US 20240278235A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2024/0278235 A1**

Tan (43) **Pub. Date: Aug. 22, 2024**

(54) **AUTONOMOUS ROBOTIC SYSTEM FOR BIOCHEMICAL TESTING IN HEALTHCARE ENVIRONMENTS**

(71) Applicant: **ACCESS MEDICAL SYSTEMS, LTD.**, Palo Alto, CA (US)

(72) Inventor: **Hong Tan**, San Jose, CA (US)

(21) Appl. No.: **18/652,649**

(22) Filed: **May 1, 2024**

Related U.S. Application Data

(63) Continuation of application No. PCT/US2022/079246, filed on Nov. 3, 2022.

(60) Provisional application No. 63/275,545, filed on Nov. 4, 2021.

Publication Classification

(51) **Int. Cl.**

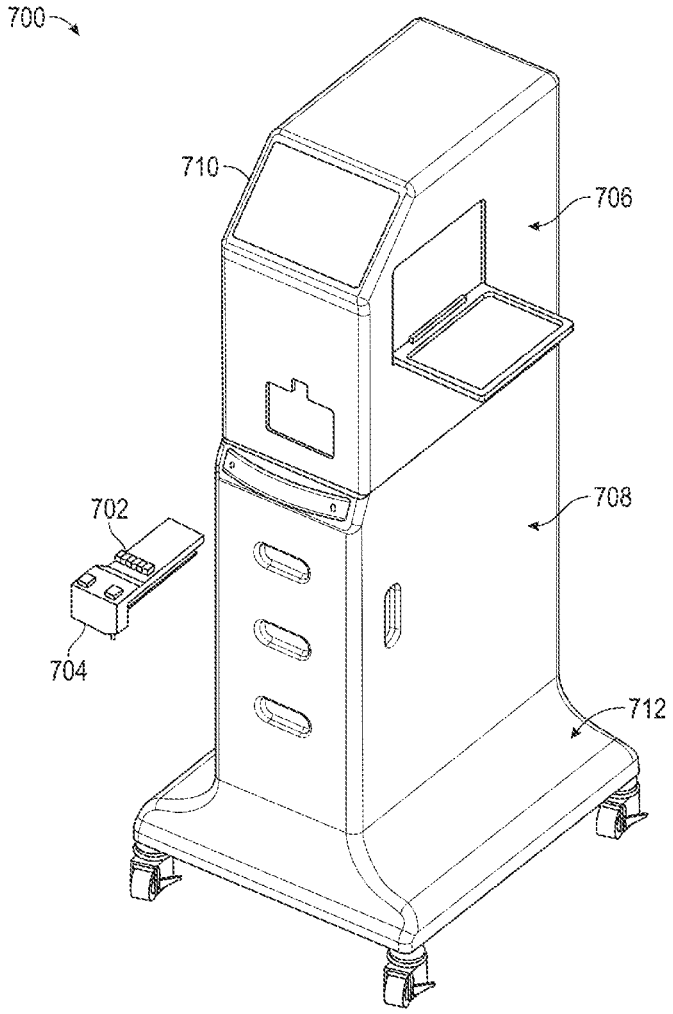
B01L 3/00	(2006.01)
G01N 35/04	(2006.01)
G16H 50/20	(2006.01)

(52) **U.S. Cl.**

CPC ***B01L 3/5025*** (2013.01); ***G16H 50/20*** (2018.01); *G01N 2035/0429* (2013.01)

(57) **ABSTRACT**

Introduced here are diagnostic systems that are able to autonomously move to a desired location within a healthcare environment. As such, a diagnostic system may allow an operator to conduct a biochemical test on site. A diagnostic system may include (i) a cartridge in which a patient sample can be deposited, (ii) a robotic cart in which the cartridge can be inserted for analysis, and (iii) a control platform that is responsible for managing movement of the robotic cart throughout its physical environment. In addition to having the components needed to analyze the sample deposited into the cartridge, the robotic cart could also include storage for "used" or "unused" cartridges. Thus, the robotic cart may not only be able to perform analysis of the sample on site, but the robotic cart may also be able to transport all of the supplies needed to obtain the sample to the operator.



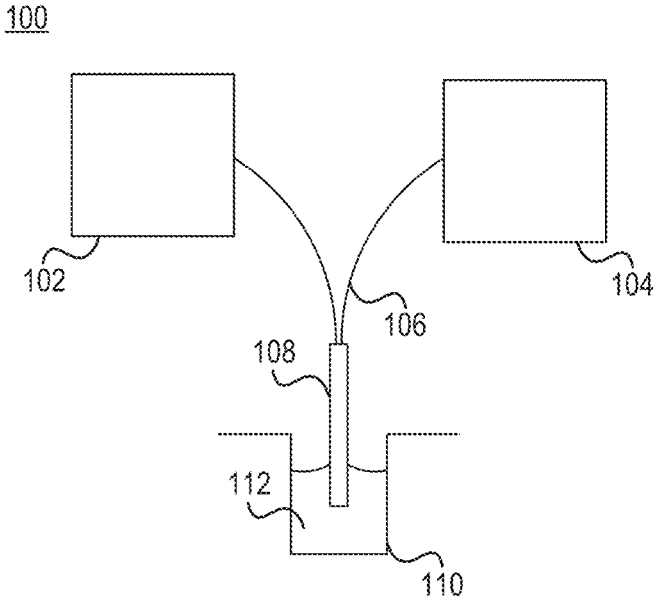


FIGURE 1

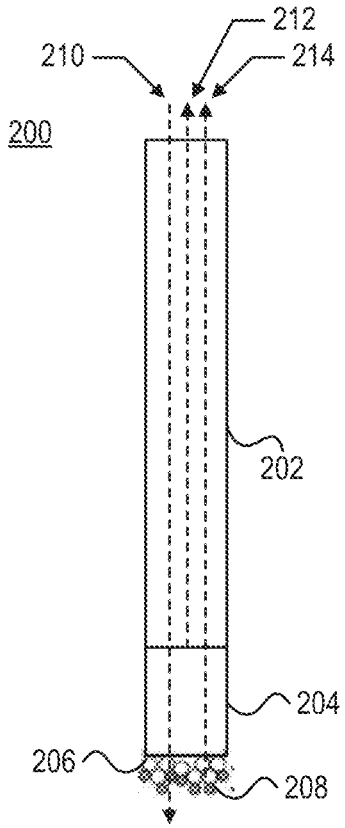


FIGURE 2

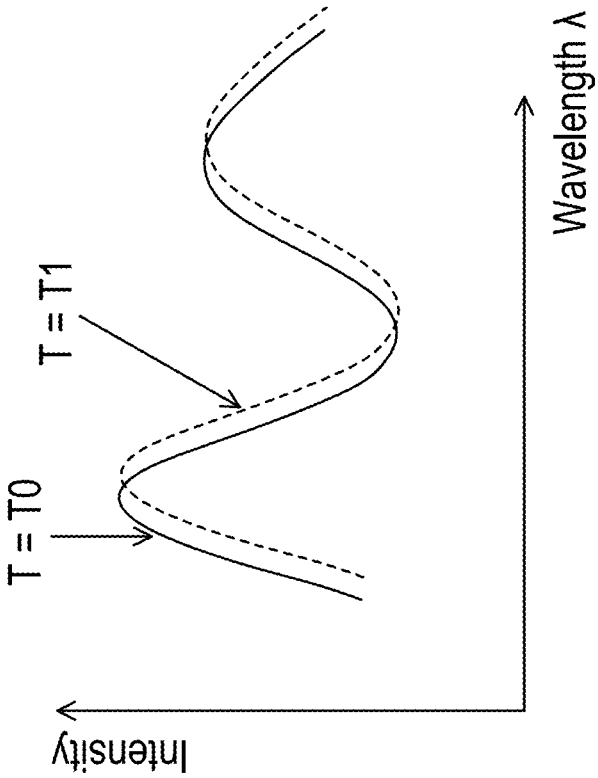

T = T0
T = T1
Intensity
Wavelength λ

FIG. 3B

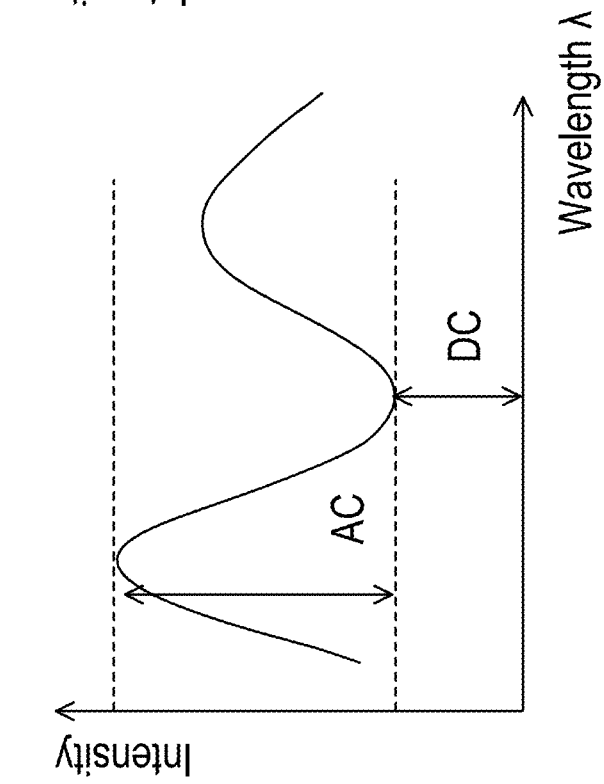

AC
DC
Intensity
Wavelength λ

FIG. 3A

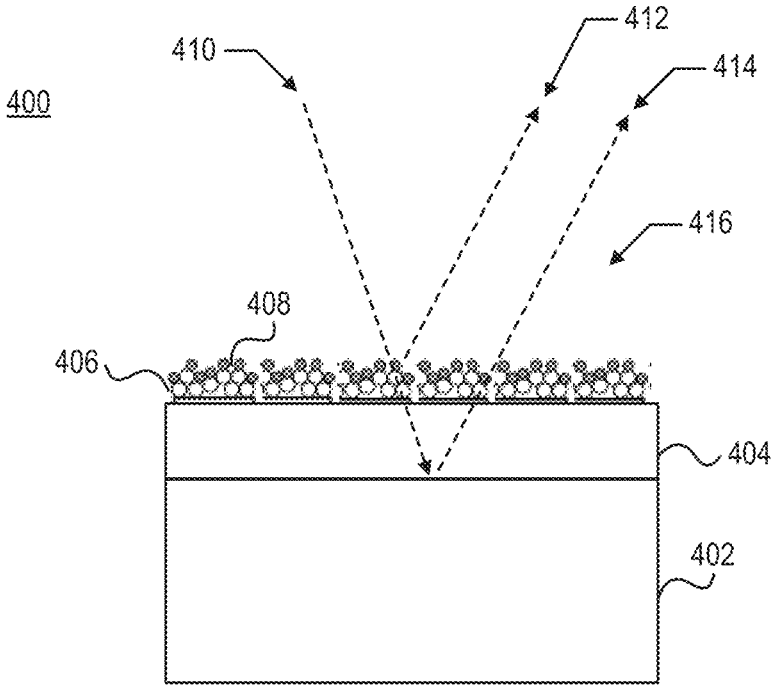


FIGURE 4

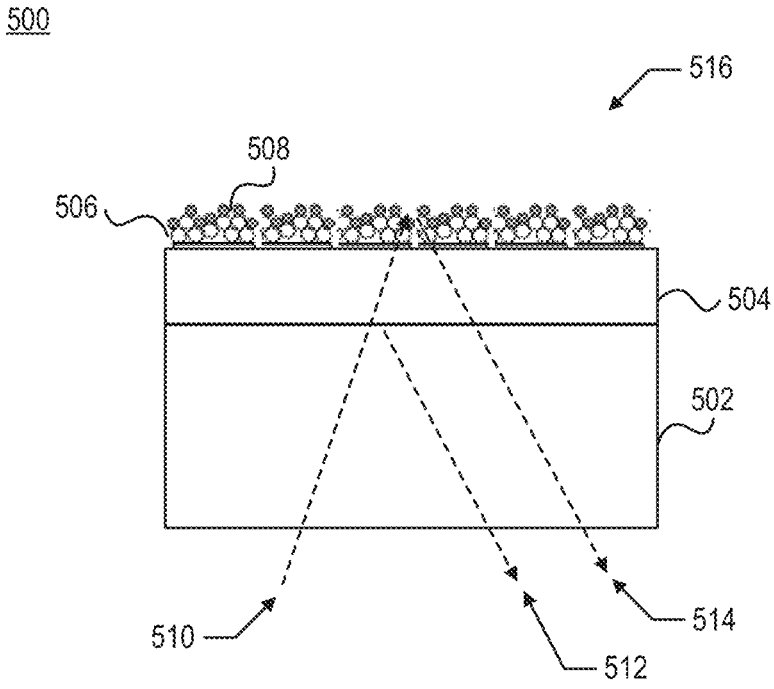


FIGURE 5

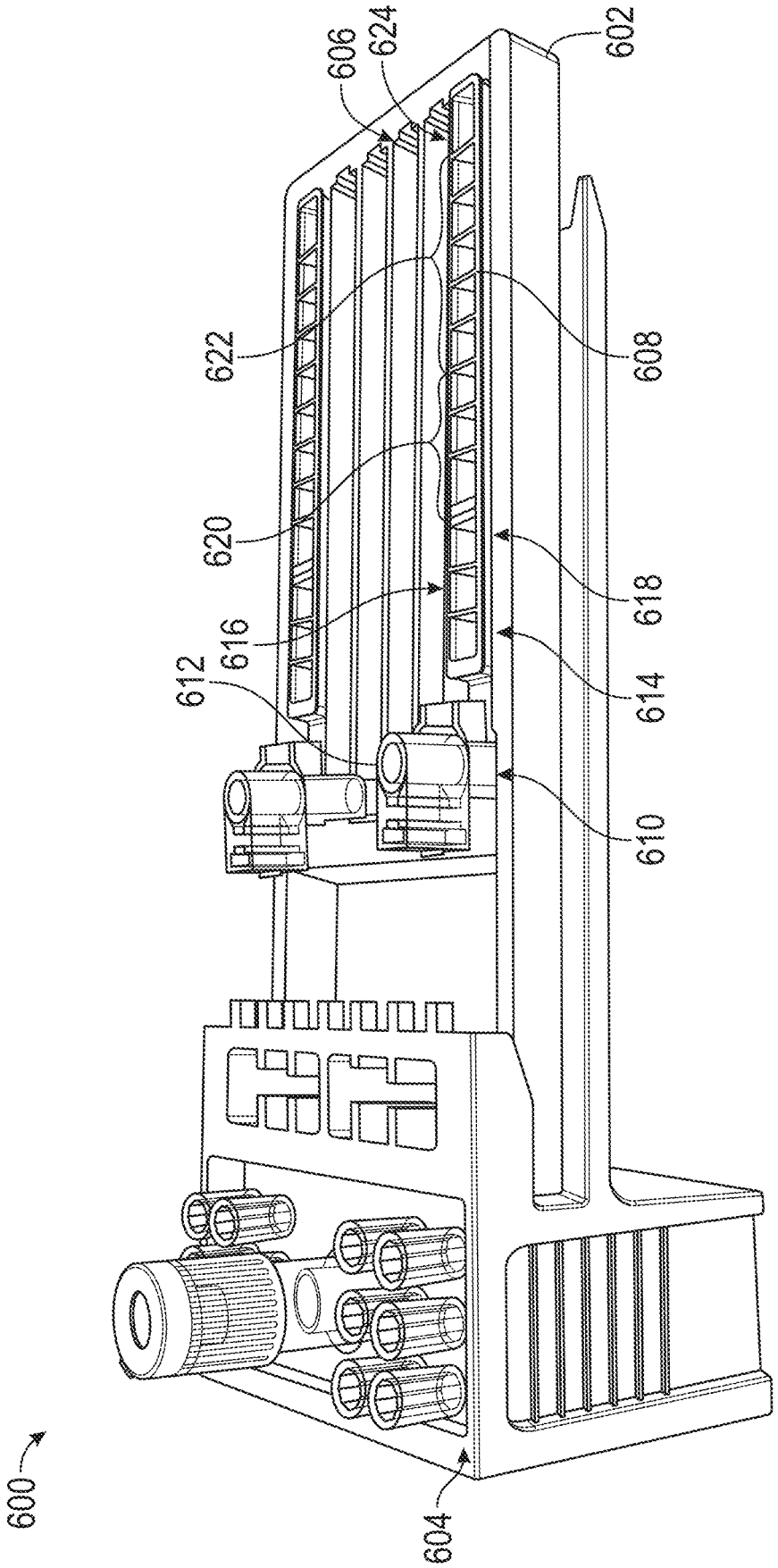


FIGURE 6

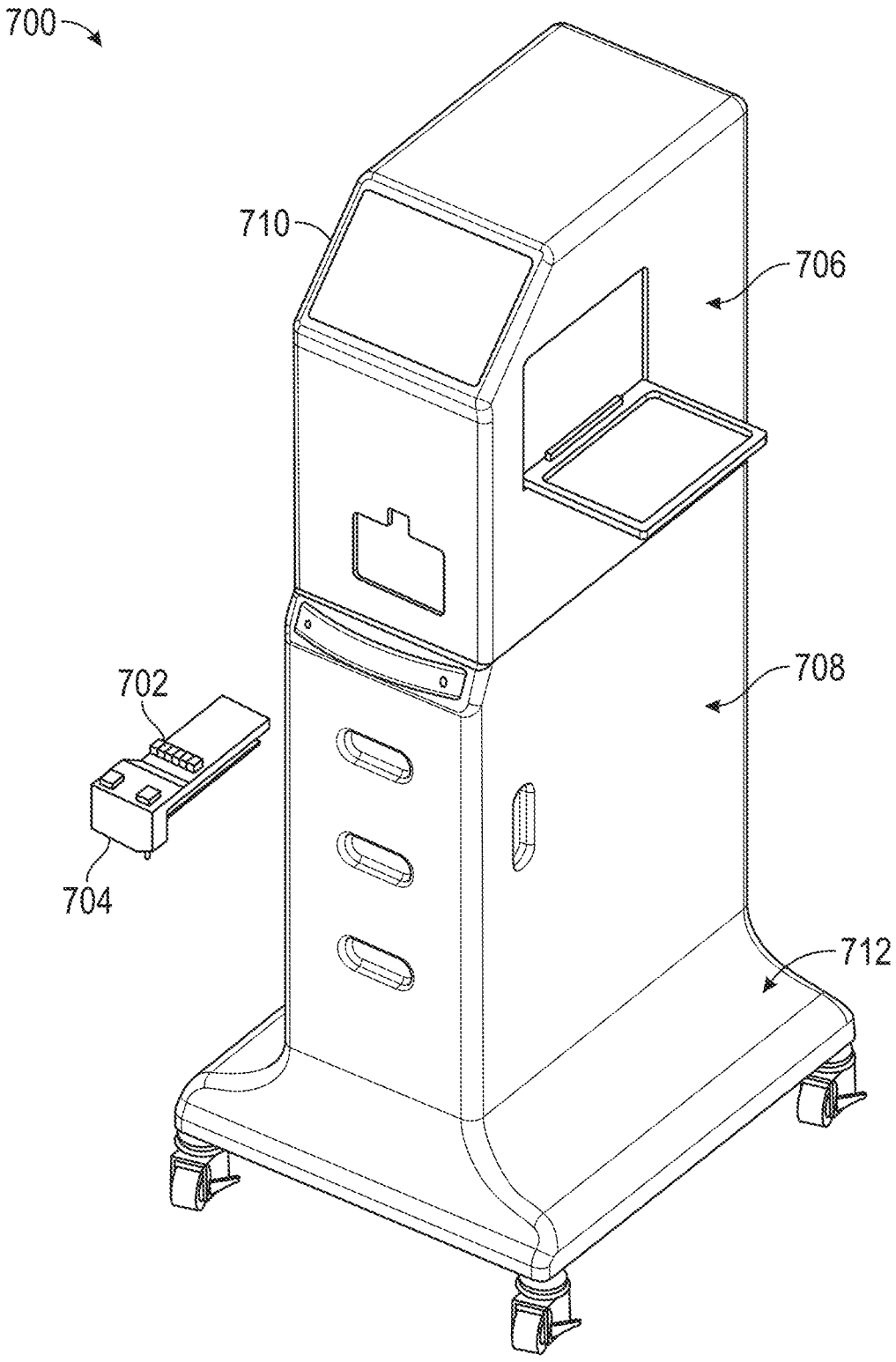


FIGURE 7A

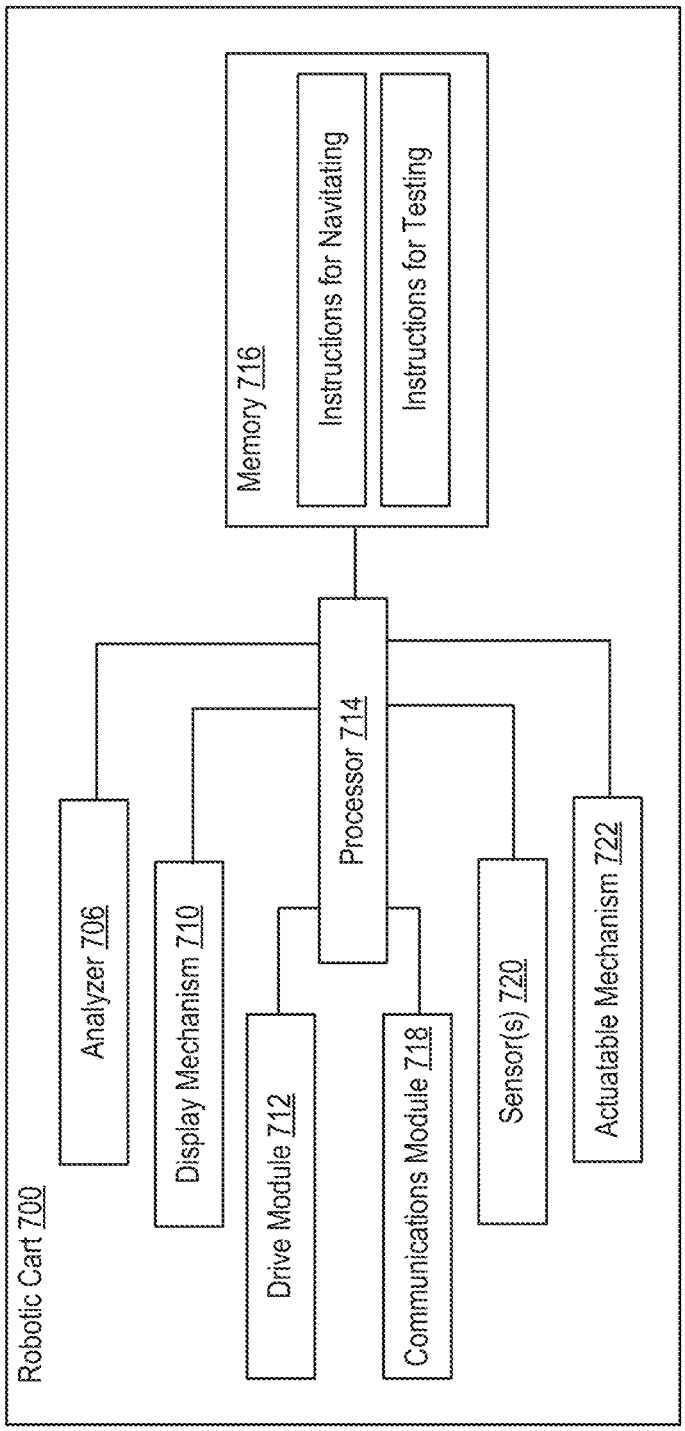

Robotic Cart 700
Analyzer 706
Display Mechanism 710
Drive Module 712
Processor 714
Communications Module 718
Sensor(s) 720
Actuatable Mechanism 722
Memory 716
Instructions for Navitating
Instructions for Testing

FIGURE 7B

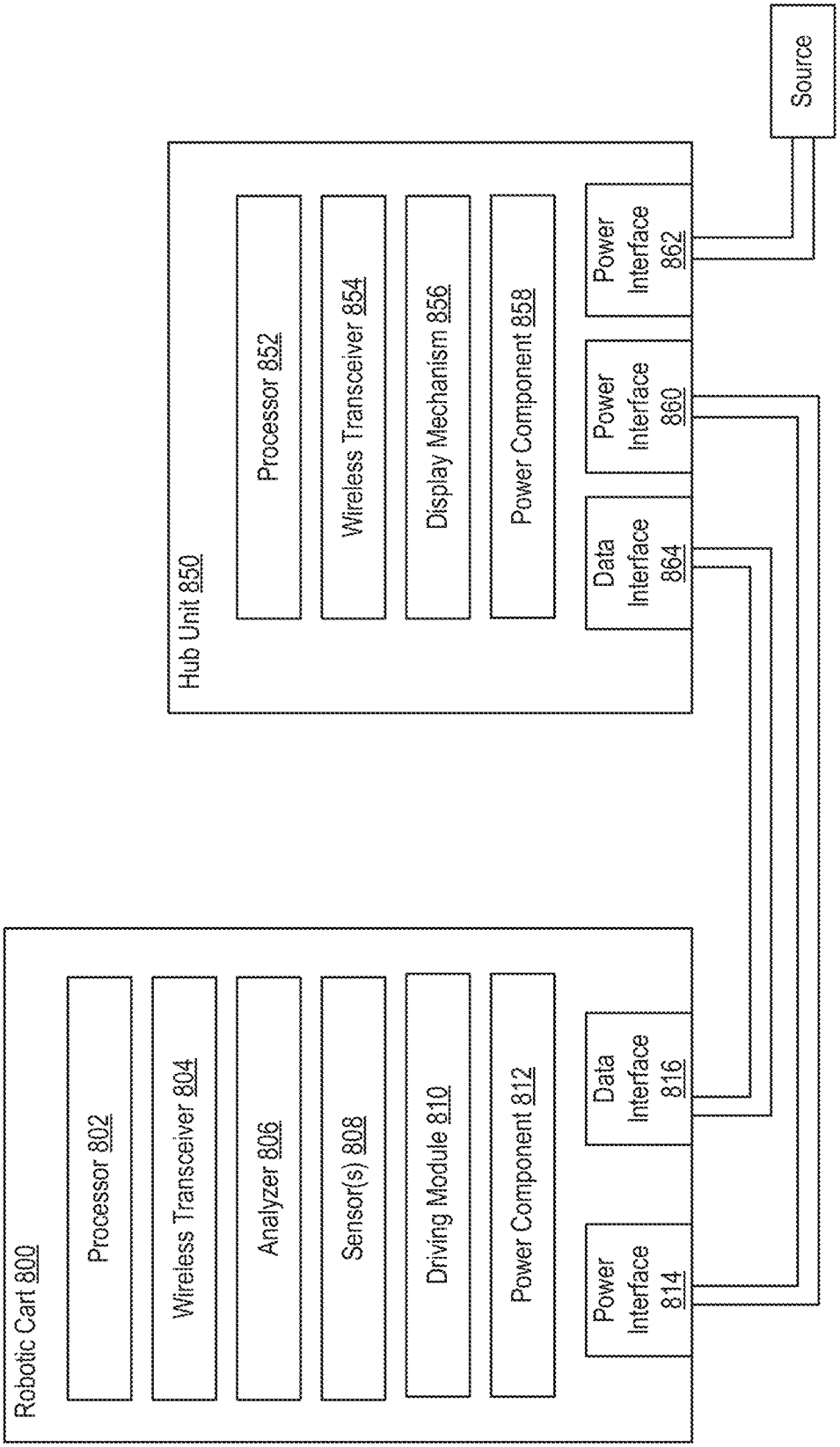

Robotic Cart 800
Processor 802
Wireless Transceiver 804
Analyzer 806
Sensor(s) 808
Driving Module 810
Power Component 812
Power Interface 814
Data Interface 816
Hub Unit 850
Processor 852
Wireless Transceiver 854
Display Mechanism 856
Power Component 858
Data Interface 864
Power Interface 860
Power Interface 862
Source

FIGURE 8

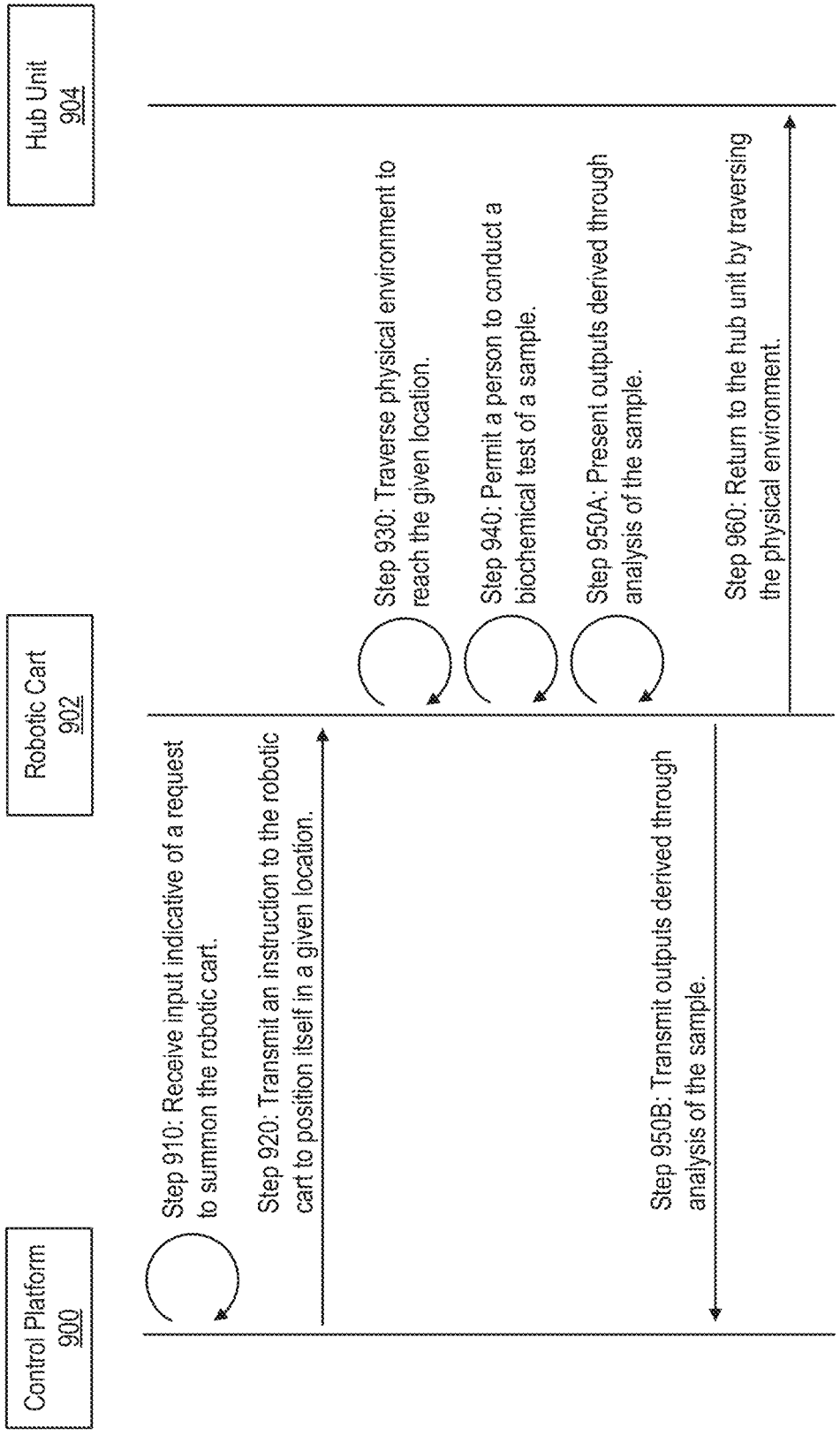

Control Platform 900
Robotic Cart 902
Hub Unit 904
Step 910: Receive input indicative of a request to summon the robotic cart.
Step 920: Transmit an instruction to the robotic cart to position itself in a given location.
Step 930: Traverse physical environment to reach the given location.
Step 940: Permit a person to conduct a biochemical test of a sample.
Step 950A: Present outputs derived through analysis of the sample.
Step 950B: Transmit outputs derived through analysis of the sample.
Step 960: Return to the hub unit by traversing the physical environment.

FIGURE 9

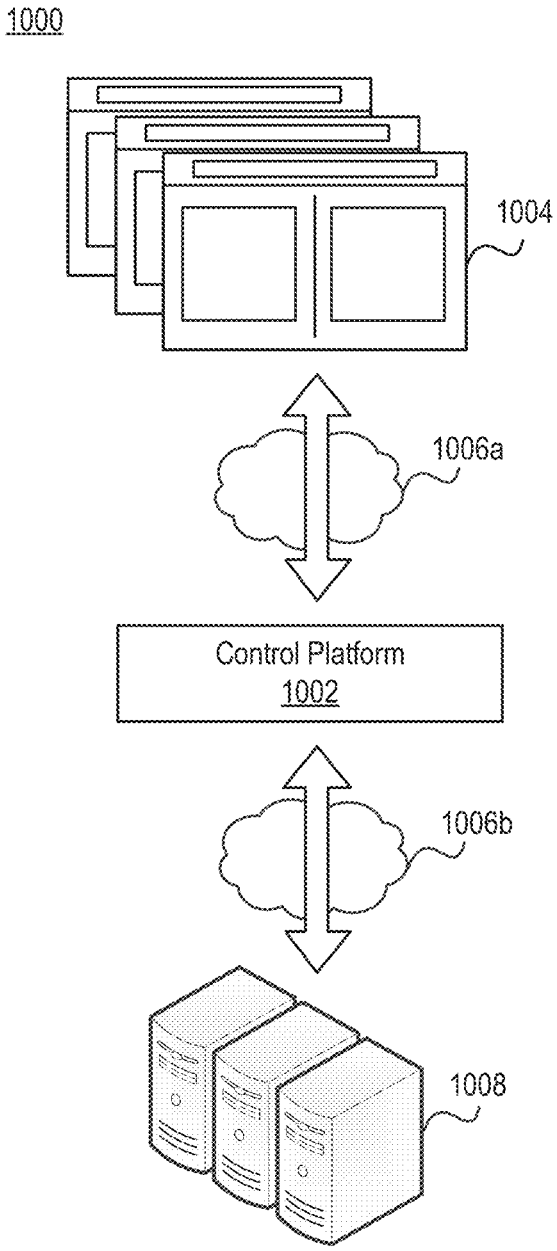


FIGURE 10

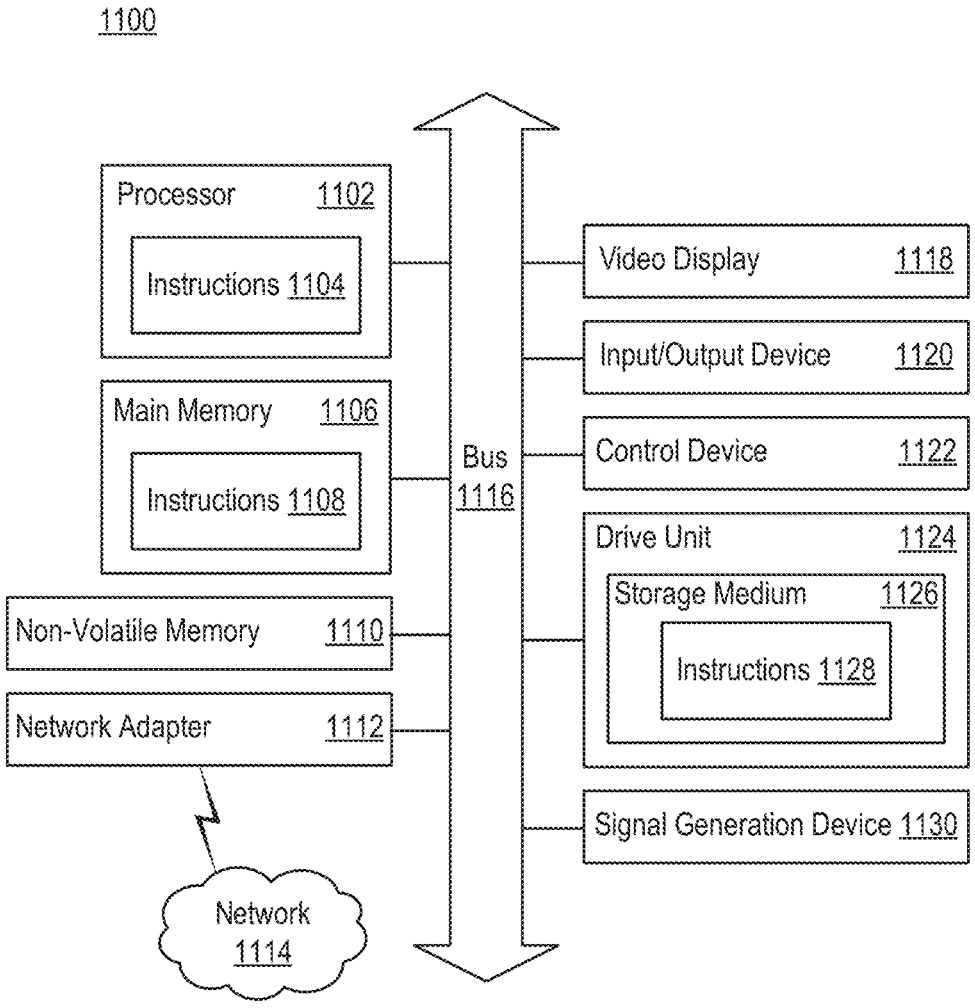

1100
Processor 1102
Instructions 1104
Main Memory 1106
Instructions 1108
Non-Volatile Memory 1110
Network Adapter 1112
Network 1114
Bus 1116
Video Display 1118
Input/Output Device 1120
Control Device 1122
Drive Unit 1124
Storage Medium 1126
Instructions 1128
Signal Generation Device 1130

FIGURE 11

AUTONOMOUS ROBOTIC SYSTEM FOR BIOCHEMICAL TESTING IN HEALTHCARE ENVIRONMENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of International Application No. PCT/US2022/079246, filed on Nov. 3, 2022, which claims priority to U.S. Provisional Application No. 63/275,545, filed on Nov. 4, 2021, each of which is incorporated by reference herein in its entirety.

FIELD OF THE INVENTION

[0002] Various embodiments concern mobile robotic devices that are able to autonomously traverse physical environments to perform biochemical testing.

BACKGROUND

[0003] Mobile robotic devices (also referred to as "mobile robots") are electronic machines that are able to move around physical environments, and therefore are not fixed to a single physical location. Many mobile robots rely on instructions received from guidance devices (also referred to as "controllers") to navigate uncontrolled physical spaces. For example, a mobile robot may rely on instructions received from a corresponding controller to travel a predefined navigation route in a relatively controlled space. However, some mobile robots are capable of navigating uncontrolled physical environments without the need for controllers. Said another way, these mobile robots can operate autonomously with minimal oversight from an individual (also referred to as an "operator"). Operators will normally be healthcare professionals, though that need not necessarily be the case.

[0004] Autonomous robotics is generally considered to involve a combination of interdisciplinary fields, including artificial intelligence, robotics, and information engineering. While the term "autonomous" could be used to indicate that a mobile robot is able to perform any task with a high degree of autonomy (i.e., without external influence), that term is generally used to refer to the ability of the mobile robot to navigate a physical space with little or no assistance. To successfully navigate a physical space, a mobile robot must know its own position—a concept referred to as "localization"—and then be able to navigate around obstacles in the physical space.

[0005] Mobile robots have been tasked to perform various tasks in various physical environments. For example, mobile robots have been used to autonomously deliver goods from a source to a destination. As another example, mobile robots have been used to surveil areas that are impractical, inappropriate, or impossible for individuals to visit. There are several physical environments that have historically been ill suited for mobile robots, however. One of these physical environments is healthcare facilities. Although several entities have developed mobile robots for healthcare facilities, adoption has been limited in part because the usefulness of these mobile robots is limited.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1** depicts a biosensor interferometer that includes a light source, a detector, a waveguide, and an optical assembly.

[0007] FIG. **2** depicts an example of a probe in accordance with various embodiments.

[0008] FIGS. **3**A-B illustrate the principles of detection in a thin-film interferometer.

[0009] FIG. **4** depicts an example of a slide in accordance with various embodiments.

[0010] FIG. **5** depicts another example of a slide in accordance with various embodiments.

[0011] FIG. **6** depicts an example of a cartridge assembly in accordance with various embodiments.

[0012] FIG. **7**A includes a perspective view of a robotic cart in accordance with various embodiments.

[0013] FIG. **7**B includes a block diagram illustrating various components of the robotic cart shown in FIG. **7**A.

[0014] FIG. **8** is a high-level block diagram illustrating how a robotic cart may be able to interface with a hub unit, for example, for charging purposes.

[0015] FIG. **9** includes a high-level illustration of communications that may occur between a control platform, a robotic cart, and a hub unit.

[0016] FIG. **10** illustrates a network environment that includes a control platform.

[0017] FIG. **11** is a block diagram illustrating an example of a processing system in which at least some operations described herein can be implemented.

[0018] Embodiments are illustrated by way of example and not limitation in the drawings. While the drawings depict various embodiments for the purpose of illustration, those skilled in the art will recognize that alternative embodiments may be employed without departing from the principles of the technology. Accordingly, while specific embodiments are shown in the drawings, the technology is amenable to various modifications.

DETAILED DESCRIPTION

[0019] Biochemical tests based on binding events between analyze molecules and analyte-binding molecules are widely used in medical, veterinary, agricultural, and research applications. These biochemical tests can be employed to detect whether analyte molecules are present in a sample, the amount of analyte molecules in a sample, or the rate at which analyte molecules bind to analyte-binding molecules. Together, an analyte-binding molecule and its corresponding analyte molecule form an analyte-anti-analyte binding pair (or simply "binding pair"). Examples of binding pairs include complementary strands of nucleic acids, antigen-antibody pairs, and receptor-receptor binding agents. The analyte can be either member of the binding pair, and the anti-analyte can be the other member of the binding pair.

[0020] Several entities have developed systems that are designed to conduct biochemical tests. FIG. **1** illustrates an example of a system that is able to monitor adherence of analyte molecules to analyte-binding molecules immobilized on a surface, while FIGS. **2**, **4**, and **5** illustrate different examples of surfaces on which analyte-binding molecules can be immobilized. These drawings are discussed in greater detail below.

[0021] These biochemical tests have several drawbacks, however. One drawback is the resources that are needed to conduct a biochemical test. Assume, for example, that a sample (e.g., of blood) associated with a patient is to be biochemically tested to determine whether a given analyte is present in the sample. In such a scenario, a healthcare

professional may need to obtain the sample and then traverse a healthcare environment to find a cartridge that includes at least one interferometric sensor and one or more wells in which fluids can be deposited. Thereafter, the healthcare professional may deposit at least a portion of the sample in a well and then insert the cartridge into a system that is able to examine the sample. Outputs produced by the system may be analyzed by the healthcare professional, who might then return to the patient to describe the outputs. For example, the healthcare professional may provide a diagnosis for an ailment if the system determines that an analyte indicative of the ailment is present in the sample.

[0022] Although the system may be located in the same healthcare environment as the patient, the system is rarely, if ever, proximate to the patient. For example, the patient may be situated in a room upon being admitted to a hospital, while the system may be situated in a laboratory that is located in another room, floor, or building altogether. Accordingly, the process for conducting biochemical tests may not only be laborious, but also expensive due to the time that healthcare professionals must spend on these biochemical tests. Moving samples from one location (e.g., the room assigned to a patient) to another location (e.g., a laboratory) also introduces another opportunity for these samples to be lost, tainted, or otherwise mismanaged.

[0023] Introduced here is a diagnostic system that is able to autonomously move to a desired location within a healthcare environment. As such, the diagnostic system may allow an operator (also referred to as a "user") to conduct a biochemical test on site. For example, the operator may be able to conduct a biochemical test from alongside the bed in which a patient is situated.

[0024] As further discussed below, the diagnostic system may include (i) a cartridge in which a sample can be deposited, (ii) a robotic cart in which the cartridge can be inserted for analysis, and (iii) a control platform that is responsible for managing movement of the robotic cart throughout its physical environment. In addition to having the components needed to analyze the sample deposited into the cartridge, the robotic cart could also include storage for "used" or "unused" cartridges. Thus, the robotic cart may not only be able to perform analysis of the sample on site, but the robotic cart may also be able to transport all of the supplies needed to obtain the sample to the operator.

[0025] Assume, for example, that an operator is interested in conducting a biochemical test to determine whether a given analyte is present in a sample. In such a scenario, the operator may provide, to the control platform, input indicative of a request to summon the robotic cart. As further discussed below, the control platform may be embodied as a computer program (e.g., a mobile application) that is executing on a computing device (e.g., a mobile phone) that the operator is able to access. Upon receiving this input, the control platform may transmit an instruction to the robotic cart to locate itself proximate to the operator. In some embodiments the operator may be prompted to specify her location (e.g., through the computer program), while in other embodiments the location of the operator may be inferred by the control platform (e.g., based on a location of the computing device, a schedule of the operator, etc.).

[0026] After the robotic cart arrives at its intended destination, the operator may open the storage and remove a cartridge. Normally, ancillary materials like syringes and needles will already be readily accessible, through the robotic cart could also store these materials. The operator can obtain a sample and deposit the sample into the cartridge, and then the operator can load the cartridge into the robotic cart for analysis. The outputs that are produced by the robotic cart can be presented by the robotic cart (e.g., on a display). Additionally or alternatively, the outputs that are produced by the robotic cart can be forwarded to the control platform for presentation on the computing device.

[0027] Such an approach to locally performing biochemical tests will not only save costs by lessening the amount of time that these tests require, but can also ensure prompt results as the analysis can be performed by the robotic cart without requiring that the sample be transported to another location. Lessening the distance over which samples must be transported may also help reduce errors that are caused by tainting or otherwise mismanaging samples.

[0028] Note that while the robotic cart may be described as having the necessary equipment for conducting biochemical tests using interferometric sensors, the robotic cart could additionally or alternatively include the equipment needed to conduct other types of biochemical tests. Accordingly, the robotic cart may be able to facilitate interferometric assays, fluorescent assays, chemiluminescent-fluorescent assays, or combinations thereof. Fluorescent assays are further described in U.S. Pat. No. 8,647,889, titled "Luminescent Polymer Cyclic Amplification," while chemiluminescent-fluorescent assays are further described in U.S. Provisional Application No. 63/129,946, titled "Detection Method Using Both Fluorescence and Chemiluminescence Labels," each of which is incorporated by reference herein in its entirety. Meanwhile, interferometric assays are further described in International Application No. PCT/US2021/021653, titled "Interferometric Sensors for Biochemical Testing," which is also incorporated by reference herein in its entirety.

Definitions

[0029] The term "about" means within ±10% of the recited value.

[0030] The term "analyte-binding molecule" refers to any molecule capable of participating in a binding reaction with an analyte molecule. Examples of analyte-binding molecules include, but are not limited to, (i) antigen molecules; (ii) antibody molecules; (iii) protein molecules; (iv) ligands; and (v) single-stranded nucleic acid molecules.

[0031] The term "interferometric sensor" refers to any sensing apparatus upon which a biolayer formed to produce an interference pattern. One example of an interferometric sensor is a probe designed to be suspended in a solution containing the sample having the analyte molecules. Another example of an interferometric sensor is a slide with a planar surface upon which a biolayer can be formed over the course of a biochemical test.

[0032] The term "probe" refers to a monolithic substrate having as aspect ratio (length-to-width) of at least 2 to 1 with a thin-film layer coated on the sensing side.

[0033] The term "monolithic substrate" refers to a solid piece of material having a uniform composition, such as glass, quartz, or plastic, with one refractive index.

[0034] The term "waveguide" refers to a device (e.g., a duct, coaxial cable, or optic fiber) designed to confine and direct the propagation of electromagnetic waves (as light). One example of a waveguide is a metal tube for channeling ultrahigh-frequency waves.

[0035] The term "healthcare professional" may refer to any individual who is involved in conducting a biochemical test. This term is commonly used to refer to physicians and nurses, though this term could also be used to refer to researchers and other individuals who are not directly involved in administering health care to patients.

[0036] The term "healthcare environment" may refer to a physical space in which health care is provided to patients. Examples of healthcare environments include hospitals, clinics, nursing homes, and hospice facilities.

Interferometric Approach to Biochemical Testing

[0037] FIG. **1** depicts a biosensor interferometer **100** (or simply "interferometer") that includes a light source **102**, a detector **104**, a waveguide **106**, and an optical assembly **108** (also referred to as a "probe"). The probe **108** may be connected to the waveguide **106** via a coupling medium.

[0038] The light source **102** may emit light that is guided toward the probe **108** by the waveguide **106**. For example, the light source **102** may be a light-emitting diode (LED) that is configured to produce light over a range of at least 50 nanometers (nm), 100 nm, or 150 nm within a given spectrum (e.g., 400 nm or less to 700 nm or greater). Alternatively, the interferometer **100** may employ a plurality of light sources having different characteristic wavelengths, such as LEDs designed to emit light at different wavelengths in the visible range. The same function could be achieved by a single light source with suitable filters for directing light with different wavelengths onto the probe **108**.

[0039] The detector **104** is preferably a spectrometer that is capable of recording the spectrum of interfering light received from the probe **108**. Alternatively, if the light source **102** operates to direct different wavelengths onto the probe **108**, then the detector **104** can be a simple photodetector capable of recording intensity at each wavelength. In another embodiment, the detector **104** can include multiple filters that permit detection of intensity at each of multiple wavelengths.

[0040] The waveguide **106** can be configured to transport light emitted by the light source **102** to the probe **108**, and then transport light reflected by surfaces within the probe **108** to the detector **104**. In some embodiments the waveguide **106** is a bundle of optical fibers (e.g., single-mode fiber optic cables), while in other embodiments the waveguide **106** is a multi-mode fiber optic cable.

[0041] As shown in FIGS. **2-3**, the probe **108** can include a monolithic substrate, a thin-film layer (also referred to as an "interference layer"), and a biomolecular layer (also referred to as a "biolayer") that comprises analyte molecules that have bound to analyte-binding molecules. The monolithic substrate comprises a transparent material through which light can travel. The interference layer also comprises a transparent material. When light is shone on the probe **108**, the proximal surface of the interference layer may act as a first reflecting surface and the biolayer may act as a second reflecting surface. As further described below, light reflected by the first and second reflecting surfaces may form an interference pattern that can be monitored by the interferometer **100**.

[0042] To perform a diagnostic test, the probe **108** can be suspended in a microwell **110** (or simply "well") that includes a sample **112**. This well **110** may be formed in a cartridge as further discussed below. Analyte molecules in the sample **112** will bind to the analyte-binding molecules along the distal end of the probe **108** over the course of the diagnostic test, and these binding events will result in an interference pattern that can be observed by the detector **104**. The interferometer **100** can monitor the thickness of the biolayer that is formed along the distal end of the probe **108** by detecting shifts in a phase characteristic of the interference pattern.

[0043] Note that, for the purpose of illustration, embodiments may be described in the context of a robotic cart that has an interferometer stored therein. However, the robotic cart could include other investigative tools for conducting biochemical tests as mentioned above. As an example, a robotic cart may be able to determine the presence or concentration of molecules through the use of fluorescent tags (also referred to as "fluorescent labels") and/or chemiluminescence tags (also referred to as "chemiluminescence labels"). Accordingly, the robotic cart may simply be said to include an "analyzer" or "test system" that is able to administer, conduct, manage, or otherwise support biochemical tests. The "analyzer" may be able to facilitate interferometric assays, fluorescent assays, chemiluminescent assays, combination assays (e.g., chemiluminescent-fluorescent assays), or any combination thereof.

Overview of Interferometric Sensors

[0044] The probe that is suspended in the well may be representative of an interferometric sensor (also referred to as an "interferometric biosensor" or "sensing apparatus"). Generally, the probe includes a monolithic substrate that has first and second surfaces arranged substantially parallel to one another at opposite ends of the monolithic substrate, an interference layer coated on the second surface of the monolithic substrate, and a layer of analyte-binding molecules coated on the interference layer. A first interface between the monolithic substrate and the interference layer acts as a first reflecting surface when light is shone on the probe, while a second interface between a biolayer formed by analyte molecules in a sample binding to the analyte-binding molecules and a solution containing the sample acts as a second reflecting surface when the light is shone on the probe. As described above, the thickness of the biolayer can be estimated based on the interference pattern of light reflected by the first and second reflecting surfaces.

[0045] FIG. **2** depicts an example of a probe **200** in accordance with various embodiments. The probe **200** includes an interference layer **204** that is secured along the distal end of a monolithic substrate **202**. Analyte-binding molecules **206** can be deposited along the distal surface of the interference layer **204**. Over the course of a biochemical test, a biolayer will form as analyte molecules **208** in a sample bind to the analyte-binding molecules **206**.

[0046] As shown in FIG. **2**, the monolithic substrate **202** has a proximal surface (also referred to as a "coupling side") that can be coupled to, for example, a waveguide of an interferometer and a distal surface (also referred to as a "sensing side") on which additional layers are deposited. Generally, the monolithic substrate **202** has a length of at least 3 millimeters (mm), 5 mm, 10 mm, or 15 mm. In a preferred embodiment, the aspect ratio (length-to-width) of the monolithic substrate **202** is at least 5 to 1. In such embodiments, the monolithic substrate **202** may be said to have a columnar form. The cross section of the monolithic substrate **202** may a circle, oval, square, rectangle, triangle, pentagon, etc. The monolithic substrate **202** preferably has

a refractive index that is substantially higher than the refractive index of the interference layer **204**, such that the proximal surface of the interference layer **204** effectively reflects light directed onto the probe **200**. The preferred refractive index of the monolithic substrate may be higher than 1.5, 1.8, or 2.0. Accordingly, the monolithic substrate **202** may comprise a high-refractive-index material such as glass (refractive index of 2.0), though some embodiments of the monolithic substrate **202** may comprise a low-refractive-index material such as quartz (refractive index of 1.46) or plastic (refractive index of 1.32-1.49).

[0047] The interference layer **204** comprises at least one transparent material that is coated on the distal surface of the monolithic substrate **202**. These transparent material(s) are deposited on the distal surface of the monolithic substrate **202** in the form of thin films ranging in thickness from fractions of a nanometer (e.g., a monolayer) to several micrometers. The interference layer **204** may have a thickness of at least 500 nm, 700 nm, or 900 nm. An exemplary thickness is between 500-5,000 nm (and preferably 800-1, 200 nm). Here, for example, the interference layer **204** has a thickness of approximately 900-1,000 nm, or 940 nm.

[0048] Note that the interference layer **204** may have a substantially similar refractive index as the biolayer. This ensures that the reflection from the distal end of the probe **200** is predominantly due to the analyte molecules **208** rather than the interface between the interference layer **204** and the analyte-binding molecules **206**. Generally, the biolayer has a refractive index of approximately 1.36, though this may vary depending on the type of analyte-binding molecules (and thus analyte molecules) along the distal end of the probe **200**.

[0049] In some embodiments the interference layer **204** comprises magnesium fluoride (MgF_2), while in other embodiments the interference layer **204** comprises potassium fluoride (KF) with a refractive index of 1.36, lithium fluoride (LiF) with a refractive index of 1.39, sodium fluoride (NaF) with a refractive index of 1.32, lithium calcium aluminum fluoride ($LiCaAlF_6$) with a refractive index of 1.39, strontium fluoride (SrF_2) with a refractive index of 1.37, aluminum fluoride (AlF_3) with a refractive index of 1.38, sulphur hexafluoride (SF_6) with a refractive index of 1.00, sodium aluminum hexafluoride (Na_3AlF_6) (also referred to as "cryolite") with a refractive index of 1.34, sodium aluminum fluoride ($Na_5Al_3F_{14}$) (also referred to as "chiolite") with a refractive index of 1.34, etc. Additionally or alternatively, the interference layer **204** could comprise a polymer such as FICOLL®. Magnesium fluoride has a refractive index of 1.38, which is substantially identical to the refractive index of the biolayer formed along the distal end of the probe **200**. Generally, the refractive index of the interference layer **204** is between 1.32 and 1.42, between 1.36 and 1.42, or between 1.38 and 1.40. Because the interference layer **204** and biolayer have similar refractive indexes, light will experience minimal scattering as it travels from the interference layer **204** into the biolayer and then returns from the biolayer into the interference layer **204**.

[0050] The thickness of the biolayer is designed to optimize the overall sensitivity based on the hardware (e.g., the optical components) of the interferometer. Conventional immobilization chemistries can be used to covalently (e.g., chemically) or non-covalently (e.g., by adsorption) attach the analyte-binding molecules **206** to the distal surface of the interference layer **204**.

[0051] The layer of analyte-binding molecules **206** is preferably formed under conditions in which the distal end of the probe **200** is densely coated, so that binding of analyte molecules **208** to the analyte-binding molecules **206** results in a change in the thickness of the biolayer rather than filling in the layer. The layer of analyte-binding molecules **206** can be a monolayer or a multi-layer matrix.

[0052] During a biochemical test, the probe **200** can be suspended within a cavity (e.g., a well) that includes a sample as shown in FIG. **1**. Over the course of the biochemical test, a biolayer will form along the distal end of the probe **200** as analyte molecules **208** bind to the analyte-binding molecules **206**.

[0053] When light is shone on the probe **200**, the proximal surface of the interference layer **204** may act as a first reflecting surface and the distal surface of the biolayer may act as a second reflecting surface. The presence, concentration, or binding rate of analyte molecules **208** to the probe **200** can be estimated based on the interference of beams of light reflected by these two reflecting surfaces. As analyte molecules **208** attach to (or detach from) the analyte-binding molecules **206**, the distance between the first and second reflecting surfaces will change. Because the dimensions of all other components in the probe **200** remain the same, the interference pattern formed by the light reflected by the first and second reflecting surfaces is phase shifted in accordance with changes in biolayer thickness due to binding events.

[0054] The use of a monolithic substrate **202** provides several advantages. As noted above, the refractive index of the monolithic substrate **202** is preferably higher than the refractive index of the interference layer **204**. For example, the refractive index of the monolithic substrate **202** may be at least 0.1, 0.2, 0.4, 0.5, or 0.6 higher than the refractive index of the interference layer **204**. Because the monolithic substrate **202** is a solid piece of material having a uniform composition, it is easier to select a material having a higher refractive index than that of the interference layer **204**.

[0055] In operation, an incident light signal **210** emitted by a light source is transported through the monolithic substrate **202** toward the biolayer. Within the probe **200**, light will be reflected at the first reflecting surface resulting in a first reflected light signal **212**. Light will also be reflected at the second reflecting surface resulting in a second reflected light signal **214**. The second reflecting surface initially corresponds to the interface between the analyte-binding molecules **206** and the sample in which the probe **200** is immersed. As binding occurs during the biochemical test, the second reflecting surface becomes the interface between the analyte molecules **208** and the sample.

[0056] The first and second reflected light signals **212**, **214** form a spectral interference pattern, as shown in FIG. **3**A. When analyte molecules **208** bind to the analyte-binding molecules **206** on the distal surface of the interference layer **204**, the optical path of the second reflected light signal **214** will lengthen. As a result, the spectral interference pattern shifts from T**0** to T**1** as shown in FIG. **3**B. By measuring the phase shift continuously in real time, a kinetic binding curve can be plotted as the amount of shift versus the time. The association rate of an analyte molecule to an analyte-binding molecule immobilized on the distal surface of the interference layer **204** can be used to calculate analyte concentration

in the sample. Hence, the measure of the phase shift is the detection principle of a thin-film interferometer.

[0057] In some embodiments, a reflection layer (not shown) is deposited along the distal end of the monolithic substrate **202** such that the reflection layer is positioned between the monolithic substrate **202** and interference layer **204**. Since its main purpose is to ensure that the first reflected light signal **212** reflects at the interface between the monolithic substrate **202** and interference layer **204**, the reflection layer may comprise a material having a higher refractive index than either the monolithic substrate **202** or interference layer **204**. The reflection layer may be very thin in comparison to the interference layer **204**. For example, the reflection layer may have a thickness of approximately 3-10 nm.

[0058] Moreover, an adhesion layer (not shown) may be deposited along the distal surface of the interference layer **204** affixed to the monolithic substrate **202** in some embodiments. The adhesion layer may comprise a material that promotes adhesion of the analyte-binding molecules **206**. One example of such a material is silicon dioxide. The adhesion layer is generally very thin in comparison to the interference layer **204**, so its impact on light traveling toward, or returning from, the biolayer will be minimal. For example, the adhesion layer may have a thickness of approximately 3-10 nm, while the interference layer **204** may have a thickness of approximately 800-1,000 nm. The biolayer formed by the analyte-binding molecules **206** and analyte molecules **208** will normally have a thickness of several nm.

[0059] While embodiments may be described in the context of sensing surfaces having a columnar form, these features may be similarly applicable to sensing surfaces having other forms. One example of such a sensing surface is a slide (also referred to as a "chip") with a planar surface upon which a biolayer is formed by flowing a solution over the planar surface over the course of a biochemical test. Several examples of planar surfaces are discussed below with reference to FIGS. **4-5**.

[0060] FIG. **4** depicts an example of a slide **400** in accordance with various embodiments. The slide **400** includes a substrate **402** upon which an interference layer **404** is deposited. In some embodiments the interference layer **404** is deposited along the entire upper surface of the substrate **402**, while in other embodiments the interference layer **404** is deposited along a portion of the upper surface of the substrate **402**. For example, the interference layer **404** may be deposited within channels or wells formed within the upper surface of the substrate **402**. As discussed above, the monolithic substrate **202** of FIG. **2** is generally much larger in height than in width. Here, however, the inverse may be true. In fact, the width of the substrate **402** may be larger than the length by a factor of 5, 7.5, 10, or 20. As an example, the substrate may be approximately 75 mm by 26 mm with a height/thickness of roughly 1 mm.

[0061] Over the course of a biochemical test, analyte molecules **408** can bind to analyte-binding molecules **406** that have been secured along the upper surface of the interference layer **404** to form a biolayer. To establish the thickness of the biolayer, light can be shone at the upper surface of the slide **400** as shown in FIG. **4**. More specifically, an incident light signal **410** emitted by a light source can be shone at the biolayer that has formed along the upper surface of the slide **400**. This may require that the incident light signal **410** travel through ambient media **416**, which may be vacuum, air, or solution. The incident light signal **410** will be reflected at a first reflecting surface resulting in a first reflected light signal **412**. The first reflecting surface may be representative of the interface between the biolayer and ambient media **416**. The incident light signal **410** will also be reflected at a second reflecting surface resulting in a second reflected light signal **414**. The second reflecting surface may be representative of the interface between the interference layer **404** and substrate **402**. As discussed above, the first and second reflected light signals **412**, **414** form a spectral interference pattern that can be analyzed to establish the thickness of the biolayer. Note that because the incident light signal **410** is not transported through the substrate **402**, the substrate **402** could be either transparent or non-transparent (e.g., opaque).

[0062] FIG. **5** depicts another example of a slide **500** in accordance with various embodiments. Slide **500** of FIG. **5** may be largely similar to slide **400** of FIG. **4**. Thus, the slide **500** may include a substrate **502** upon which an interference layer **504** and analyte-binding molecules **506** are deposited. Over the course of a diagnostic test, analyte molecules **508** can bind to the analyte-binding molecules **506** to form a biolayer.

[0063] Here, however, the incident light signal **510** is shone at the lower surface of the slide **500**. In operation, the incident light signal **510** is transported through the substrate **502** toward the biolayer. Within the slide **500**, light will be reflected at a first reflecting surface resulting in a first reflected light signal **512**. The first reflecting surface may be representative of the interface between the interference layer **504** and substrate **502**. Light will also be reflected at a second reflecting surface resulting in a second reflected light signal **514**. The second reflecting surface may be representative of the interface between the biolayer and ambient media **516**. As discussed above, the first and second reflected light signals **512**, **514** form a spectral interference pattern that can be analyzed to establish the thickness of the biolayer.

[0064] While not shown in FIGS. **4-5**, the slides **400**, **500** could include a reflection layer that is disposed between the substrate **402**, **502** and interference layer **404**, **504** to improve reflectivity along that interface and/or an adhesion layer that is disposed along the upper surface of the interference layer **404**, **504** to secure the analyze-binding molecules **406**, **506**.

Overview of Cartridge

[0065] Regardless of its form, a sensing surface may need to contact a solution that contains a sample associated with a patient. For example, if the sensing surface is a probe with a columnar form as shown in FIG. **2**, the sensing surface may be suspended in a well. This well may be formed along the surface of a cartridge that can be loaded into a robotic cart for analysis by an interferometer.

[0066] FIG. **6** depicts an example of a cartridge assembly **600** in accordance with various embodiments. The cartridge assembly **600** may include a tray **602** that includes a matrix of cavities **304** in which probes can be loaded, either temporarily (e.g., for cleaning) or semi-permanently (e.g., for storing), and an array of slots **606** into which cartridges can be loaded. As shown in FIG. **6**, the slots included in the

array **606** may be arranged linearly in parallel so that more than one cartridge can be loaded into the tray **602** at one time.

[0067] Each cartridge **608** may include a probe well **610** and a protective cap **612** that is designed to accommodate a probe when loaded into the probe well **610**. At a high level, the probe well **610** may serve as a protective container for the probe. In some embodiments, the protective cap **612** is mechanically coupled to the probe well **610**, for example, via a hinge. After a probe is inserted into the probe well **610**, the protective cap **612** can be folded over the probe well **610** to partially or fully enclose the probe. The probe may be vertically stored inside the probe well **610** such that its distal end is suspended in the probe well **610** when the protective cap **612** is in the closed position.

[0068] Each cartridge **608** may comprise two separate compartments of wells. The first compartment may include a sample well **614**, a first reagent well **616**, and a second reagent well **618**. The first and second reagent wells **616**, **618** may contain the same reagent, or the first and second reagent wells **616**, **618** may contain different reagents. The second compartment may include one or more reconstitution wells **620**, one or more wash wells **622**, and a measurement well **624**. The reconstitution well(s) **620** may contain a reconstitution buffer to be dispensed into the sample contained in the sample well **614**, as well as the first and second reagent wells **616**, **618** for reconstituting dry reagents in these wells. The fluids contained in the reconstitution well(s) **620** may be transferred to the sample well **614**, first reagent well **616**, or second reagent well **618** using pipettes, for example. Each wash well **622** may contain an aqueous solution to wash the probe after placing the probe in the sample well **614**, first reagent well **616**, or second reagent well **618**.

[0069] Meanwhile, the measurement well **624** may contain another aqueous solution. In some embodiments. the aqueous solution in the measurement well **624** is the same as the aqueous solution in the well well(s) **622**. In other embodiments, the aqueous solution in the measurement well **624** is different than the aqueous solution in the well well(s) **622**. In some embodiments, the measurement well **624** has a light-transmissive bottom that can be used for optical reading of the biolayer that is formed along the distal end of the probe during a biochemical test. For example, the measurement well **624** may have a light-transmissive bottom if the robotic cart is designed for fluorescent assays, chemiluminescent assays, or combination assays (e.g., chemiluminescent-fluorescent assays) rather than interferometric assays. Thus, light may be emitted toward the distal end of the probe through the light-transmissive bottom of the measurement well **624** rather than proximal end of the probe in embodiments where the light is intended to excite fluorescent labels or chemiluminescent labels. In such a scenario, the fluorescent or chemiluminescent signals can be "read" through the light-transmissive bottom of the measurement well **624**.

Overview of Robotic Cart

[0070] FIG. **7**A includes a perspective view of a robotic cart **700** in accordance with various embodiments. FIG. **7**B includes a block diagram illustrating various components of the robotic cart **700** shown in FIG. **7**A. As discussed above, an operator may deposit a probe in a well of a cartridge **702** where the well contains a sample to be analyzed. While the cartridge **702** could be loaded into the robotic cart **700** on its own, the cartridge **702** could also be installed into a tray **704** that could then be loaded into the robotic cart **700**. Collectively, the tray **704** and any cartridges installed therein may be referred to as a "cartridge assembly." In some embodiments, the operator may even be permitted to load the sample (e.g., in a tube) directly into the robotic cart **700**.

[0071] As shown in FIG. **7**A, a cartridge assembly could be loaded through an aperture (e.g., a slot with a movable cover) in the durable housing of the robotic cart **700**. The aperture could be a slot with a cover that is manually movable by the operator. Alternatively, the aperture could be a slot with a cover that is automatically movable by the robotic cart **700**. For instance, the robotic cart **700** may retract or pivot the cover to expose the slot in response to a determination that the operator is interested in loading the tray **704**. This determination could be based on input provided by the operator (e.g., a selection of a digital element shown on a display mechanism **710**, a selection of a physical button accessible along the surface of the durable housing), or this determination could be based on an action performed by the operator. As an example, the robotic cart **700** may include circuitry that is able to detect and then examine electronic signatures emitted by nearby beacons. Accordingly, if a tray **704** that includes a beacon is presented to the robotic cart **700** (e.g., positioned near the cover), the robotic cart may be able to detect the electronic signature and then retract or pivot the cover to expose the slot.

[0072] Generally, the robotic cart **700** is designed such that when a cartridge **702** is loaded into the robotic cart **700**, its contents can be examined by an analyzer **706** located inside the robotic cart **700**. The term "analyzer" may collectively refer to the hardware, firmware, or software that is needed to analyze the sample contained in the cartridge. As mentioned above, the analyzer **706** may be able to facilitate interferometric assays, fluorescent assays, chemiluminescent assays, combination assays (e.g., chemiluminescent-fluorescent assays), or any combination thereof. Accordingly, its components may depend on the type(s) of assays to be permitted by the robotic cart **700**. As an example, the analyzer **706** may include a light source (e.g., light source **102** of FIG. **1**), detector (e.g., detector **104** of FIG. **1**), and waveguide (e.g., waveguide **106** of FIG. **1**) that are installed within the robotic cart **700** such that when the cartridge **702** is loaded into the robotic cart **700** with a probe installed in the measurement well (e.g., measurement well **624** of FIG. **6**), the waveguide is aligned with the probe.

[0073] Generally, the operator may be expected to perform aspects of the biochemical test, such as moving the probe between the various wells of the cartridge **702** before the cartridge **702**—with the probe loaded therein—into the robotic cart **700** for analysis. However, in some embodiments, the robotic cart **700** includes an actuatable assembly **722** that is designed to move the probe on behalf of an operator. In embodiments where the robotic cart **700** includes the actuatable assembly **722**, the operator may simply load the cartridge **702** into the robotic cart **700**, and the actuatable assembly **722** may be responsible for removing the probe between the probe well (e.g., probe well **610** of FIG. **6**), sample well (e.g., sample well **614** of FIG. **6**), first reagent well (e.g., first reagent well **616** of FIG. **6**), second reagent well (e.g., second reagent well **618** of FIG. **6**), reconstitution wells (e.g., reconstitution wells **620** of FIG. **6**), wash wells (e.g., wash wells **622** of FIG. **6**), and

measurement well (e.g., measurement well **624** of FIG. **6**). As an example, the actuatable assembly **722** may remove the probe from the probe well and then load the probe into the sample well, a first wash well, the first reagent well, a second wash well, and the measurement well in succession. As another example, the actuatable assembly **722** may remove the probe from the probe well and then load the probe into the sample well, the first reagent well, a first wash well, the second reagent well, a second wash well, and the measurement well in succession. The order and count of wells into which the probe is loaded may depend on the nature of the biochemical test being performed (and more specifically, the nature of the analyte molecule of interest). In some embodiments the actuatable assembly **722** is able to remove the protective cap (e.g., protective cap **612** of FIG. **6**) from the probe well on its own, while in other embodiments the operator is required to remove the protective cap before the cartridge **702** is loaded into the robotic cart **700**. At a high level, the actuatable assembly **722** may include a grasping element, such as actuatable pair of elements or actuatable manipulator (also referred to as an "arm"), that is able to grasp and move the probe. In operation, the grasping element could grasp the probe near its proximal end, or the grasping element could grasp the probe near its midpoint so as to avoid potentially damaging (e.g., scratching) its proximal end.

[0074] Assume, for example, that an operator is interested in conducting a biochemical test to determine whether a given analyte is present in a sample. In such a scenario, the operator may provide, to a control platform, input indicative of a request to summon the robotic cart **700**. Upon receiving this input, the control platform may transmit an instruction to the robotic cart **700** to locate itself proximate to the operator. In some embodiments the operator may be prompted to specify her location (e.g., through a computing device used to interface with the control platform), while in other embodiments the location of the operator may be inferred by the control platform (e.g., based on a location of the computing device, a schedule of the operator, etc.).

[0075] The robotic cart **700** can then autonomously navigate its physical environment to reach the intended destination. To accomplish this, the robotic cart **700** may rely on outputs generated by one or more sensors **720** installed therein. These sensors may include proximity sensors, ambient light sensors, and the like. For example, the robotic cart **700** may include one or more light detection and ranging (LiDAR) sensors that use pulsed lasers to detect the variable distance between the robotic cart **700** and obstacles in the physical environment.

[0076] After the robotic cart **700** arrives at its intended destination, the operator may open the storage **708** and remove a cartridge **702**. Normally, ancillary materials like syringes and needles will already be readily accessible, through the robotic cart could also store these materials in the storage **708**. The operator can obtain a sample and deposit the sample into the cartridge **702**, and then the operator can load the cartridge **702** into the robotic cart **700** for analysis. The outputs that are produced by the robotic cart **700** (and, more specifically, its analyzer **706**) may be presented by the robotic cart.

[0077] For example, these outputs—or analyses of these outputs—may be shown on a display mechanism **710**. The display mechanism **710** can be any component that is operable to visually convey information. For example, the display mechanism **710** may be a panel that includes LEDs, organic LEDs, liquid crystal elements, or electrophoretic elements. In some embodiments, the display mechanism **710** is touch sensitive. Thus, an operator may be able to provide input to the robotic cart **700** by interacting with the display mechanism **710**. In embodiments where the display mechanism **710** is not touch sensitive, the operator may be able to interact with the robotic cart **700** using a control device, such as a keyboard, a physical element (e.g., a mechanical button), or a pointing device (e.g., a computer mouse). Additionally or alternatively, the operator may be able to interact with the robotic cart **700** using another computing device that is communicatively connected to the robotic cart **700**. For example, the operator may provide instructions to the robotic cart **700** via the control platform that is responsible for managing the robotic cart **700**.

[0078] Outputs that are produced by the robotic cart **700** may be stored in its memory **716**. The outputs that are produced by the robotic cart **700** can also be forwarded to the control platform that is responsible for managing the robotic cart **700**. Accordingly, the outputs may not only be viewable on another computing device that is communicatively connected to the robotic cart **700**, either directly or indirectly (e.g., via a network-accessible server system as discussed below with reference to FIG. **10**), but the outputs may also be stored on the other computing device. This helps ensure that outputs are readily accessible in the event that the robotic cart **700** is no longer operable (e.g., experiences a power failure or an equipment failure). Storing the outputs in multiple locations may increase the likelihood of authorized access. Therefore, the robotic cart **700** may be designed to encrypt its outputs for safekeeping purposes. For example, the robotic cart **700** (and more specifically, its processor **714**) may employ an encryption scheme that encrypts outputs with a cryptographic key. Outputs may be forwarded to the control platform in encrypted form, but the control platform may be able to decrypt the outputs using a complementary cryptographic key.

[0079] In some embodiments, the robotic cart **700** performs actions based on the current state of inventory within the storage **708**. As an example, when the number of unused cartridges in the storage **708** falls beneath a threshold (e.g., 3 or 5), the robotic cart **700** may transmit a notification to the control platform that is representative of a request for additional supply of unused cartridges. As another example, when the number of used cartridges loaded into the robotic cart **700** exceeds a threshold (e.g., 5 or 7), the robotic cart **700** may transmit a notification to the control platform that is representative of a request to clean or service the robotic cart **700**. Thus, the robotic cart **700** may be able to consistently and intelligently monitor its state, though decisions on which actions to perform may be made by the control platform.

[0080] The robotic cart **700** may include a drive module **712** that allows it to autonomously navigate a physical environment. The drive module **712** (also referred to as a "movement module") may include multiple controllable wheels that enable the robotic cart **700** to follow a safe path through the physical environment as determined based on outputs produced by the sensors **720** mentioned above. These wheels may be collectively and/or individually controllable by a processor **714**. In embodiments where these wheels are individually controllable, the processor **714** may be configured to generate, based on the data produced by the

sensors **720**, a separate signal for each of these wheels, so as to autonomously avoid the obstacles and navigate the ambient environment. These signals may not be identical, however. For example, the robotic cart **700** may move through the use of differential steering, in which wheels are rotated at different speeds to change direction. Alternatively, only a subset of these wheels may be "drive" via signals output by the processor **714**, and therefore at least some of the wheels may be freely manipulable.

[0081] As shown in FIG. **7**A, the wheels can be coupled to the underside of the durable housing of the robotic cart **700**. The illustrated wheels are casters that are able to rotate and swivel relative to the drive module **712** during movement along a surface. Normally, all of the wheels are powered and thus steerable. However, a subset of the wheels may be powered in some embodiments. For example, only the wheels located along the rear side of the durable housing may be powered in order to conserve power. In such embodiments, the remaining non-powered wheels may be non-steerable or steerable. The robotic cart **700** preferably includes 3, 4, or 6 wheels to provide sufficient stability as it moves, though embodiments could include any number of wheels.

[0082] As shown in FIG. **7**B, the robotic cart **700** can include a processor **714**, memory **716**, and communication module **718** in addition to the analyzer **706**, display mechanism **710**, drive module **712**, and sensor(s) **720** discussed above. Each of these components is discussed in greater detail below.

[0083] The processor **714** can have generic characteristics similar to general-purpose processors, or the processor **714** may be an application-specific integrated circuit (ASIC) that provides control functions to the robotic cart **700**. The processor **714** can be connected to all components of the robotic cart **700**, either directly or indirectly, for communication purposes.

[0084] The memory **716** may be comprised of any suitable type of storage medium, such as static random-access memory (SRAM), dynamic random-access memory (DRAM), electrically erasable programmable read-only memory (EEPROM), flash memory, or registers. In addition to storing instructions (e.g., instructions for controlling the drive system **712** for navigation purposes, instructions for controlling the analyzer **706** for testing purposes) that can be executed by the processor **714**, the memory **716** can also store data that is generated by the various components of the robotic cart **700**. For example, over the course of a biochemical test, the analyzer **706** may generate values that relate to development of a biolayer as discussed above with reference to FIGS. **1-5**. These values may be stored in the memory **716** in a "raw" form, or these values may be stored in the memory **716** in a "processed" form, for example, following processing by the processor **714**.

[0085] The communication module **718** may be responsible for managing communications between the various components of the robotic cart **700**, or the communication module **718** may be responsible for managing communications with other computing devices. For example, in embodiments where the control platform that manages the robotic cart **700** is executed by another computing device, the communication module **718** can facilitate communications with the other computing device. The communication module **718** may be wireless communication circuitry that is designed to establish communication channels with other computing devices. Examples of wireless communication circuitry include antenna modules configured for cellular networks (also referred to as "mobile networks") and integrated circuits configured for Near Field Communication (NFC), Wireless Universal Serial Bus (USB), Bluetooth, and the like.

[0086] FIG. **8** is a high-level block diagram illustrating how a robotic cart **800** may be able to interface with a hub unit **850**, for example, for charging purposes. In some embodiments, the hub unit **850** (also referred to as a "docking station" or "charging station") is associated with a single robotic cart **800**. In other embodiments, the hub unit **850** is associated with multiple robotic carts, and those robotic carts may be able to interface with the hub unit **850** either sequentially or simultaneously (e.g., in embodiments where the hub unit **850** includes multiple docking mechanisms).

[0087] As mentioned above, the robotic cart **800** may be able to autonomously traverse a physical environment to situate itself near an operator who is interested in conducting a biochemical test. The robotic cart **800** may include a processor **802**, a wireless transceiver **804**, an analyzer **806**, one or more sensors **808**, a drive module **810**, and a power component **812** that is electrically coupled to a power interface **814**. These components may reside within a durable housing (also referred to as the "structural body" of the robotic cart **800**). Embodiments of the robotic cart **800** can include any subset of the components shown in FIG. **8**, as well as additional components not illustrated here.

[0088] The processor **802** may be responsible for controlling the drive module **810** to navigate the physical environment. Assume, for example, that the robotic cart **800** receives, via the wireless transceiver **804**, input indicative of a request to navigate to a given location. In such a scenario, the robotic cart **800** can control the drive module **810** based on outputs produced the sensor(s) **808** to travel from its original location to the given location. The sensor(s) **808** may include proximity sensors, ambient light sensors, and the like. Generally, the request to navigate to the given location is submitted by an operator who is interested in performing a biochemical test. Accordingly, after the robotic cart **800** arrives at the given location, the processor **802** may control the analyzer **806** to administer, conduct, manage, or otherwise support the biochemical test.

[0089] Over the course of the biochemical test, data generated by the analyzer **806** may be stored, at least temporarily, in a memory (not shown). In some embodiments, the processor **802** are responsible for processing and then examining the data so as perform analysis locally. In other embodiments, the data is forwarded onward to a destination for analysis. For example, the processor **802** may process the data prior to transmission downstream to the hub unit **850** or another computing device.

[0090] In some embodiments, the robotic cart **800** and the hub unit **850** transmit data between one another via a physical connection between respective data interfaces **816**, **864**. For example, when the robotic cart **800** physically docks with the hub unit **850**, data generated by the analyzer **806** may be forwarded to the data interface **816** of the robotic cart **800** for transmission to the data interface **864** of the hub unit **800**. Alternatively, the data interface **816** may be part of the wireless transceiver **804**. In such embodiments, the wireless transceiver **804** could be configured to establish a wireless connection with a wireless transceiver **854** of the hub unit **850**. The wireless transceivers **804**, **854**

may communicate with one another via a short-range communication protocol (e.g., NFC, Wireless USB, or Bluetooth), a cellular data protocol (e.g., LTE, 4G, or 5G), or a proprietary point-to-point protocol.

[0091] Because the robotic cart **800** is autonomous, its power component **812** may become depleted over time. At a high level, the power component **812** may be responsible for providing power to the other components of the robotic cart **800** as necessary. Examples of power components include rechargeable lithium-ion (Li-Ion) batteries, rechargeable nickel-metal hydride (NiMH) batteries, rechargeable nickel-cadmium (NiCad) batteries, etc. By interfacing with the hub unit **850**, the robotic cart **800** may be able to recharge its power component **812**. For example, when the robotic cart **800** physically docks with the hub unit **850**, power may be transmitted form the hub unit **850** to the robotic cart **800** via a physical connection of electrical contacts included in respective power interfaces **814**, **860**. Accordingly, power may automatically be transferred from the hub unit **850** to the robotic cart **800** when the robotic cart **800** is determined to be properly docked with the hub unit **850** (e.g., based on whether there is a physical connection between the electrical contacts). Note that the hub unit **850** may include a processor **852** that may manage power transfer, among other things. For example, if the processor **852** determines that the robotic cart **800** is fully charged, then the processor **852** may terminate power transfer from the hub unit **850**. Moreover, the hub unit **850** may include a display mechanism **816** that is able to indicate whether the robotic cart **800** is properly docked with the hub unit **850**, whether power is presently being transferred to the robotic cart **800**, whether data is presently being transferred from the robotic cart **800**, etc.

[0092] As shown in FIG. **8**, the hub unit **850** may also include another power interface **862** that allows the hub unit **850** to be physically connected to a power source (e.g., an electrical outlet) from which power can be obtained without limitation. Alternatively, the power interface **862** may be representative of an integrated circuit that is able to wirelessly receive power from the power source. The integrated circuit may be able to receive power transmitted in accordance with the Qi standard developed by the Wireless Power Consortium or some other wireless power standard. Similarly, the power interfaces **814**, **860** of the robotic cart **800** and hub unit **850** could be integrated circuits that are able to wirelessly transfer power.

[0093] Regardless of its power, the power interface **862** may allow power to be received from a source external to the hub unit **850**. As mentioned above, the hub unit **850** may also include a power component **858** that can store power received at the power interface **862**. However, the power component **858** may not be present in some embodiments. Instead, power received by the hub unit **850** at the power interface **862** from the source may simply be directed to the other power interface **860** for transmission onward to the robotic cart **800**, when appropriate.

[0094] As part of its autonomous nature, the robotic cart **800** may be configured to intelligently charge itself when not in use. For example, if the robotic cart **800** has not moved for a predetermined interval of time (e.g., due to a lack of requests from operators), then the robotic cart **800** may return to its corresponding hub unit **850** that serves as a charging station. Power may automatically flow from the hub unit **850** to the robotic cart **800** via wired transmission of power when the robotic cart **800** is physically docked to the hub unit **850**. Likewise, power may automatically flow from the hub unit **850** to the robotic cart **800** via wireless transmission of power when the robotic cart **800** is physically docked to, or simply located near, the hub unit **850**.

[0095] FIG. **9** includes a high-level illustration of communications that may occur between a control platform **900**, a robotic cart **902**, and a hub unit **904**. Initially, the control platform **900** may receive input indicative of a request to summon the robotic cart **902** (step **910**). As mentioned above, the control platform **900** normally resides on, and thus is executed by, a computing device that is communicatively connected to the robotic cart **902**, either directly or indirectly. One example of a computing device is a mobile phone associated with the person who has summoned the robotic cart **902**. Another example of a computing device is a network-accessible server system, though in such embodiments the control platform **900** may be accessible via a computer program executing on a mobile phone, tablet computer, mobile workstation, etc.

[0096] Then, the control platform **900** can transmit an instruction to the robotic cart **902** to position itself in a given location (step **920**). The instruction may depend on how the control platform **900** is implemented. For example, in an embodiment where the control platform **900** resides on a computing device that is locally accessible to the person who is interested in summoning the robotic cart **904**, the given location may be established based on the current location of the computing device. Alternatively, the given location may be specified in the request submitted by the person.

[0097] Upon receiving the instruction, the robotic cart **902** may autonomously traverse its physical environment to position itself in the given location (step **930**). Thereafter, the robotic cart **902** may permit the person to conduct a biochemical test (step **940**) as discussed above. For example, the person may retrieve a cartridge from the robotic cart, obtain a sample from a patient, and then deposit the sample into the cartridge before loading the cartridge into the robotic cart **902** for analysis. Generally, the robotic cart **902** will analyze the sample while situated in the given location. However, the robotic cart **902** may return to its corresponding hub unit **904** before analyzing the sample in some situations (e.g., where insufficient power is available to complete the biochemical test). As shown in FIG. **9**, the outputs that are produced by the robotic cart from analyzing the sample can be presented for display (step **950**A) or transmitted to the control platform (step **950**B).

[0098] After the biochemical test is complete, the robotic cart **902** may return to its corresponding hub unit **904** (step **960**). In some embodiments, this is done automatically. For example, the robotic cart **902** may automatically traverse the physical environment to dock with the hub unit **904** upon determining that the robotic cart **902** is no longer of use to the person (e.g., based on inactivity). As another example, the robotic cart **902** may return to dock with the hub unit **904** when the power stored in its power component falls beneath a predetermined threshold (e.g., 20, 25, or 30 percent of total capacity). In other embodiments, the robotic cart **904** returns to the hub unit **904** upon receiving a request to do so. For example, the person may be prompted to indicate when she is done with the robotic cart **904**, and when such an indication is made, the robotic cart **904** may return to the hub unit **904**.

Overview of Control Platform

[0099] As mentioned above, a control platform may be responsible for managing movement of the robotic cart throughout its physical environment, among other things. FIG. **10** illustrates a network environment **1000** that includes a control platform **1002**. Individuals can interact with the control platform **1000** via interfaces **1004**. For example, an operator may be able to summon a robotic cart via an interface, as well as instruct the robotic cart to travel to another location (e.g., its default location). As another example, the operator may be able to view the status of a robotic cart via an interface. The interface may indicate the current location of the robotic cart, the current power level of the robotic cart, the supplies currently stored in the robotic cart, etc. Thus, the interfaces **1004** may serve as interactive dashboards through which operators can manage robotic carts. Additionally or alternatively, the interfaces **1004** may serve as informative dashboards through which operators and other individuals can observe information regarding robotic carts. For example, operators may be able to review analyses of data generated by an analyzer included in a robotic cart as part of a biochemical test.

[0100] As shown in FIG. **10**, the control platform **1002** may reside in a network environment **1000**. The control platform **1002** may reside on, and be executed by, a computing device (not shown) that is connected to one or more networks **1006***a-b*. The computing device could be a robotic cart or another device, such as a mobile phone, tablet computer, computer server, etc. The networks **1006***a-b* can include personal area networks (PANs), local area networks (LANs), wide area networks (WANs), metropolitan area networks (MANs), cellular networks, the Internet, etc. Additionally or alternatively, the control platform **1002** can be communicatively coupled to one or more computing devices over a short-range wireless connectivity technology, such as Bluetooth, NFC, Wireless USB, and the like.

[0101] The interfaces **1004** may be accessible via a web browser, mobile application, desktop application, over-the-top (OTT) application, or some other computer program.

[0102] For example, an operator may be able to initiate a mobile application that is executing on her mobile phone and then input, through an interface generated by the mobile application, data that is representative of a request to summon a robotic cart to her current location. The operator may specify her current location through the interface, or her current location may be inferred by the control platform **1002** based on, for example, the strength or presence of wireless access point (WAP) signals received by the mobile phone, the strength or presence of beacons (e.g., Bluetooth beacons or WiFi beacons), the strength or presence of background noises, and the like. Alternatively, the control platform **1002** may infer her current location based on a schedule that is associated with the operator. If, for example, the schedule indicates that the operator is presently scheduled to be in a given room, then the control platform **1002** may infer that the operator is located in the given room.

[0103] As another example, an operator may be able to access an interface on which information regarding a patient can be reviewed through a desktop application that is executing on a mobile workstation. Such information can include name, date of birth, diagnoses, symptoms, or medications. With this information, the healthcare professional may be able to readily establish the status of the patient, render diagnoses, and the like. Through this interface, the operator may be able to manage a robotic cart as discussed above.

[0104] Accordingly, the interfaces **1004** may be viewed on computing devices such as mobile workstations (also referred to as "medical carts"), personal computers, tablet computers, mobile phones, wearable electronic devices, and the like.

[0105] In some embodiments, at least some components of the control platform **1002** are hosted locally. That is, part of the control platform **1002** may reside on the computing device used to access one of the interfaces **1004**. For example, the control platform **1002** may be embodied as a mobile application executing on a mobile phone associated with an operator, or the control platform **1002** may be embodied as a desktop application executing on a mobile workstation associated with a healthcare facility. Note, however, that the mobile and desktop applications may be communicatively connected to a network-accessible server system **1008** on which other components of the control platform **1002** are hosted. As mentioned above, components of the control platform **1002** could also be hosted on the robotic cart itself. Thus, the control platform **1002** could be distributed across, or at least communicatively connected to, the robotic cart, network-accessible server system **1008**, and computing device through which input is provided to the control platform **1002**.

[0106] In other embodiments, the control platform **1002** is executed entirely by a cloud computing service operated by, for example, Amazon Web Services®, Google Cloud Platform™, or Microsoft Azure®. In such embodiments, the control platform **1002** may reside on a network-accessible server system **1008** that comprises one or more computer servers. These computer servers can include computer-implemented models, algorithms (e.g., for processing data generated by the analyzer of the robotic cart), patient information (e.g., profiles, credentials, and health-related information such as age, date of birth, geographical location, disease classification, disease state, healthcare provider, etc.), and other assets. Those skilled in the art will recognize that this information could also be distributed among the network-accessible server system **1008** and one or more computing devices.

Processing System

[0107] FIG. **11** is a block diagram illustrating an example of a processing system **1100** in which at least some operations described herein can be implemented. For example, components of the processing system **1100** may be hosted on a robotic cart (e.g., robotic cart **700** of FIGS. **7**A-B, robotic cart **800** of FIG. **8**, or robotic cart **902** of FIG. **9**). As another example, components of the processing system **1100** may be hosted on a hub unit (e.g., hub unit **850** of FIG. **8** or hub unit **904** of FIG. **9**). As another example, components of the processing system **1100** may be hosted on a computing device that is used to interface with a control platform (e.g., control platform **1000** of FIG. **10**).

[0108] The processing system **1100** may include a processor **1102**, main memory **1106**, non-volatile memory **1110**, network adapter **1112**, video display **1118**, input/output device **1120**, control device **1122**, drive unit **1124** that includes a storage medium **1126**, or signal generation device **1130** that are communicatively connected to a bus **1116**. The bus **1116** is illustrated as an abstraction that represents one

or more physical buses or point-to-point connections that are connected by appropriate bridges, adapters, or controllers. The bus **1116**, therefore, can include a system bus, Peripheral Component Interconnect (PCI) bus, PCI-Express bus, HyperTransport bus, Industry Standard Architecture (ISA) bus, Small Computer System Interface (SCSI) bus, Universal Serial Bus (USB), Inter-Integrated Circuit (I^2C) bus, or a bus compliant with Institute of Electrical and Electronics Engineers (IEEE) Standard 1394.

[0109] The processing system **1100** may share a similar computer processor architecture as that of a computer server, personal computer, tablet computer, mobile phone, wearable electronic device (e.g., an activity tracker or head-mounted display), network-connected electronic device (e.g., a television or home assistant device), or another computing device that is capable of executing a set of instructions (sequential or otherwise) that specify actions to be taken by the processing system **1100**.

[0110] While the main memory **1106**, non-volatile memory **1110**, and storage medium **1126** are shown to be a single medium, the terms "storage medium" and "machine-readable medium" should be taken to include a single medium or multiple media that stores instructions **1128**. The terms "storage medium" and "machine-readable medium" should also be taken to include any medium that is capable of storing, encoding, or carrying instructions for execution by the processing system **1100**.

[0111] In general, the routines executed to implement the embodiments of the present disclosure may be implemented as part of an operating system or a specific component, program, object, module, or sequence of instructions (collectively referred to as "computer programs"). The computer programs typically comprise instructions (e.g., instructions **1104**, **1108**, **1128**) set at various times in various memories and storage devices in a computing device. When read and executed by the processor **1102**, the instructions may cause the processing system **1100** to perform operations to execute various aspects of the present disclosure.

[0112] While embodiments have been described in the context of fully functioning computing devices, those skilled in the art will appreciate that the embodiments are capable of being distributed in a variety of forms. The present disclosure applies regardless of the particular type of machine- or computer-readable medium used to actually cause the distribution. Further examples of machine- and computer-readable media include recordable-type media such as volatile memory, non-volatile memory **1110**, removable disks, hard disk drives, optical disks (e.g., Compact Disk Read-Only Memory (CD-ROMS) and Digital Versatile Disks (DVDs)), cloud-based storage media, and transmission-type storage media such as digital and analog communication links.

[0113] The network adapter **1112** enables the processing system **1100** to mediate data in a network **1114** with an entity that is external to the processing system **1100** through any communication protocol supported by the processing system **1100** and the external entity. The network adapter **1112** can include a wired network adaptor card, wireless network interface card, switch, protocol converter, gateway, bridge, hub, receiver, repeater, or transceiver that includes an appropriate chip (e.g., enabling communication over Bluetooth or Wi-Fi).

REMARKS

[0114] The foregoing description of various embodiments of the technology has been provided for the purposes of illustration and description. It is not intended to be exhaustive or to limit the claimed subject matter to the precise forms disclosed.

[0115] Many modifications and variation will be apparent to those skilled in the art. Embodiments were chosen and described in order to best describe the principles of the technology and its practical applications, thereby enabling others skilled in the relevant art to understand the claimed subject matter, the various embodiments, and the various modifications that are suited to the particular uses contemplated.

What is claimed is:

1. A robotic cart for facilitating biochemical tests, the robotic cart comprising:
- a durable housing that includes an aperture adapted to receive a cartridge containing a sample from a patient;
- a test system that is configured to perform a biochemical test on the sample and provide test results;
- a sensor that is configured to produce data indicative of obstacles in an ambient environment;
- a drive module that includes multiple independently controllable wheels; and
- a processor that is configured to generate, based on the data produced by the sensor, multiple signals for the multiple independently controllable wheels of the drive module, so as to autonomously avoid the obstacles and navigate the ambient environment.

2. The robotic cart of claim **1**, wherein the sensor is a light detection and ranging (LiDAR) sensor that uses one or more pulsed lasers to detect a variable distance between the robotic cart and the obstacles in the ambient environment.

3. The robotic cart of claim **1**, wherein the aperture is a slot that is designed to receive the cartridge and has a movable cover.

4. The robotic cart of claim **1**, wherein the test system includes
- (i) a light source that, in operation, emits light toward a probe included in the cartridge, and
- (ii) a detector that, in operation, records a spectrum of the light reflected by the probe.

5. The robotic cart of claim **4**, wherein the light emitted by the light source is conveyed to the probe via a waveguide, and wherein the light received from the probe is conveyed to the detector via the waveguide.

6. The robotic cart of claim **4**, wherein the detector is able to record intensity of the light received from the probe at a plurality of wavelengths.

7. The robotic cart of claim **4**, further comprising:
- an actuatable assembly that, in operation, moves a probe amongst different wells included in the cartridge.

8. A diagnostic system comprising:
- a cartridge that includes a plurality of wells, at least one of which includes a sample from a patient is deposited by an operator;
- a robotic cart into which the cartridge is insertable by the operator for analysis; and
- a control platform that is responsible for managing
  - (i) movement of the robotic cart through a physical environment, and
  - (ii) testing of the sample when the cartridge is inserted into the robotic cart.

9. The diagnostic system of claim **8**, wherein the control platform is executed by a computing device that is communicatively connected to the robotic cart via a network.

10. A method performed by a robotic cart that includes a test system for performing a biochemical test, the method comprising:

receiving, from a control platform, input that is indicative of an instruction to be positioned in a given location inside a facility;

traversing the facility in an autonomous manner based on signals output by one or more sensors included in the robotic cart;

permitting insertion of a cartridge with a sample deposited therein; and

performing a biochemical test with the test system in response to the cartridge being inserted into the robotic cart.

11. The method of claim **10**, further comprising:

causing display of an output of the biochemical test on a display mechanism of the robotic cart.

12. The method of claim **10**, further comprising:

transmitting an output of the biochemical test to a computing device via a network, for display by the computing device.

13. The method of claim **10**, further comprising:

encrypting an output of the biochemical test, and

storing the encrypted output in a memory of the robotic cart.

14. A non-transitory medium with instructions stored thereon that, when executed by a processor of a computing device, cause the computing device to perform operations comprising:

receiving first input that is indicative of a request to summon a robotic cart;

transmitting an instruction to the robotic cart to position itself in a given location;

receiving second input that is indicative of an output derived by the robotic cart through analysis of a sample taken from a patient; and

displaying an analysis of the output on a display mechanism, for review by an operator of the computing device.

15. The non-transitory medium of claim **14**, wherein the given location included in the instruction is specified by the operator in the request.

16. The non-transitory medium of claim **14**, wherein the given location included in the instruction is inferred based on a current location of the computing device.

17. The non-transitory medium of claim **14**, wherein the given location included in the instruction is inferred based on a schedule of the operator.

* * * * *