6-foot conveyor **110**A, etc.). Notably, centrifugation is part of CAT testing. If centrifugation is not required for a particular test, step **645** may be omitted.

[0138] In step **650**, processing system **200** determines the results of the testing. The results may be acquired as the output from an automated reading station (e.g., implemented as a bridge **120**). In an embodiment, the automated reading station may read the results during step **645** (i.e., as first carousel conveyor **110**A is spinning as a centrifuge). This may be done using stroboscopic light. Alternatively, the automated reading station may read the results after step **645**, while processing system **200** rotates first carousel conveyor **110**A, in stepwise fashion, so that the automated reading station may read the results of a test cell while first carousel conveyor **110**A is stationary. In either case, processing system **200** may interpret and report the results to an LIS (e.g., via an API of the LIS and/or over at least one network between the automated system and LIS) and/or a user (e.g., in a graphical user interface provided by the automated system).

2.3. Software

[0139] Processing system **200** may store and execute one or more software modules (e.g., stored in main memory **215** and/or secondary memory **220**, and executed by processor(s) **210**) that control conveyance system **100**. This control may comprise optimizing the timing of movements of conveyors **110** relative to each other and operations being performed (e.g., minimizing dwell time and increasing throughput), implementing required lead times for processing (e.g., to fill tests cells with the appropriate reagent in advance of a scheduled test), selecting items for processing, bringing together a collection of items for processing, and/or the like.

[0140] In an embodiment, the control software may utilize artificial intelligence to anticipate the intentions of the automated system and/or human users. For example, the control software may train a machine-learning algorithm to predict the next operation to be performed based on an observed series of events, using historical datasets that have been observed and stored. Additionally or alternatively, artificial intelligence (e.g., employing neural networks) may be used to recognize and/or classify objects in image data captured by one or more reading stations.

[0141] Processing system **200** may also store and execute one or more software modules (e.g., stored in main memory **215** and/or secondary memory **220**, and executed by processor(s) **210**) to analyze data, including sensed results, produced by the automated system (e.g., by the instruments **140** of one or more stations). This analysis may comprise determining and interpreting the results of tests (e.g., based on image data of microwells **500** captured by a camera of a reading station), inventorying items (e.g., based on image data of machine-readable indicia captured by a camera of a reading station), mapping items to locations (e.g., C-coordinates), mapping C-coordinates to G-coordinates (e.g., updating PIDs), and/or the like. For example, with respect to interpreting the results of tests, the analysis software may be configured to (e.g., based on imaging of microwells **500**) distinguish agglutinated red-blood cells from non-agglutinated red-blood cells, detect ligand-antibody interactions in which either the ligand or antibody is labeled with a chromophore, fluorophore, or similar label that is detectable in the visible, infrared, and/or ultraviolet light spectra, and/or the like.

[0142] Notably, the same control and analysis software can be used by processing system **200**, regardless of the size of the automated system. Thus, the automated system can be scaled up or down as needed or desired for a particular application, without having to develop new software. Regardless of the size of the automated system, the software will optimize operation of conveyance system **100** and analyze the data produced by conveyance system **100**.

[0143] For example, the automated system may be provided in small, medium, and/or large units. In the clinical setting, the small unit may be sufficient for small-volume, low-throughput laboratory applications. Such a unit may be sized to process five to six tests per specimen, with a capacity of twelve to twenty specimens. It could serve both routine and emergency requests for various panels (e.g., kidney function tests, cardiac tests, liver tests, toxicology tests, etc.). Larger sizes of units may be provided for use in clinical research labs in the academic setting, as well as industrial analytical laboratories and industrial production laboratories (e.g., for quality control of the production line or production batches of drugs, internal monitoring of parameters for Good Laboratory Practice (GLP) or Good Manufacturing Practice (GMP) regulations, etc.).

[0144] The diagnostic testing processes on a carousel conveyor **110** can often be divided into two phases which cannot be operational at the same time: (1) loading items (e.g., test cells, reagent, samples) on the carousel conveyor **110**; and (2) spinning the carousel conveyor **110** as a centrifuge. This can increase dwell time and reduce throughput. For example, when loading items, pipetting into test cells, or incubating test cells, the respective carousel conveyor **110** must either be stationary or rotating at low RPM. Conversely, when spinning a carousel conveyor **110** as a centrifuge, items cannot be loaded, pipetted, or incubated on the respective carousel conveyor **110**. Since centrifugation can require significant time (e.g., ten minutes), throughput is diminished. Similarly, while reagent or sample containers are being loaded onto a carousel conveyor **110**, the carousel conveyor **110** cannot be rotated to move a particular item to a station (e.g., for pipetting, reading, etc.)

[0145] Thus, in an embodiment, a plurality of independently operable carousel conveyors **110** (e.g., two first carousel conveyors **110**A) are used for one or more types of items (e.g., test cells). Thus, for example, while one first carousel conveyor **110**A is spinning at high RPM as a centrifuge, test cells may be loaded, unloaded, incubated, or otherwise operated upon on another one of the first carousel conveyors **110**A which is stationary or spinning at low RPM. As another example, while one carousel conveyor **110**B or **110**C is delivering a reagent or sample container to a station, reagent or sample containers can be loaded or unloaded from the other carousel conveyor **110**B or **110**C. In other words, multiple batches of the same type of item may be processed on separate carousel conveyors **110**.

[0146] The control software may optimize this time sharing between the plurality of carousel conveyors **110** that share the same type of item, to minimize dwell time. For example, processing system **200**, executing the control software, may monitor what processes are active on each carousel conveyor **110** at any given time. When no processes are active on a particular carousel conveyor **110** that requires the carousel conveyor **110** to remain stationary, processing system **200** may automatically rotate the carousel conveyor **110** to position segments of the carousel conveyor that are empty or occupied with outdated items (e.g., used and previously read test cells, empty reagent or sample containers, etc.) for easier access by an operator (e.g., closer to an openable access point of the automated system) or other system (e.g., a robotic loading/unloading system) for quicker loading and/or unloading.

[0147] Similarly, when it would not interrupt any active processes, the control software, executed by processing system **200**, may automatically rotate one or more carousel conveyors **110** to minimize the distance between the positions of frequently used items and a station at which those frequently used items are operated upon. For example, during a period of inactivity, the control software may automatically rotate a segment of second carousel conveyor **110**B, holding a frequently used reagent, so that is aligned with an automated pipetting station. This can decrease the lead time required to start a new operation that involves the frequently used reagent.

[0148] In an embodiment, the control software may also optimize operations for scheduled operations. For example, if a plurality of tests are scheduled for a given time and each test requires certain preparations before the test can be initiated, the control software, executed by processing system **200**, may prioritize the preparations according to lead time. Thus, preparations for the test with the longest lead time may be given the highest priority and be performed first, whereas the test with the shortest lead time may be given the lowest priority and be performed last.

[0149] The control software may also be sensitive to historical time-of-day loads. For example, the control software may store historical usage data for the automated system, and use that historical usage data to anticipate upcoming needs. For example, if certain tests are regularly performed at a certain time on a certain day, the control software, executed by processing system **200**, may automatically begin preparations for such tests (e.g., filling test cells with reagent) with sufficient lead time, such that the preparations will be completed at approximately the particular time on the particular day at which the tests are regularly performed.

2.4. Specific Example

[0150] To aid in understanding, a specific, non-limiting example of how conveyance system **100** may be used for a single AHG test will now be described. Assume that a blood bank needs to know, as part of a donor workup, whether the blood of a particular donor is blood group Kell negative. This is done by phenotyping the donor's blood for the Kell antigen by testing the donor's red-blood-cell suspension using reagent anti-K antibody using the indirect AHG method.

[0151] A technician of the blood bank may utilize a remote user system to instruct the automated system (e.g., via one or more public and/or private networks, potentially including the Internet) to perform this test on the donor's specimen, which has been loaded onto a carousel conveyor **110** holding specimens (e.g., third carousel conveyor **110**C) or which is archived as an active sample already on a carousel conveyor (e.g., third carousel conveyor **110**C). In response to the instruction, processing system **200**, executing the control software, will automatically perform several coordinated procedures: [0152] (1) Rotate the donor's specimen and an empty red-blood-cell

suspension vessel, on the same or separate carousel conveyors **110**, to a pipetting station; [0153] (2) At and by the pipetting station, make a 1% red-blood-cell suspension, in the suspension vessel, from the donor's specimen; [0154] (3) Rotate an anti-K reagent container, on a separate carousel conveyor **110**, to the pipetting station; [0155] (4) Prepare a fresh AHG-gel test cell and rotate the test cell, on a separate 37° C. temperature-controlled carousel conveyor **110**, to the pipetting station; [0156] (5) At and by the pipetting station, aspirate 50 microliters of anti-K reagent and dispense it into the test cell; [0157] (6) A gitate the carousel conveyor **110**, holding the test cell, to thoroughly mix the anti-K reagent with the AHG gel; [0158] (7) Incubate the test cell, on the 37° C. temperature-controlled carousel conveyor **110** at 37° C. for 15 minutes; [0159] (8) Centrifuge the carousel conveyor **110**, holding the test cell, at a controlled speed for 10 minutes; [0160] (9) At a reading station, during the centrifugation, read the test cells; and [0161] (10) Once the test cells have been read, record the results and report to the blood bank's screener.
2.5. Other Applications
[0162] Disclosed embodiments may be utilized and adapted for other applications than those described above. For instance, any system, which must coordinate the movements of disparate items for a particular purpose or re-sort items into new locations, can benefit from the disclosed conveyance system **100**. Such systems include, without limitation, testing water samples for environmental monitoring of water quality, assembling components into a product on a manufacturing production line, the preparation of various dishes in a restaurant kitchen, assembling outfits for a personal shopper in a high-end clothing store, assembling a shopping list for bagging and convenient checkout in a store (e.g., grocery store, electronics store, convenience store, etc.), assembling products from an online shopping cart into a package for shipping, and/or the like.
[0163] The above description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the general principles described herein can be applied to other embodiments without departing from the spirit or scope of the invention. Thus, it is to be understood that the description and drawings presented herein represent a presently preferred embodiment of the invention and are therefore representative of the subject matter which is broadly contemplated by the present invention. It is further understood that the scope of the present invention fully encompasses other embodiments that may become obvious to those skilled in the art and that the scope of the present invention is accordingly not limited.
[0164] Combinations, described herein, such as “at least one of A, B, or C,” “one or more of A, B, or C,” “at least one of A, B, and C,” “one or more of A, B, and C,” and “A, B, C, or any combination thereof” include any combination of A, B, and/or C, and may include multiples of A, multiples of B, or multiples of C. Specifically, combinations such as “at least one of A, B, or C,” “one or more of A, B, or C,” “at least one of A, B, and C,” “one or more of A, B, and C,” and “A, B, C, or any combination thereof” may be A only, B only, C only, A and B, A and C, B and C, or A and B and C, and any such combination may contain one or more members of its constituents A, B, and/or C. For example, a combination of A and B may comprise one A and multiple B's, multiple A's and one B, or multiple A's and multiple B's.

Claims

1. A system comprising: a plurality of concentric conveyors that each has a different radius, wherein, in plan view, all but one of the plurality of concentric conveyors is nested within another one of the plurality of concentric conveyors, and wherein at least one of the plurality of concentric conveyors is configured to hold test cells for blood testing; at least one hardware processor; and software configured to, when executed by the at least one hardware processor, control the at least one concentric conveyor to spin as a centrifuge.
2. The system of claim 1, wherein spinning as a centrifuge comprises spinning at 1,500 revolutions

or greater per minute.

3. The system of claim 1, wherein each of the plurality of conveyors comprises a plurality of segments configured to hold at least one item.

4. The system of claim 1, wherein each of the plurality of conveyors is circular.

5. The system of claim 1, wherein the software is further configured to, when executed by the at least one hardware processor, control the at least one concentric conveyor to agitate the test cells by, alternately and repeatedly, accelerating in a first direction and decelerating to a stop, and then accelerating in a second direction, which is opposite the first direction, and decelerating to a stop.

6. The system of claim 1, wherein each of the plurality of concentric conveyors is configured to rotate in two directions, and wherein the software is configured to, when executed by the at least one hardware processor, when determining to move one or more of the plurality of concentric conveyors: determine in which of the two directions to rotate each of the one or more concentric conveyors so as to minimize movement; and control each of the one or more concentric conveyors to rotate in the determined direction for that concentric conveyor.

7. The system of claim 1, further comprising at least one station that comprises one or more instruments.

8. The system of claim 7, wherein the plurality of concentric conveyors comprises a first conveyor, a second conveyor, and a third conveyor, wherein the first conveyor is the at least one concentric conveyor configured to hold test cells, the second conveyor is configured to hold reagent containers, and the third conveyor is configured to hold specimen containers, wherein the one or more instruments comprise a pipettor, and wherein the software is configured to, when executed by the at least one hardware processor: while the first conveyor and the second conveyor are aligned at the at least one station, control the pipettor to move over a reagent container on a second segment of the second conveyor, aspirate an amount of reagent from the reagent container on the second segment, move over a test cell on a first segment of the first conveyor, and dispense the amount of reagent into the test cell on the first segment; and, while the first conveyor and the third conveyor are aligned at the at least one station, control the pipettor to move over a specimen container on a third segment of the third conveyor, aspirate an amount of specimen from the specimen container, prepare a sample from the specimen, move over the test cell on the first segment, and dispense the sample into the test cell on the first segment.

9. The system of claim 8, wherein the first conveyor is nested within the second conveyor, and wherein the second conveyor is nested within the third conveyor.

10. The system of claim 8, wherein each of the first conveyor, the second conveyor, and the third conveyor is configured to rotate independently under control of the software.

11. The system of claim 1, wherein each test cell comprises one or more microwells, wherein each microwell comprises a receptacle portion and a well portion, wherein the well portion is configured to rest horizontally on a top surface of the at least one concentric conveyor, and wherein the receptacle portion comprises an opening that is accessible to one or more instruments while the well portion is resting horizontally on the top surface of the at least one concentric conveyor.

12. The system of claim 11, wherein each test cell comprises a plurality of microwells arranged in an annulus sector, which is attachable to and detachable from the top surface of the at least one concentric conveyor, such that, when the annulus sector is attached to the top surface of the at least one concentric conveyor, the plurality of microwells longitudinally extend along a radial line of the plurality of concentric conveyors, and wherein a peripheral curve of the annulus sector matches a peripheral curve of the top surface of the at least one concentric conveyor.

13. The system of claim 1, wherein each of one or more of the plurality of concentric conveyors comprises a thermoelectric cooling component that cools a top surface of the concentric conveyor.

14. The system of claim 1, wherein each of the plurality of concentric conveyors is configured to stop at each of a plurality of indexed positions.

15. The system of claim 1, further comprising one or more stations that each comprises one or more instruments, wherein the one or more instruments of at least one of the one or more stations comprises a reader device configured to read a characteristic of items on at least one of the plurality of concentric conveyors.

16. The system of claim 15, wherein the reader device comprises a camera configured to capture an image of a machine-readable indicia on each of the items, and wherein the software is configured to, when executed by the at least one hardware processor, for each captured image: identify an item from the machine-readable indicia in the captured image; identify a segment of the at least one concentric conveyor on which the identified item is held; and map an identifier of the identified item to an identifier of the identified segment.

17. The system of claim 16, wherein the identifier of the identified segment comprises C-coordinates that uniquely identify a location on the at least one concentric conveyor on which the identified item is held, and wherein the software is configured to, when executed by the at least one hardware processor, map the C-coordinates to G-coordinates that uniquely identify a location of the identified segment within an automated system.

18. The system of claim 15, wherein each item comprises a microwell, wherein the reader device comprises a camera configured to capture an image of the microwell, and wherein the software is configured to, when executed by the at least one hardware processor analyze the image of the microwell to determine a test result.

19. A method, within a system that comprises a plurality of concentric conveyors that each has a different radius, wherein, in plan view, all but one of the plurality of concentric conveyors is nested within another one of the plurality of concentric conveyors, and wherein at least one of the plurality of concentric conveyors is configured to hold test cells for blood testing, the method comprising using at least one hardware processor to control the at least one concentric conveyor to spin as a centrifuge.

20. A non-transitory computer-readable medium having instructions stored therein, wherein the instructions, when executed by a processor, within a system that comprises a plurality of concentric conveyors that each has a different radius, wherein, in plan view, all but one of the plurality of concentric conveyors is nested within another one of the plurality of concentric conveyors, and wherein at least one of the plurality of concentric conveyors is configured to hold test cells for blood testing, cause the processor to control the at least one concentric conveyor to spin as a centrifuge.
