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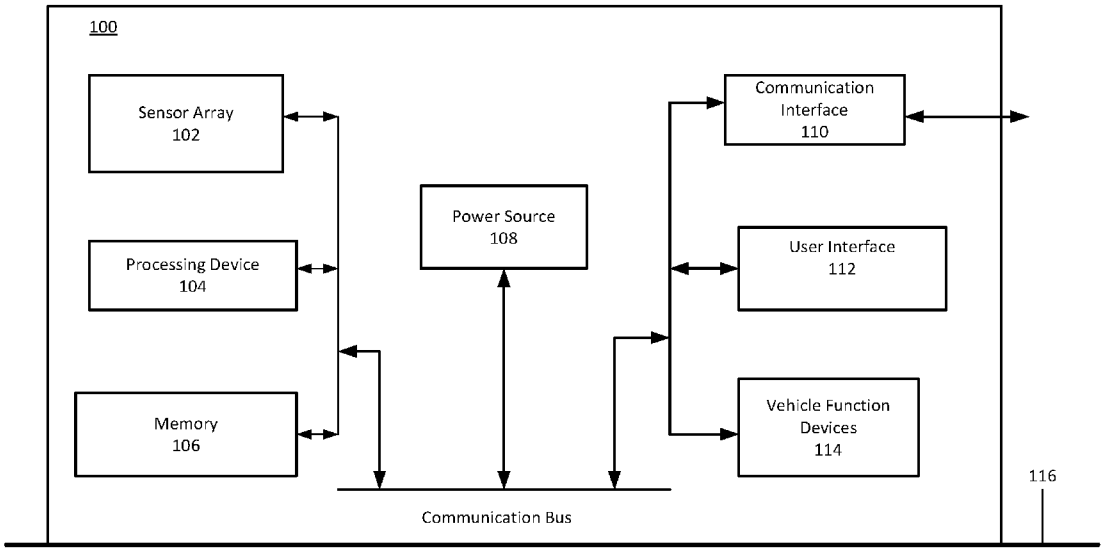


FIG. 1

(57) Abstract: A robotic device includes a user interface, one or more sensors, a processor, and a non¬ transitory computer readable medium. The robotic device is configured to receive, via the user interface, a selection of a mode corresponding to a viitual boundary. The virtual boundary may delineate an avoid area to be avoided by the robotic device during navigation in the environment. The robotic device is also configured to identify at least one detectable boundary in the environment for defining the virtual boundary, and define the virtual boundary relative to the at least one detectable boundary based on the mode. The robotic device may move in the environment without crossing the virtual boundary to enter the avoid area.

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TITLE: METHODS AND SYSTEMS FOR DEFINING VIRTUAL BOUNDARIES FOR A ROBOTIC DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/780,518, filed December 17, 2018, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

[0001] The present disclosure is in the technical field of robotic device navigation, particularly navigation of robotic devices (e.g., robotic cleaning devices). More particularly, the present disclosure is directed to a method for defining virtual boundaries for the robotic devices when navigating in environments.

[0002] Robotic devices have the ability to minimize the human effort involved in performing everyday tasks. For example, robotic devices may be used as cleaning devices to help maintain and clean surfaces, such as hard floor surfaces, carpets, and the like. While robotic devices are useful, it can be challenging for robotic devices to operate in a variety of different locations.

[0003] Navigation in environments is typically done with the aid of sensors that are on board the robotic devices. In the case of floor cleaning, such robots are generally confined within (i) vertical walls and other obstacles within the rooms of a dwelling, (ii) IR-detected staircases (cliffs) leading downward; and/or (iii) user-placed detectable barriers such as directed IR beams, physical barriers or magnetic tape. Walls provide much of the confinement perimeter. Some robots may try to map the dwelling using a complex system

of sensors and/or active or passive beacons (e.g., sonar, RFID or bar code detection, or various kinds of machine vision). These sensors provide information by which the robotic device is able to navigate. However, real-time processing of sensor data can be slow, causing the robotic device to move slowly to allow time for processing of the sensor data.

SUMMARY

[0004] This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This summary is not intended to identify key features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0005] In an embodiment, systems and methods for controlling the navigation of a robotic device in an environment is disclosed. The system may include robotic device that includes a user interface, one or more sensors, a processor, and a non-transitory computer readable medium. The non-transitory computer readable medium may include programming instructions that are configured to cause the processor to execute the methods described in this disclosure. The method may include receiving a selection of a mode corresponding to a virtual boundary (for example, via the user interface of the robotic device). The virtual boundary may delineate an avoid area to be avoided by the robotic device during navigation in the environment. The method may also include identifying at least one detectable boundary in the environment for defining the virtual boundary, defining the virtual boundary relative to the at least one detectable boundary based on the mode, and operating the robotic device in the environment by causing the robotic device to move in the environment while ensuring that the robotic device does not cross the virtual boundary to enter the avoid area.

[0006] Optionally, the robotic device may receive the selection of the mode via the user interface. Furthermore, the robotic device may identify the at least one detectable boundary by analyzing sensor data collected by the one or more sensors.

[0007] In certain embodiments, defining the virtual boundary relative to the at least one detectable boundary (based on the mode) may include identifying one or more rule sets corresponding to the mode. Optionally, the one or more rule sets may include rules for defining one or more of the following: a shape of the virtual boundary, a position of the virtual boundary relative to the robotic device, and/or a position of the virtual boundary relative to the at least one detectable boundary.

[0008] In one or more embodiments, identifying at least one detectable boundary in the environment for defining the virtual boundary may include identifying one or more detectable boundaries in the environment; and identifying the at least one detectable boundary from the amongst the one or more detectable boundaries based on one or more rules corresponding to at least one of the following: position of the avoid area in the environment, position of the at least one detectable boundary, characteristics of sensor data collected from the avoid area, and/or shape of the at least on detectable boundary. Optionally, the one or more detectable boundaries in the environment may be identified based on sensor data collected by the robotic device, and/or map data corresponding to the environment. In certain embodiments, the detectable boundary may not be located in the avoid area if characteristics of sensor data collected from the environment are not reliable.

[0009] In certain embodiments, the virtual boundary may be defined relative to the at least one detectable boundary by traversing an initial path through the permissible area to determine a shape and a position of the virtual boundary relative to the robotic device or relative to the at least one detectable boundary.

[0010] In certain more embodiments, the virtual boundary may be defined relative to the at least one detectable boundary by defining a linear virtual boundary at a location relative to the robotic device and/or relative to the at least one detectable boundary. Optionally a shape of the virtual boundary may be a replication of a shape of the at least one detectable boundary, a mirror image of a shape of the at least one detectable boundary, and/or linear.

[0011] In at least one embodiment, the at least one detectable boundary may be identified to be located to a left side of the robotic device; and the virtual boundary may be defined relative to the at least one detectable boundary by defining the virtual boundary to a right side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment. Optionally, the predetermined distance may be equal to a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

[0012] In one or more embodiments, the at least one detectable boundary may be identified to be located to a left side of the robotic device; and the virtual boundary may be defined relative to the at least one detectable boundary by defining the virtual boundary to the left side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment. Optionally, the predetermined distance may be is less than a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

[0013] In at least one embodiment, the at least one detectable boundary may be identified to be located to a right side of the robotic device; and the virtual boundary may be defined relative to the at least one detectable boundary by defining the virtual boundary to a left side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment. Optionally, the predetermined distance may be equal to a

distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

[0014] In one or more embodiments, the at least one detectable boundary may be identified to be located to a right side of the robotic device; and the virtual boundary may be defined relative to the at least one detectable boundary by defining the virtual boundary to the right side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment. Optionally, the predetermined distance may be is less than a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The foregoing aspects and many of the attendant advantages of the disclosed subject matter will become more readily appreciated as the same become better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

[0016] FIG. 1 depicts a block diagram of an example robotic device, in accordance with the embodiments described herein;

[0017] FIG. 2 depicts an embodiment of an example system that includes the robotic device shown in FIG. 1, in accordance with the embodiment described herein;

[0018] FIG. 3 depicts a perspective view of an environment in which a robotic device can operate, in accordance with the embodiment described herein;

[0019] FIGS. 4A – 4I illustrate various example modes of operation of a robotic device, in accordance with the embodiment described herein;

[0020] FIG. 5 depicts an example method for defining a virtual boundary in an environment, in accordance with the embodiment described herein;

[0021] FIG. 6 depicts an example of internal hardware that may be included in any of the electronic components of the system, in accordance with the embodiments described herein.

DETAILED DESCRIPTION

[0022] The present disclosure describes embodiments for the creation of virtual boundaries for aiding in the navigation of robotic devices such as robotic cleaning devices in an environment. The virtual boundaries can be generated based on environmental data of the environments (e.g., one or more detectable boundaries) in which the robotic devices are intended to navigate. The robotic devices can then navigate autonomously within the environments based on the virtual boundary.

[0023] As used in this document, any word in singular form, along with the singular forms "a," "an" and "the," include the plural reference unless the context clearly dictates otherwise. Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art. All publications mentioned in this document are incorporated by reference. Nothing in this document is to be construed as an admission that the embodiments described in this document are not entitled to antedate such disclosure by virtue of prior invention. As used in this document, the term "comprising" means "including, but not limited to."

[0024] The terms "computing device" and "electronic device" refer to a device having a processor and a non-transitory, computer-readable medium (i.e., memory). The memory may contain programming instructions in the form of a software application that, when executed by the processor, causes the device to perform one or more processing operations according to the programming instructions. An electronic device also may include

additional components such as a touch-sensitive display device that serves as a user interface, as well as a camera for capturing images. An electronic device also may include one or more communication hardware components such as a transmitter and/or receiver that will enable the device to send and/or receive signals to and/or from other devices, whether via a communications network or via near-field or short-range communication protocols. If so, the programming instructions may be stored on the remote device and executed on the processor of the computing device as in a thin client or Internet of Things (IoT) arrangement. Example components of an electronic device are discussed below in the context of FIG. 6.

[0025] The terms "memory," "memory device," "computer-readable medium" and "data store" each refer to a non-transitory device on which computer-readable data, programming instructions or both are stored. Unless the context specifically states that a single device is required or that multiple devices are required, the terms "memory," "memory device," "computer-readable medium" and "data store" include both the singular and plural embodiments, as well as portions of such devices such as memory sectors.

[0026] A "processor" or "processing device" is a hardware component of an electronic device that is configured to execute programming instructions. The term "processor" may refer to a single processor or to multiple processors that together implement various steps of a process. Unless the context specifically states that a single processor is required or that multiple processors are required, the term "processor" includes both the singular and plural embodiments.

[0027] As used herein, the term "robot" or "robotic device" refers to an electro-mechanical machine guided by a processor. The robotic device may also include a memory that may contain programming instructions in the form of a software application that, when executed

by the processor, causes the device to perform one or more processing operations according to the programming instructions. A robotic device also may include one or more communication hardware components such as a transmitter and/or receiver that will enable the device to send and/or receive signals to and/or from other devices, whether via a communications network or via near-field or short-range communication protocols. If so, the programming instructions may be stored on the remote device and executed on the processor of the robotic device as in a thin client or Internet of Things (IoT) arrangement. Mobile robotic devices have the capability to move around in their environment and are not fixed to one physical location. An example of a mobile robotic device that is in common use today is an automated guided vehicle or automatic guided vehicle (AGV). An AGV is generally a mobile robot that follows markers or wires in the floor, or uses electromagnetic emitter-detectors, including for example sonar, a vision system or lasers for navigation. Mobile robots can be found in industry, military and security environments. They also appear as consumer products, for entertainment or to perform certain tasks like vacuum cleaning and home assistance.

[0028] Mobile robotic devices may interact or interface with humans to provide a number of services that range from home assistance to commercial assistance and more. In the example of home assistance, a mobile robotic device can assist elderly people with everyday tasks, including, but not limited to, maintaining a medication regime, mobility assistance, communication assistance (e.g., video conferencing, telecommunications, Internet access, etc.), home or site monitoring (inside and/or outside), person monitoring, and/or providing a personal emergency response system (PERS). For commercial assistance, the mobile robotic device can provide videoconferencing (e.g., in a hospital setting), a point of sale terminal, interactive information/marketing terminal, etc. Mobile

robotic devices need to navigate in a robust or reliable manner, for example, to avoid obstacles and reach intended destinations.

[0029] The term "virtual boundary" refers to a non-physical border that acts as a demarcation between two or more areas of an environment. The virtual boundary of the current disclosure may be an arbitrarily shaped border such as, without limitation, a straight line, a curved line, a zigzag line, or any other shape. Virtual barriers can keep a robotic device from exiting or entering a particular area, e.g., to prevent a cleaning robot from moving from a hallway into a cubicle area, from a tiled area onto a carpeted floor, etc. The virtual boundary may be temporary in that, upon satisfaction of one or more conditions, the robotic device may be permitted to cross the virtual boundary.

[0030] When used in this document, terms such as "top" and "bottom," "upper" and "lower", or "front" and "rear," are not intended to have absolute orientations but are instead intended to describe relative positions of various components with respect to each other. For example, a first component may be an "upper" component and a second component may be a "lower" component when a light fixture is oriented in a first direction. The relative orientations of the components may be reversed, or the components may be on the same plane, if the orientation of a light fixture that contains the components is changed. The claims are intended to include all orientations of a device containing such components.

[0031] The embodiments disclosed herein can be used to navigate a robotic device in an environment that does not include a landmark, boundary, or other physical parameters to delineate or demarcate an area of the environment that should be avoided (referred to in this document as an "avoid area") and/or an area within which travel is permitted (referred to in this document as a "permissible area") by the robotic device. For example, the environment to be navigated may include a tiled floor area that can be cleaned by water (permissible

area) adjacent to a carpeted area that cannot be cleaned by water (avoid area), with no detectable boundary or landmark between the tiled floor and the carpeted area that the robotic device's sensors can detect. Alternatively, the boundary may be detectable by hardware such as cameras and processes such as edge detection or other image processing techniques, but doing so to detect the boundary between the tiled floor and the carpeted area may add processing time, require prior learning and/or memory space, or the like. Optionally, the defining the virtual boundary may be performed in addition to detections performed by one or more sensors of the robotic device. Similarly, the environment to be navigated may include an area that should be avoided by the robotic device, but the data collected by the sensors of the robotic device corresponding to the area to be avoided may be unreliable such that it cannot be used to navigate the robotic device. For example, the permissible area may be bordered by dynamic moving objects that would provide unreliable data for navigation and localization. Alternatively and/or additionally, the avoid area may include objects that are not easily detectable by the sensors of the robotic device due to their size, composition, shape, etc. In yet another embodiment, the avoid area may be an area of an otherwise contiguous surface that is considered low-traffic. It may be desirable to avoid cleaning the low-traffic areas to, for example, preserve a floor coating finish. Finally, an avoid area may simply be an area that includes one or more objects that can act as detectable boundaries, but which does not need to be cleaned for certain reasons.

[0032] As such, the embodiments disclosed in this disclosure include methods that allow a robotic device to define a virtual boundary between permissible areas and avoid areas based at least partly, on detectable boundaries or landmarks in the environment. The detectable boundaries and/or landmarks may or may not be located in the avoid area. This enables the robotic device to avoid certain areas in the environment in the absence of and/or without using complex sensing devices that require computation time or power. Hence, the

embodiments disclosed herein also can be used to help ensure that the navigation methods do not overwhelm the memory and/or processing capabilities of the robotic device since not all robotic devices have sufficient memory or processing power to handle or process large numbers of data points gathered by complex three-dimensional sensors. Furthermore, the methods disclosed in this disclosure may obviate the need for an environment to be mapped before operating a robotic device in the environment and/or for a user to manually define a permissible area.

[0033] FIG. 1 illustrates a block diagram of components of an example embodiment of a robotic device **100**. The components and interaction of components described with respect to the robotic device **100** may be implemented in any other embodiments of robotic devices. In addition, the embodiments of robotic devices described herein are also not limited to the components and interaction of components described with respect to the robotic device **100**, but can be implemented in a number of other ways. In an embodiment, the robotic device **100** may be an autonomous device that is capable of automatically navigating its environment.

[0034] The robotic device may include, without limitation, one or more sensors **102**, a processing device **104**, a memory **106**, a power source **108**, a communications interface **110**, a user interface **112**, and one or more vehicle function devices **114**. In the depiction shown in FIG. 1, the robotic device **100** is located on the floor **116**. The robotic device **100** is configured to move across the floor **116**.

[0035] In certain embodiments, the one or more sensors **102** may include one or more sensors located on the robotic device **100** and may be configured to provide information about the robotic device **100** itself and/or the environment around the robotic device **100**. For example, the one or more sensors **102** may include a proximity sensor configured to

detect a distance from the robotic device to any object in a field of the proximity sensor. Examples of proximity sensors include infrared sensors, light detection and ranging (LIDAR) sensors, global positioning system (GPS) devices, cameras, other electromagnetic energy sensors, sonar sensors, other forms of acoustic sensors, and other forms of proximity sensors. The one or more sensors **102** may also include sensors to detect an orientation or heading of the robotic device **100**, such as a gyroscope or a compass, or to detect a speed and/or acceleration of the robotic device **100**, such as an accelerometer or encoders. The one or more sensors **102** may also include sensors that detect characteristics about the environment around the robotic device **100**, such as a temperature sensor (e.g., a thermocouple or a thermistor), a humidity sensor (e.g., a hygrometer), a pressure sensor (e.g., a barometer, a piezoelectric sensor), infrared (IR) sensor, or any other sensor.

[0036] In at least one embodiment, the one or more sensors **102** may include a landmark sensor that is configured to sense a detectable boundary or landmark in an environment and/or detect the position, orientation, etc. of the robotic device **100** with respect to the detectable boundary or landmark such as a wall, fence, shelf, line on the floor, etc. Examples of landmark sensors may include, without limitation, LIDAR sensors, sonar sensors, cameras, infrared sensors, laser detection and ranging (LADAR) sensors, radio frequency (RF) sensors, or the like.

[0037] In some embodiments, the processing device **104** may be configured to control one or more functions of the robotic device **100** such as, without limitation, navigation in an environment, cleaning (if a cleaning robotic device), communication with a user or an external system, or the like. In some embodiments, the processing device **104** is configured to control the movements of the robotic device **100** based on, without limitation, readings from the one or more sensors **102**, a digital map of the environment, readings from one or more sensors in the environment, a predefined path of movement, or any other information,

or combinations thereof. For example, in an embodiment, the processing device may receive information from the one or more sensors **102** and analyze it to control the navigation of the robotic device **100**. The robotic device **100** also includes memory **106** and the processing device may write information to and/or read information from the memory **106**. For example, one or more rules for generating a virtual boundary may be stored in the memory **106** and the processing device **104** may read the data from the memory **106** to aid in controlling movements of the robotic device.

[0038] The processing device **104** may communicate with each of the other components of the robotic device **100**, via for example, a communication bus or any other suitable mechanism.

[0039] In one or more embodiments, a communications interface **110** may be configured to facilitate communication of data into and out of the robotic device **100**. In some embodiments, the communications interface **110** may include, without limitation, a WiFi transceiver, a Bluetooth transceiver, an Ethernet port, a USB port, and/or any other type of wired and/or wireless communication interfaces. The communications interface **110** is configured to transmit data to and receive data from computing devices and/or networks that are not included in the robotic device **100**.

[0040] In certain embodiments, the user interface **112** may include any type of input and/or output devices that permit a user to input commands into or receive information from the robotic device **100**. In some embodiments, the user input/output devices **112** may include, without limitation, a push button, a toggle switch, a touchscreen display, an LED light interface, a keyboard, a microphone, a speaker, or any other kind of input and/or output device. The user input/output devices **112** may permit a user to control the operation of the robotic device **100**, define settings (e.g., modes) of the robotic device **100**, receive

information about operations of the robotic device **100**, troubleshoot problems with the robotic device **100**, or the like.

[0041] In one or more embodiments, the vehicle functional devices **114** of the robotic device **100** may include any device that is capable of causing the robotic device **100** to function in a particular way. In some embodiments, the vehicle functional devices **114** may include one or more motors that drive wheels of the robotic device **100** to cause it to move. In some other embodiments, the vehicle functional devices **114** may include a steering mechanism to control a direction of movement of the robotic device **100**. In some embodiments, the vehicle functional devices **114** may include a cleaning device configured to clean a surface on which the robotic device **100** moves (e.g., a sweeper, vacuum, mop, polisher, fluid dispenser, squeegee, or the like). The vehicle functional devices **114** can include any number of other functional devices that cause the robotic device **100** to function. In some embodiments, the processing device **104** may also be configured to control operation of the vehicle functional devices **114**.

[0042] In some embodiments, the power source **108** is configured to provide power to the other components of the robotic device **100**. The power source **108** may be coupled to and capable of providing power to each of the one or more sensors **102**, the computing device **104**, the memory **106**, the communications interface **110**, the user interface **112**, and/or the vehicle function devices **114**. The power source **108** may include one or more of a rechargeable battery, a non-rechargeable battery, a solar cell panel, an internal combustion engine, a chemical reaction power generator, or any other device configured to provide power to the robotic device **100** and its components.

[0043] FIG. 2 illustrates an example embodiment of a system **200** that includes the robotic device **100**. The system may include a network **210** that is in communication with the

communications interface **110** of the robotic device **100**. The network **210** may include a wireless network, a wired network, or any combination of wired and/or wireless networks. The system **200** also includes a remote computing device **220** that is located remotely from the robotic device **100**, and is in communication with the robotic device **100** via the network **210**. In some embodiments, the remote computing device **220** may include, without limitation, a laptop computer, a desktop computer, a server, a mobile phone, a tablet, or any other type of computing device.

[0044] In some embodiments, the robotic device **100** may operate in a facility (e.g., a building, a campus of buildings, etc.), where the network **210** may include a private network to the facility (e.g., a WiFi network associated with the facility), and the remote computing device **220** may be a computing device located in the facility at a location different from the operation of the robotic device **100**. In some other embodiments, the robotic device **100** may operate in a facility (e.g., a building, a campus of buildings, etc.) where the network **210** may include a public network (e.g., the Internet), and the remote computing device **220** may be located somewhere other than the facility (e.g., in a "cloud" data center, in a facility of a distributor of the robotic device **100**, etc.). It will be understood that many other arrangements of the network **210** and the remote computing device **220** are within the scope of this disclosure. It will be understood that the remote computing device **220** may be a single computing device or may be a number of computing devices that are capable of interacting with each other.

[0045] FIG. 3 illustrates a perspective view of an example environment **300** in which a robotic device **100** such as a robotic cleaning device is configured to move and operate. In the depicted embodiment, the environment **300** is in the form of a room that includes a floor **310** and one or more detectable boundaries and/or landmarks (e.g., a wall **312**, a wall **314**, and a shelf **316**). As used herein, the terms "detectable boundary" or "landmark"

interchangeably refer to any object, detectable boundary, landmark, or other differentiating boundary (e.g., detectable boundary formed by, for example, a change in color, a change in texture, a change in material, a change in orientation, a change in height, a change in density, or the like), that is detectable by one or more sensors of the robotic device. In certain other embodiments, the one or more sensors of the robotic device using any now or hereafter known methods. Examples of the detectable boundary may include, without limitation, furniture pieces, walls, stair wall edges, a line painted on the floor, edge between types of flooring (e.g., hard floor and carpeted floor, between different color tiles, between different types of carpet, or the like).

[0046] The environment **100** may also include a ceiling, other walls, doors, windows, and the like, which are not depicted in the view shown in FIG. 3.

[0047] As shown in FIG. 3, the environment **300** may include at least one avoid area **320** that should be avoided during navigation of the robotic device. Examples of the avoid area **320** may include, without limitation, a carpeted area; a clustered area that does not have enough navigable space and/or has objects that cannot be relied upon as landmarks during navigation (e.g., wires, toys, or the like); an entrance to another area (e.g., a cubicle); an area that includes moving objects (e.g., people) that renders sensor data corresponding to the area unrealizable for navigation purposes; or any other area that has no detectable boundary on at least one side but should be avoided during navigation of the robotic device. In an embodiment, the avoid area **320** is bounded on at least one side by a virtual boundary **321**. As described below, the virtual boundary is defined by the robotic device relative to at least one of the one or more detectable boundaries in the environment.

[0048] As discussed above, the virtual boundary **321** is a demarcation between a permissible area where the robotic device can travel and an avoid area where the robotic

device is not allowed to travel. A virtual boundary may correspond in whole or in part to one or more detectable boundaries but it does not need to do so. However, in certain embodiments, the system may use a detectable boundary or landmark to define the virtual boundary, where the detectable boundary or landmark may be located anywhere in the environment **300** such as, without limitation, in a permissible area, in an avoid area, and/or any other area.

[0049] In the embodiment shown in FIG. 3, the robotic device **100** is located on the floor **310** and is configured to move across the floor **310**. In some examples, the robotic device **100** may be one of a SWINGBOT, an AEROBOT, or a DUOBOT, cleaning robots.

[0050] In one or more embodiments, the virtual boundary **321** may be defined as a function of distance, orientation, and/or shape of a detectable boundary or landmark. Specifically, the robotic device **100** is configured to define the virtual boundary **321** relative to one or more detectable boundaries based on one or more rule sets. Each rule set may correspond to a user-selectable mode of the robotic device. In an embodiment, a user may select the mode based on, for example and without limitation, the location of one or more detectable boundaries or landmarks in the environment; location of the avoid area; reliability of sensor data collected from avoid area; size and/or configuration of the permissible area and/or the avoid area; current position and/or orientation of the mobile device; or combinations thereof.

[0051] Non-limiting examples of user-selectable modes and corresponding rule sets are described below.

[0052] Ignore left mode: If the sensor data from an avoid area is unreliable and a detectable boundary or landmark is located to the right side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) ignore sensor data

collected from left side of the robotic device; and (2) define a virtual boundary to the left side of the robotic device at a predefined distance from an initial position of the robotic device, and relative to a detectable boundary or landmark. Since sensor data collected from the left side of the robotic device is ignored, the selected detectable boundary or landmark will be located on the right side of the robotic device. Alternatively and/or additionally, if the sensor data from an avoid area is unreliable and the avoid area to located to the left side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) ignore sensor data collected from left side of the robotic device; and (2) define a virtual boundary to the left of the robotic device at a predefined distance from an initial position of the robotic device, and relative to a detectable boundary or landmark. Since sensor data collected from the left side of the robotic device is ignored, the selected detectable boundary or landmark will be located on the right side of the robotic device.

[0053] Mirror left mode: If a detectable boundary or landmark is located to the left side of the robotic device and/or an avoid area is located to the right side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) select detectable boundary or landmark located on the left side of the robotic device; and (2) define a virtual boundary to the right side of the robotic device relative to the detectable boundary or landmark such that the virtual boundary is at a distance from the robotic device that is equal to an initial distance of the detectable boundary or landmark from the robotic device.

[0054] Ignore right mode: If the sensor data from an avoid area is unreliable and a detectable boundary or landmark is located to the left side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) ignore sensor data collected from right side of the robotic device; and (2) define a virtual boundary to the right side of the robotic device at a predefined distance from an initial position of the

robotic device, and relative to a detectable boundary or landmark. Since sensor data collected from the right side of the robotic device is ignored, the selected detectable boundary or landmark will be located on the left side of the robotic device. Alternatively and/or additionally, if the sensor data from an avoid area is unreliable and the avoid area is located to the right side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) ignore sensor data collected from right side of the robotic device; and (2) define a virtual boundary to the right side of the robotic device at a predefined distance from an initial position of the robotic device, and relative to a detectable boundary or landmark. Since sensor data collected from the right side of the robotic device is ignored, the selected detectable boundary or landmark will be located on the left side of the robotic device.

[0055] Mirror right mode: If a detectable boundary or landmark is located to the right side of the robotic device and/or an avoid area is located to the left side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) select detectable boundary or landmark located on the right side of the robotic device; and (2) define virtual boundary to the left side of the robotic device relative to the detectable boundary or landmark such that the virtual boundary is at a distance from the robotic device that is equal to an initial distance of the detectable boundary or landmark from the robotic device.

[0056] Allowed left mode: If the sensor data from an avoid area is reliable, and the avoid area is located to the right side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) use all sensor data collected from the environment, (2) define a virtual boundary, relative to a detectable boundary or landmark, in an area between the robotic device's current position and the avoid area (that is located to the right side of the robotic device), and (3) the virtual boundary is defined at a predefined

distance from an initial position of the robotic device in the area between the robotic device's current position and the avoid area. Since all sensor data is used, the detectable boundary or landmark may be located on either side of the robotic device.

[0057] Allowed left, ignore right mode: If the sensor data from an avoid area is unreliable and the avoid area is located to the right side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) ignore sensor data collected from right side of the robotic device; and (2) define a virtual boundary in an area between the robotic device's current position and the avoid area (that is located on the right side of the robotic device) relative to a detectable boundary or landmark that is located on the left side of the robotic device. The virtual boundary may be at a predefined distance from an initial position of the robotic device.

[0058] Allowed right mode: If the sensor data from an avoid area is reliable, and the avoid area is located to the left side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) use all sensor data collected from the environment, (2) define a virtual boundary, relative to a detectable boundary or landmark, in an area between the robotic device's current position and the avoid area (that is located to the left side of the robotic device, and (3) the virtual boundary is defined at a predefined distance from an initial position of the robotic device in the area between the robotic device's current position and the avoid area. Since all sensor data is used, the detectable boundary or landmark may be located on either side of the robotic device.

[0059] Allowed right, ignore left mode: If the sensor data from an avoid area is unreliable and the avoid area is located to the left side of the robotic device, the robotic device may define a virtual boundary based on at least the following rules: (1) ignore sensor data collected from left side of the robotic device; and (2) define a virtual boundary in an area

between the robotic device's current position and the avoid area (that is located on the left side of the robotic device) relative to a detectable boundary or landmark that is located on the right side of the robotic device. The virtual boundary may be at a predefined distance from an initial position of the robotic device.

[0060] Mirror mode: If the sensor data from an avoid area is reliable, the robotic device may define a virtual boundary based on at least the following rules: (1) use all sensor data collected from the environment; (2) define a virtual boundary relative to a detectable boundary or landmark that is closest to the robotic device; (3) define the virtual boundary in an area that is on a side of the robotic device that does not include the detectable boundary or landmark; and (4) the virtual boundary is defined such that it is at a distance that is equal to the distance of the detectable boundary or landmark from an initial position of the robotic device.

[0061] As discussed above, the shape of the virtual boundary may be arbitrary. In certain embodiments, the virtual boundary may be a straight line or any other shape irrespective of the shape or configuration of the corresponding detectable boundary or landmark. Alternatively and/or additionally, the shape of the virtual boundary may be the same as the shape or configuration of the corresponding detectable boundary or landmark. In other embodiments, the shape of the virtual boundary may be a mirror image of the shape or configuration of the corresponding detectable boundary or landmark. Each of the above described modes may also include rules for defining the shape of the virtual boundary.

[0062] In some embodiments, the distance of the virtual boundary from the robotic device may be a function of the distance (e.g., equal to) of the robotic device from the detectable boundary or landmark. For example, in the mirror left mode, the robotic device may define a virtual boundary that is a straight line parallel to a detectable boundary on the left of the

robotic device, such that the virtual boundary is located on the right side of the robotic device at a distance from the robotic device that is equal to the distance between the robotic device and the detectable boundary. The robotic device may detect the detectable boundary and determine its distance from the detectable boundary using one or more of its sensors (e.g., ultrasonic sensor). Alternatively, the distance of the virtual boundary from the robotic device may be predetermined based on a mode, adjustable by the user, and/or automatically determined by the robotic device based on sensor data collected by the robotic device. In certain embodiments, a user may provide the distance to an avoid area and the robotic device may define the virtual boundary at a distance that is less than or equal to the distance to the avoid area. In some embodiments, if a distance is not specified, the virtual boundary may be defined at a default distance such as at a distance equal to the distance to the detectable boundary.

[0063] It should be noted that the distance of a virtual boundary is always less than the distance to a detectable boundary in modes where the virtual boundary and a detectable boundary are on the same side of the robotic device. In other words, a virtually boundary will not be placed beyond a detectable boundary.

[0064] FIGS. 4A – 4D illustrate the respective "Ignore Left", "Ignore Right", "Mirror Right", and "Mirror Left" modes of a robotic device. As shown in FIG. 4A, the virtual boundary **421** is defined on the left of the robotic device **100** such that it is at a predetermined distance from an initial position of the robotic device **100** and follows a straight line path parallel to the detectable boundary. FIG. 4C illustrates a particular case of the embodiment shown in FIG. 4A where the distance of the virtual boundary **421** from the robotic device **100** is equal to the distance between the robotic device **100** in its initial position and the detectable boundary. In an initial setup process for the modes illustrated in FIGS. 4A and 4C, an operator may place the robotic device **100** at a desired position within

the permissible area **422**, then an operator can select the appropriate mode, and then the robotic device **100** defines the virtual boundary **421** on the left side of the robotic device **100** relative to its initial position, e.g. adjacent to or a predetermined distance from the robotic device **100**, as illustrated. In FIGS. 4A and 4C, the virtual boundary **421** prevents the robotic device **100** from moving outside the permissible area **422** and into the avoid area **420** on the left of the virtual boundary **421**. FIG. 4B illustrates a virtual boundary **421** that is defined on the right side of the robotic device **100** such that it is at a predetermined distance from an initial position of the robotic device **100** and follows a straight line path parallel to the detectable boundary. FIG. 4D illustrates a particular case of the embodiment shown in FIG. 4A where the distance of the virtual boundary **421** from the robotic device **100** is equal to the distance between the robotic device **100** in its initial position and the detectable boundary. Setup for the modes illustrated in FIGS. 4B and 4D is similar to the setup for the modes illustrated in FIGS. 4A and 4C, albeit with the virtual boundary **421** being located on the right side of the robotic device **100**. In FIGS. 4B and 4D, the virtual boundary **421** prevents the robotic device **100** from moving outside the permissible area **422** and into an avoid area **420** on the right of the virtual boundary **421**. It will be understood that the straight line shape of the virtual boundary is shown as example and is not limiting.

[0065] FIGS. 4E – 4G illustrate the "Allow Left" mode of a robotic device **100**. As shown in FIG 4E, the robotic device **100** defines a straight line virtual boundary **421** using either the left detectable boundary and/or the right detectable boundary at a predetermined distance from an initial position of the robotic device and on the right side of the robotic device. For example, the distance may be provided by a user such that the virtual boundary **421** exists between the robotic device's current position and an avoid area **420** on the right of the robotic device so as to prevent the robotic device **100** from moving outside the permissible area **422** and into the avoid area **420**. As shown in FIG 4F, the robotic device

100 defines a straight line virtual boundary **421** parallel to a right detectable boundary, and at a predetermined distance from an initial position of the robotic device **100** on the right side of the robotic device **100**. For example, the predetermined distance may be included in a mode and/or defined by a user such that the virtual boundary **421** exists between the robotic device's current position and an avoid area **420** on the right of the robotic device so as to prevent the robotic device **100** from moving outside the permissible area **422** and into the avoid area **420**. As shown in FIG 4G, the robotic device **100** defines a straight line virtual boundary **421** parallel to a left detectable boundary, and at a predetermined distance from an initial position of the robotic device **100** on the right side of the robotic device **100**, where the shape of the virtual boundary is the same as that of the left detectable boundary. For example, the predetermined distance may be included in a mode and/or defined by a user such that the virtual boundary **421** exists between the robotic device's current position and an avoid area **420** on the right of the robotic device so as to prevent the robotic device **100** from moving outside the permissible area **422** and into the avoid area **420**.

[0066] FIGS. 4H and 4I illustrate the "Mirror" mode of a robotic device. In certain embodiments, in the mirror mode the detectable boundary is not in the shape of a straight line. As shown in FIGS. 4H and 4I, the robotic device **100** defines a virtual boundary **421** on the right side of the robotic device **100**. The virtual boundary **421** in these example embodiments either replicates (FIG. 4H) or mirrors (FIG. 4I) the shape of a detectable boundary that is closest to the robotic device **100** and is located at a distance from the robotic device that is equal to the distance between the robotic device and the selected detectable boundary. In an initial setup process for the "Mirror" modes illustrated in FIGS. 4H and 4I, an operator may place the robotic device **100** at a desired position within the permissible area **422**, then an operator can select the appropriate "Mirror" mode, and then the robotic device **100** will traverse an initial path through the permissible area **422** to define

the virtual boundary **421** on the right side of the robotic device **100**. In FIG. 4H, the robotic device **100** will use the one or more sensors **102** to follow the contour of the detectable boundary. In following this initial path, the robotic device **100** replicates the detectable boundary so that the virtual boundary **421** follows a similar contour and is positioned on the right side of the robotic device **100** at a distance that is the same or similar to the distance between the robotic device **100** and the virtual boundary. In FIG. 4I, the robotic device **100** travels forward in a straight line instead of following the contour of the detectable boundary. In following this initial path, the robotic device **100** will still use the one or more sensors **102** to detect a distance to the detectable boundary and mirror the detectable boundary so that the virtual boundary **421** follows a mirrored contour positioned on the right side of the robotic device **100** at a distance that is the same or similar to the distance between the robotic device **100** and the virtual boundary.

[0067] FIG. 5 illustrates an example method for defining a virtual boundary in an environment based on one or more detectable boundaries. While the method **500** is described for the sake of convenience and not with an intent of limiting the disclosure as comprising a series and/or a number of steps, it is to be understood that the process does not need to be performed as a series of steps and/or the steps do not need to be performed in the order shown and described with respect to FIG. 5 but the process may be integrated and/or one or more steps may be performed together, simultaneously, or the steps may be performed in the order disclosed or in an alternate order. Likewise, any setup processes described above may be integrated and/or one or more steps may be performed together, simultaneously, or the steps may be performed in the order disclosed or in an alternate order.

[0068] At **502**, a robotic device may be positioned in an environment such that it can observe or monitor at least one detectable boundary or landmark in the environment (e.g.,

using one or more sensors). This may be in a permissible area of the environment. The robotic device may be configured to position itself automatically so it can observe or monitor a detectable boundary or landmark. Additionally and/or alternatively, it may be positioned by the user accordingly.

[0069] At **504**, the robotic device may receive a selection of a virtual boundary definition mode from a user. The virtual boundary definition modes may be one or more of those described above (e.g., mirror left, mirror right, allow left, allow right, etc.) and/or other modes. The mode selected will cause the robotic device to access and use a mode-specific rule set to define the virtual boundary. As discussed above, a user may select the mode based on, for example and without limitation, the location of one or more detectable boundaries or landmarks in the environment; location of the avoid area; reliability of sensor data collected from avoid area; size and/or configuration of the permissible area and/or the avoid area; current position and/or orientation of the robotic device; or combinations thereof.

[0070] While the above disclosure describes receiving the mode selection from a user, the disclosure is not so limiting. In certain embodiments, the robotic device may automatically select an appropriate mode without any user input and/or based on a user input that does not include a mode selection. For example, if the sensor data collected from the left side of the robotic device is unreliable, constantly changing, and/or unavailable, the robotic device may choose a mode (e.g., Ignore Left mode) that uses sensor data corresponding to a detectable boundary from the right side of the robotic device. Similarly, the robotic device may receive an identification of an avoid area and automatically select a mode that creates a virtual boundary between the robotic device and the avoid area based on, for example, the reliability of sensor data corresponding to detectable boundaries in the environment.

[0071] Based on the mode selection received, the robotic device may identify at least one detectable boundary or landmark to be used for defining the virtual boundary (**506**). As described above, each mode includes rules for identification of the detectable boundary or landmark. For example, if an "Ignore Left" mode selection is received, the robotic device cannot use a detectable boundary or landmark located to the left of the robotic device. In certain embodiments, a user may provide a selection of the detectable boundary or landmark to be used for defining the virtual boundary. Alternatively and/or additionally, the robotic device may prompt a user to confirm the identification of the detectable boundary or landmark to be used for defining the virtual boundary.

[0072] In certain embodiments, the robotic device may use one or more of its sensors (e.g., the landmark sensors) to detect the position, shape, orientation, distance, or other similar information about a plurality of detectable boundaries or landmarks in the environment. Alternatively and/or additionally, the robotic device may use pre-loaded and/or pre-mapped data corresponding to the environment to identify detectable boundaries and landmarks in the environment. For example, the robotic device may receive a mode selection as mirror left and use the rule set corresponding to the mirror left mode to define the virtual boundary. As discussed above, this may include detecting a detectable boundary on the left side of the robotic device (using one or more sensors), determining a distance between the robotic device and the detectable boundary, and defining a virtual boundary on the right side of the robotic device that is at a distance equal to the determined distance between the robotic device and the detectable boundary. The defined virtual boundary may also mirror or replicate the shape of the detected detectable boundary or maybe any other arbitrary shape. The robotic device may then use the rules corresponding to the received mode selection to identify the at least one detectable boundary or landmark to be used for defining the virtual boundary.

[0073] At **508**, the robotic device may define a virtual boundary relative to the identified detectable boundary or landmark based on the rules corresponding to the received mode selection. Specifically, the robotic device may identify, without limitation, the shape, location, distance, etc. of the virtual boundary based on the rules corresponding to the received mode selection (described above). In certain embodiments, the robotic device may save the defined virtual boundary for future operations of the robotic device. The step of defining the virtual boundary relative to the identified detectable boundary or landmark may be performed over the course of making an initial pass through the permissible area to appropriately characterize the identified detectable boundary or landmark in order to define the shape of the virtual boundary.

[0074] At **510**, the robotic device may navigate the environment such that it does not cross into an avoid area demarcated by the defined virtual boundary. During navigation, the robotic device may use the landmark sensors to maintain its desired position and orientation relative to the identified detectable boundary or landmark.

[0075] While the current disclosure describes that a virtual boundary is defined and the robotic device navigates the environment such that it does not cross into an avoid area demarcated by the defined virtual boundary, it will be understood to those skilled in the art that the robotic device need not actually define a virtual boundary and/or save it. Rather, it may use the rules corresponding to the received mode selection to navigate the environment relative to the identified detectable boundary or landmark without actually defining the virtual boundary.

[0076] FIG. 6 depicts an example of internal hardware that may be included in any of the electronic components of the system, such as a robotic device, sensor, etc. having a processing capability, or a local or remote computing device that is in communication with

the robotic device. An electrical bus **600** serves as an information highway interconnecting the other illustrated components of the hardware. Processor **605** is a central processing device of the system, configured to perform calculations and logic operations required to execute programming instructions. As used in this document and in the claims, the terms "processor" and "processing device" may refer to a single processor or any number of processors in a set of processors that collectively perform a set of operations, such as a central processing unit (CPU), a graphics processing unit (GPU), a remote server, or a combination of these. Read only memory (ROM), random access memory (RAM), flash memory, hard drives and other devices capable of storing electronic data constitute examples of memory devices **625** that may store the programming instructions. A memory device may include a single device or a collection of devices across which data and/or instructions are stored. Various embodiments of the invention may include a computer-readable medium containing programming instructions that are configured to cause one or more processors, robotic devices and/or sensors to perform the functions described in the context of the previous figures.

[0077] An optional display interface **630** may permit information from the bus **600** to be displayed on a display device **635** in visual, graphic or alphanumeric format. An audio interface and audio output (such as a speaker) also may be provided. Communication with external devices may occur using various communication devices **640** such as a wireless antenna, an RFID tag and/or short-range or near-field communication transceiver, each of which may optionally communicatively connect with other components of the device via one or more communication system. The communication device(s) **640** may be configured to be communicatively connected to a communications network, such as the Internet, a local area network or a cellular telephone data network.

[0078] The hardware may also include a user interface sensor **645** that allows for receipt of data from input devices **650** such as a keyboard, a mouse, a joystick, a touchscreen, a touch pad, a remote control, a pointing device and/or microphone. In embodiments where the electronic device is the smartphone or another image capturing device, digital images of a document or other image content may be acquired via a camera **620** that can capture video and/or still images.

[0079] The features and functions disclosed above, as well as alternatives, may be combined into many other different systems or applications. Various presently unforeseen or unanticipated alternatives, modifications, variations or improvements may be made by those skilled in the art, each of which is also intended to be encompassed by the disclosed embodiments.

[0080] As will be appreciated by those skilled in the art, one or more components of the system **600** may be located remotely from other components of the system **600** components, such as in a distributed system. Furthermore, one or more of the components may be combined and additional components performing functions described herein may be included in the system **600**. Thus, the system **600** can be adapted to accommodate a variety of needs and circumstances. The depicted and described architectures and descriptions are provided for exemplary purposes only and are not limiting to the various embodiments described herein.

[0081] It will be appreciated that the above-disclosed and other features and functions may be combined into many other different systems or applications. All such applications and alternatives are also intended to be encompassed by the disclosure of this patent document.

[0082] Embodiments described herein may be implemented in various ways, including as computer program products that comprise articles of manufacture. A computer program

product may include a non-transitory computer-readable storage medium storing applications, programs, program modules, scripts, source code, program code, object code, byte code, compiled code, interpreted code, machine code, executable instructions, and/or the like (also referred to herein as executable instructions, instructions for execution, computer program products, program code, and/or similar terms used herein interchangeably). Such non-transitory computer-readable storage media include all computer-readable media (including volatile and non-volatile media).

[0083] As should be appreciated, various embodiments of the embodiments described herein may also be implemented as methods, apparatus, systems, computing devices, and the like. As such, embodiments described herein may take the form of an apparatus, system, computing device, and the like executing instructions stored on a computer readable storage medium to perform certain steps or operations. Thus, embodiments described herein may be implemented entirely in hardware, entirely in a computer program product, or in an embodiment that comprises combination of computer program products and hardware performing certain steps or operations.

[0084] Embodiments described herein may be made with reference to block diagrams and flowchart illustrations. Thus, it should be understood that blocks of a block diagram and flowchart illustrations may be implemented in the form of a computer program product, in an entirely hardware embodiment, in a combination of hardware and computer program products, or in apparatus, systems, computing devices, and the like carrying out instructions, operations, or steps. Such instructions, operations, or steps may be stored on a computer readable storage medium for execution buy a processing element in a computing device. For example, retrieval, loading, and execution of code may be performed sequentially such that one instruction is retrieved, loaded, and executed at a time. In some exemplary embodiments, retrieval, loading, and/or execution may be performed in parallel such that

multiple instructions are retrieved, loaded, and/or executed together. Thus, such embodiments can produce specifically configured machines performing the steps or operations specified in the block diagrams and flowchart illustrations. Accordingly, the block diagrams and flowchart illustrations support various combinations of embodiments for performing the specified instructions, operations, or steps.

[0085] The principles, representative embodiments, and modes of operation of the present disclosure have been described in the foregoing description. However, aspects of the present disclosure which are intended to be protected are not to be construed as limited to the particular embodiments disclosed. Further, the embodiments described herein are to be regarded as illustrative rather than restrictive. It will be appreciated that variations and changes may be made by others, and equivalents employed, without departing from the spirit of the present disclosure. Accordingly, it is expressly intended that all such variations, changes, and equivalents fall within the spirit and scope of the present disclosure, as claimed.

CLAIMS

What is claimed is:

1. A method comprising, by a processor of a robotic device:

receiving a selection of a mode corresponding to a virtual boundary, wherein the virtual boundary delineates an avoid area to be avoided by the robotic device during navigation in an environment;

identifying at least one detectable boundary in the environment for defining the virtual boundary;

defining, based on the mode, the virtual boundary relative to the at least one detectable boundary; and

operating the robotic device in the environment by causing the robotic device to move in the environment while ensuring that the robotic device does not cross the virtual boundary to enter the avoid area.

2. The method of claim 1, wherein defining, based on the mode, the virtual boundary relative to the at least one detectable boundary comprises identifying one or more rule sets corresponding to the mode, wherein the one or more rule sets include rules for defining at least one of the following: a shape of the virtual boundary, a position of the virtual boundary relative to the robotic device, or a position of the virtual boundary relative to the at least one detectable boundary.

3. The method of claim 1, wherein identifying, based on the mode, at least one detectable boundary in the environment for defining the virtual boundary comprises:

identifying one or more detectable boundaries in the environment; and

identifying the at least one detectable boundary from the amongst the one or more detectable boundaries based on one or more rules corresponding to at least one of the following: position of the avoid area in the environment, position of the at least one detectable boundary, characteristics of sensor data collected from the avoid area, or shape of the at least on detectable boundary.

4. The method of claim 3, wherein identifying the one or more detectable boundaries in the environment comprises identifying the one or more detectable boundaries in the environment based on at least one of the following:

sensor data collected by the robotic device; or

map data corresponding to the environment.

5. The method of claim 3, wherein the one or more rules comprise a rule that the detectable boundary cannot be located in the avoid area if characteristics of sensor data collected from the environment are not reliable.

6. The method of claim 1, wherein defining the virtual boundary relative to the at least one detectable boundary comprises traversing, by the robotic device, an initial path through the permissible area to determine a shape and a position of the virtual boundary relative to the robotic device or relative to the at least one detectable boundary.

7. The method of claim 1, wherein defining the virtual boundary relative to the at least one detectable boundary comprises defining a linear virtual boundary at a location relative to the robotic device or relative to the at least one detectable boundary.

8. The method of claim 8, wherein a shape of the virtual boundary is selected from the group comprising: replication of a shape of the at least one detectable boundary, mirror image of a shape of the at least one detectable boundary, and linear.

9. The method of claim 1, wherein:

identifying the at least one detectable boundary in the environment for defining the virtual boundary comprises identifying the at least one detectable boundary to a left side of the robotic device; and

defining the virtual boundary relative to the at least one detectable boundary comprises defining the virtual boundary to a right side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment.

10. The method of claim 9, wherein the predetermined distance is equal to a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

11. The method of claim 1, wherein:

identifying the at least one detectable boundary in the environment for defining the virtual boundary comprises identifying the at least one detectable boundary to a left side of the robotic device; and

defining the virtual boundary relative to the at least one detectable boundary comprises defining the virtual boundary to the left side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment.

12. The method of claim 11, wherein the predetermined distance is less than a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

13. The method of claim 1, wherein:

identifying the at least one detectable boundary in the environment for defining the virtual boundary comprises identifying the at least one detectable boundary to a right side of the robotic device; and

defining the virtual boundary relative to the at least one detectable boundary comprises defining the virtual boundary to a left side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment.

14. The method of claim 13, wherein the predetermined distance is equal to a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

15. The method of claim 1, wherein:

identifying the at least one detectable boundary in the environment for defining the virtual boundary comprises identifying the at least one detectable boundary to a right side of the robotic device; and

defining the virtual boundary relative to the at least one detectable boundary comprises defining the virtual boundary to the right side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment.

16. The method of claim 15, wherein the predetermined distance is less than a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

17. A robotic device comprising:

a user interface;

one or more sensors;

a processor; and

a non-transitory computer readable medium comprising programming instructions that when executed cause the processor to:

receive, via the user interface, a selection of a mode corresponding to a virtual boundary, wherein the virtual boundary delineates an avoid area to be avoided by the robotic device during navigation in an environment,

identify, using the one or more sensors and based on the mode, at least one detectable boundary in the environment for defining the virtual boundary,

define, based on the mode, the virtual boundary relative to the at least one detectable boundary, and

cause the robotic device to move in the environment while ensuring that the robotic device does not cross the virtual boundary to enter the avoid area.

18. The robotic device of claim 17, wherein the programming instructions that cause the processor to define, using the one or more sensors and based on the mode, the virtual boundary relative to the at least one detectable boundary further comprise programming instructions to cause the processor to identify one or more rule sets corresponding to the mode, wherein the one or more rule sets include rules for defining at least one of the

following: a shape of the virtual boundary, a position of the virtual boundary relative to the robotic device, or a position of the virtual boundary relative to the at least one detectable boundary.

19. The robotic device of claim 18, wherein the one or more rules comprise a rule that the detectable boundary cannot be located in the avoid area if characteristics of sensor data collected from the environment are not reliable.

20. The robotic device of claim 17, wherein the programming instructions that cause the processor to identify, based on the mode, at least one detectable boundary in the environment for defining the virtual boundary further comprise programming instructions to cause the processor to:

identify one or more detectable boundaries in the environment; and

identify the at least one detectable boundary from the amongst the one or more detectable boundaries based on one or more rules corresponding to at least one of the following: position of the avoid area in the environment, position of the at least one detectable boundary, characteristics of sensor data collected from the avoid area, or shape of the at least on detectable boundary.

21. The robotic device of claim 17, wherein the programming instructions that cause the processor to identify the one or more detectable boundaries in the environment comprises further comprise programming instructions to cause the processor to identify the one or more detectable boundaries in the environment based on at least one of the following:

sensor data collected by the robotic device; or

map data corresponding to the environment.

22. The robotic device of claim 17, wherein the one or more rules comprise a rule that the detectable boundary cannot be located in the avoid area if characteristics of sensor data collected from the environment are not reliable.

23. The robotic device of claim 17, wherein the programming instructions that cause the processor to define the virtual boundary relative to the at least one detectable boundary further comprise programming instructions to cause the processor to cause the robotic device to traverse an initial path through the permissible area to determine a shape and a position of the virtual boundary relative to the robotic device or relative to the at least one detectable boundary.

24. The robotic device of claim 17, wherein the programming instructions that cause the processor to define the virtual boundary relative to the at least one detectable boundary further comprise programming instructions to cause the processor to define a linear virtual boundary at a location relative to the robotic device or relative to the at least one detectable boundary.

25. The robotic device of claim 24, wherein a shape of the virtual boundary is selected from the group comprising: replication of a shape of the at least one detectable boundary, mirror image of a shape of the at least one detectable boundary, and linear.

26. The robotic device of claim 17, wherein:

the programming instructions that cause the processor to identify the at least one detectable boundary in the environment for defining the virtual boundary further comprise programming instructions to cause the processor to identify the at least one detectable boundary to a left side of the robotic device; and

the programming instructions that cause the processor to define the virtual boundary relative to the at least one detectable boundary further comprise programming instructions to cause the processor to define the virtual boundary to a right side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment.

27. The robotic device of claim 26, wherein the predetermined distance is equal to a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

28. The robotic device of claim 17, wherein:

the programming instructions that cause the processor to identify the at least one detectable boundary in the environment for defining the virtual boundary further comprise programming instructions to cause the processor to identify the at least one detectable boundary to a left side of the robotic device; and

he programming instructions that cause the processor to define the virtual boundary relative to the at least one detectable boundary further comprise programming instructions to cause the processor to define the virtual boundary to the left side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment.

29. The robotic device of claim 28, wherein the predetermined distance is less than a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

30. The robotic device of claim 17, wherein:

the programming instructions that cause the processor to identify the at least one detectable boundary in the environment for defining the virtual boundary further comprise programming instructions to cause the processor to identify the at least one detectable boundary to a right side of the robotic device; and

the programming instructions that cause the processor to define the virtual boundary relative to the at least one detectable boundary further comprise programming instructions to cause the processor to define the virtual boundary to a left side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment.

31. The robotic device of claim 30, wherein the predetermined distance is equal to a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

32. The robotic device of claim 17, wherein:

the programming instructions that cause the processor to identify the at least one detectable boundary in the environment for defining the virtual boundary further comprise programming instructions to cause the processor to identify the at least one detectable boundary to a right side of the robotic device; and

he programming instructions that cause the processor to define the virtual boundary relative to the at least one detectable boundary further comprise programming instructions

to cause the processor to define the virtual boundary to the right side of the robotic device at a predetermined distance from an initial position of the robotic device in the environment.

33. The robotic device of claim 32, wherein the predetermined distance is less than a distance between the initial position of the robotic device in the environment and the at least one detectable boundary.

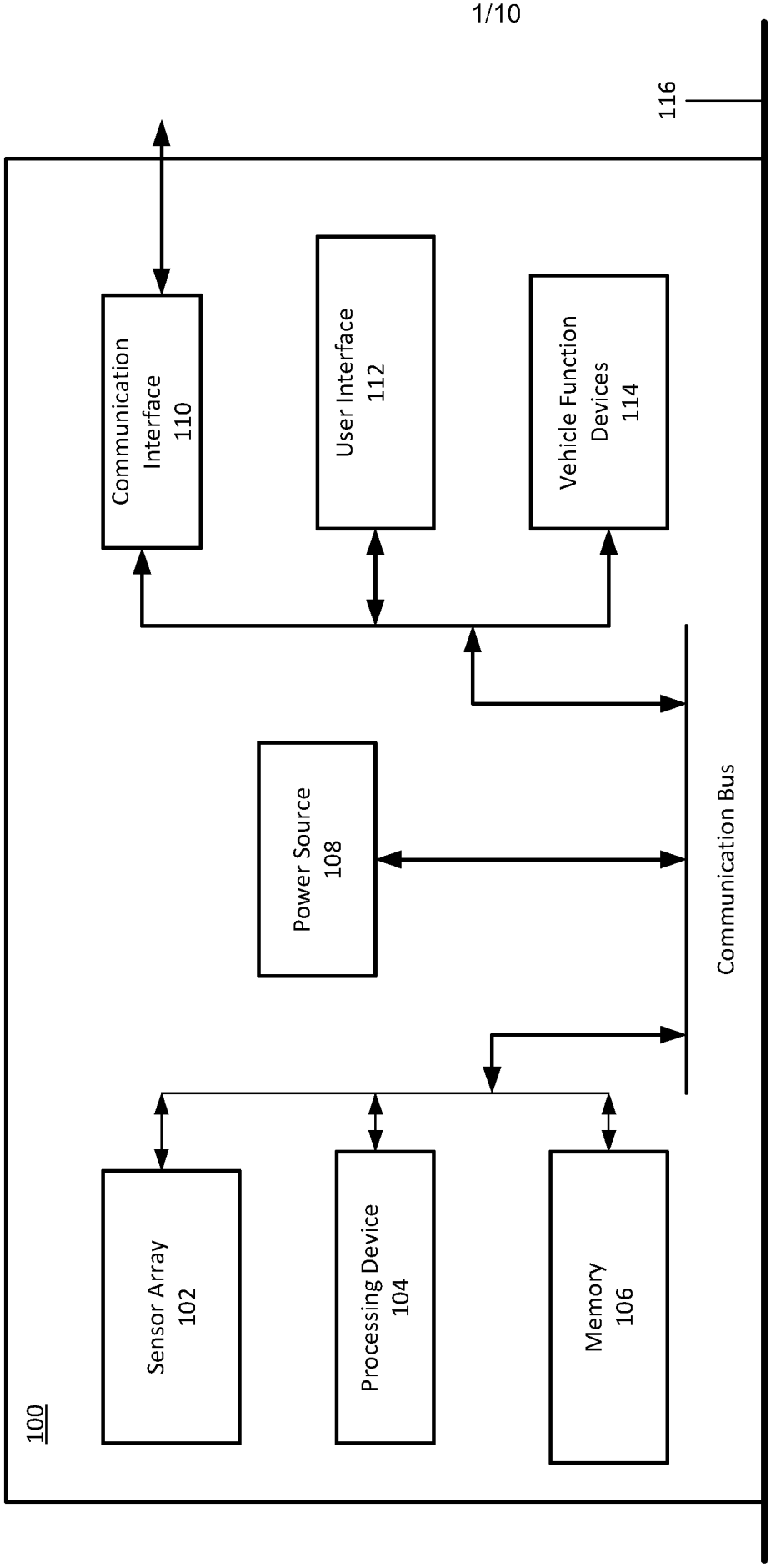

116
Communication Interface 110
User Interface 112
Vehicle Function Devices 114
Power Source 108
Communication Bus
Sensor Array 102
Processing Device 104
Memory 106
100

FIG. 1

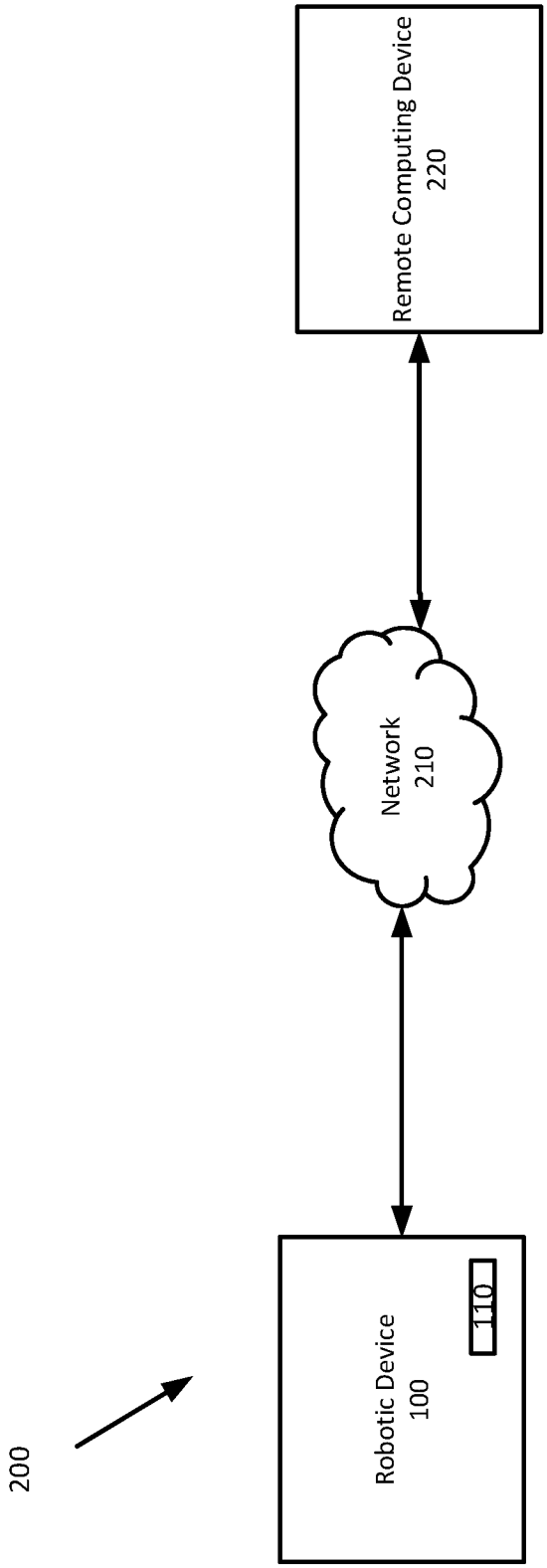

Remote Computing Device
220
Network
210
Robotic Device
100
110
200

FIG. 2

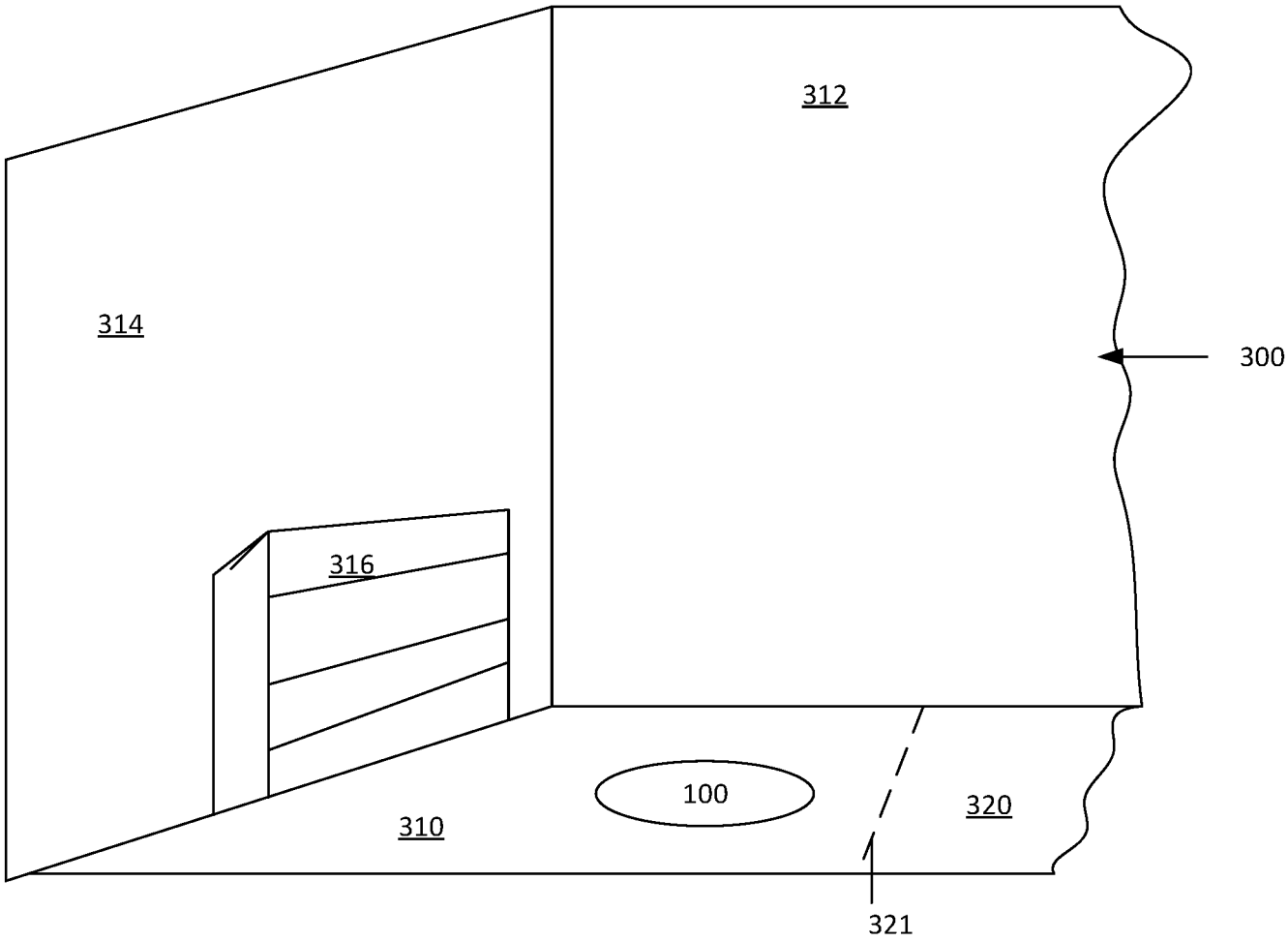


FIG. 3

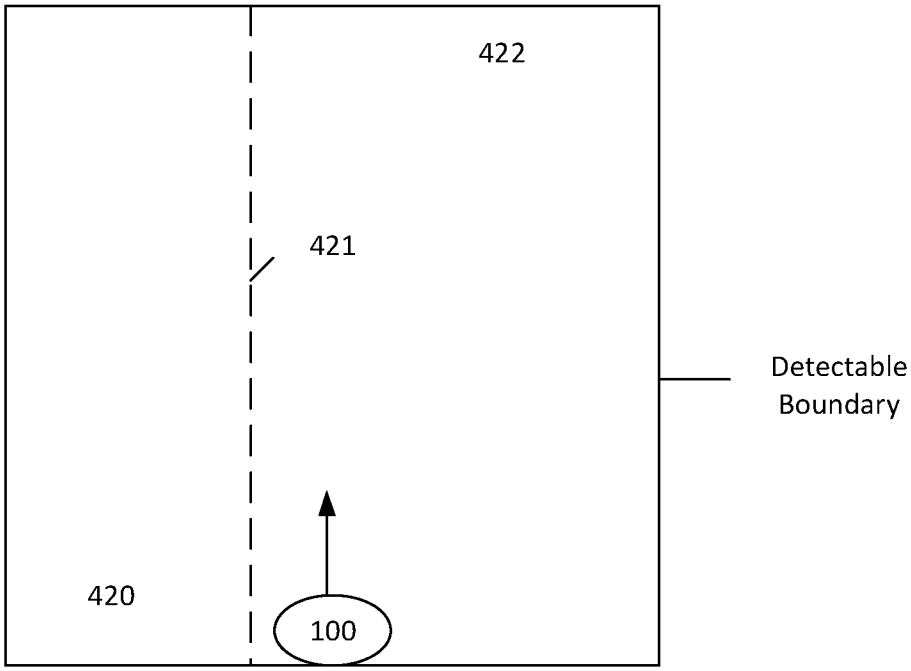

422
421
Detectable
Boundary
420
100

FIG. 4A

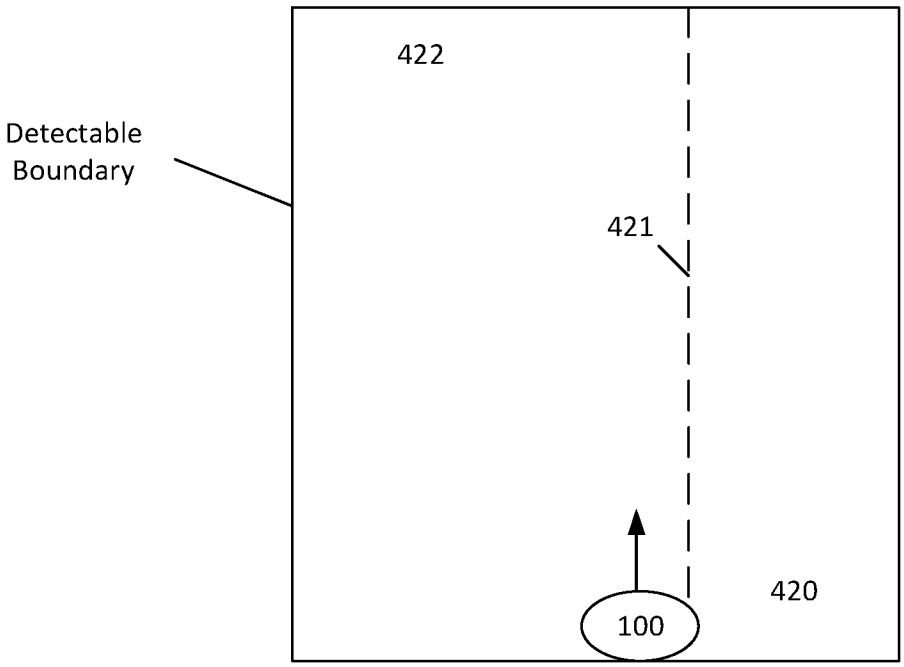

422
Detectable
Boundary
421
420
100

FIG. 4B

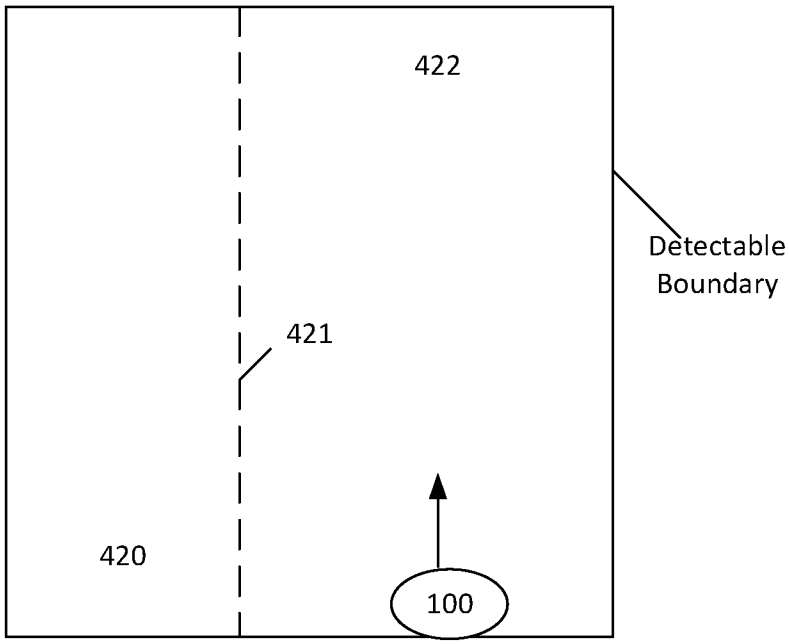

422
Detectable
Boundary
421
420
100

FIG. 4C

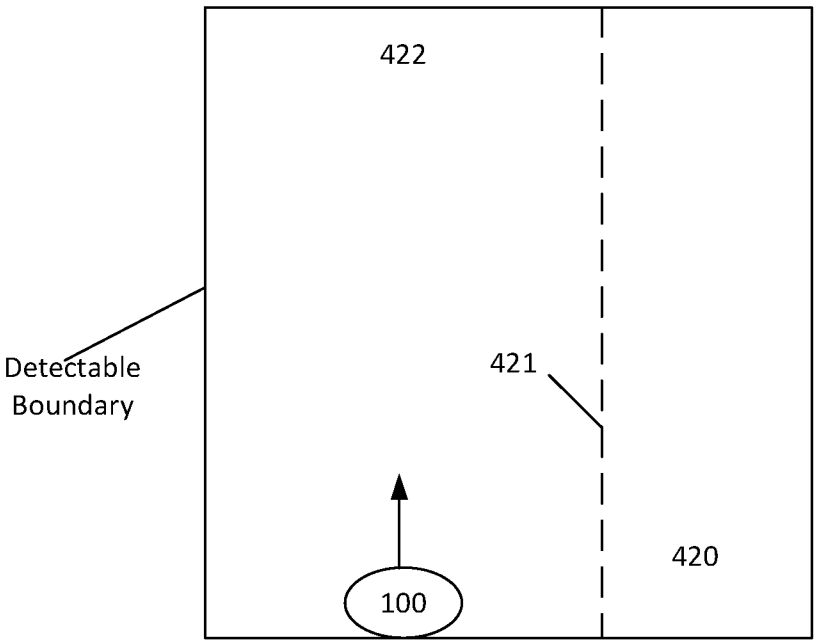

422
Detectable
Boundary
421
420
100

FIG. 4D

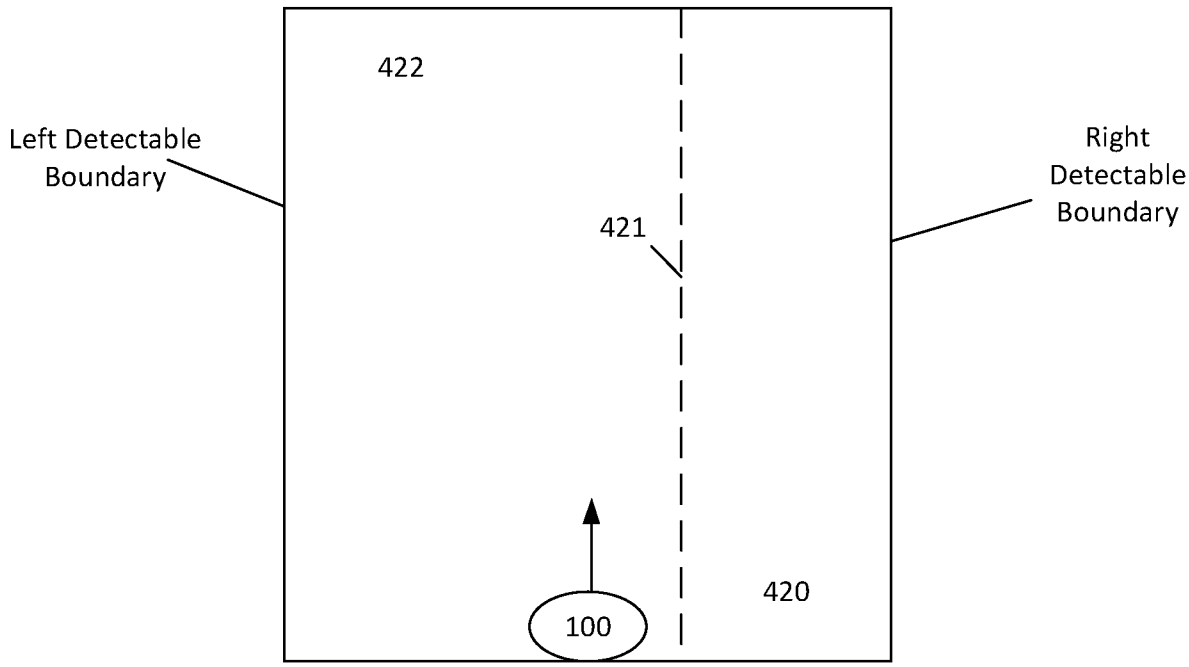

422
Left Detectable Boundary
Right Detectable Boundary
421
420
100

FIG. 4E

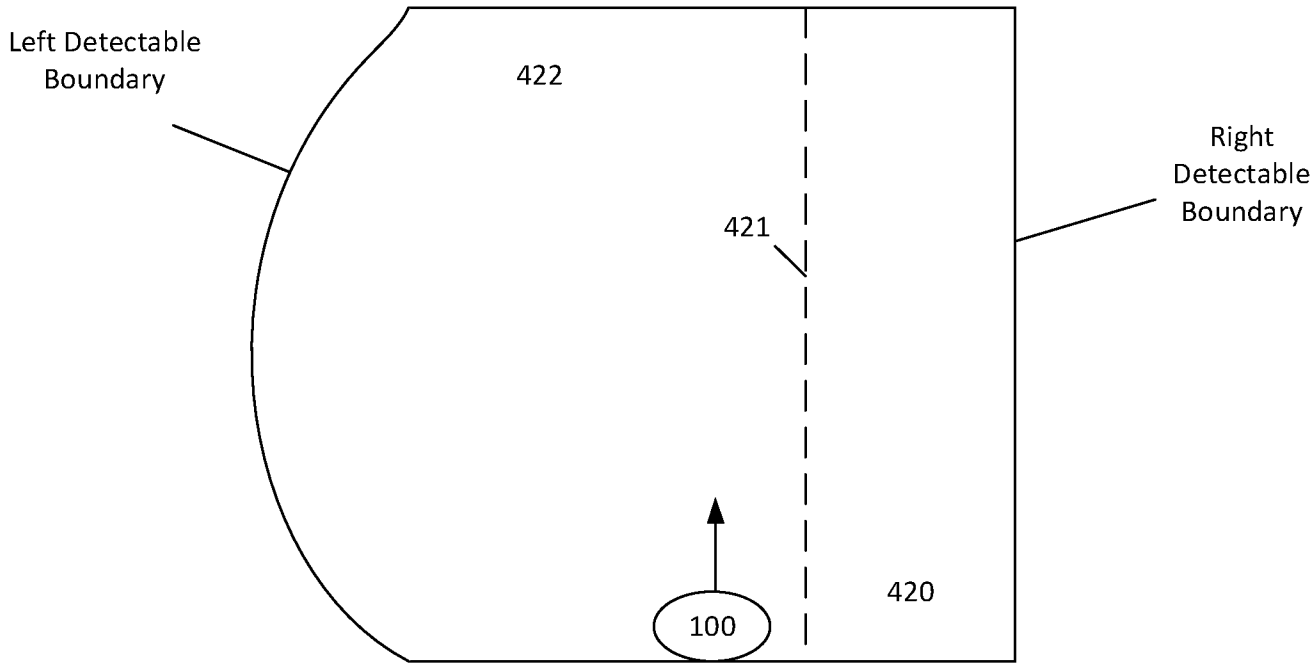

Left Detectable Boundary
422
Right Detectable Boundary
421
420
100

FIG. 4F

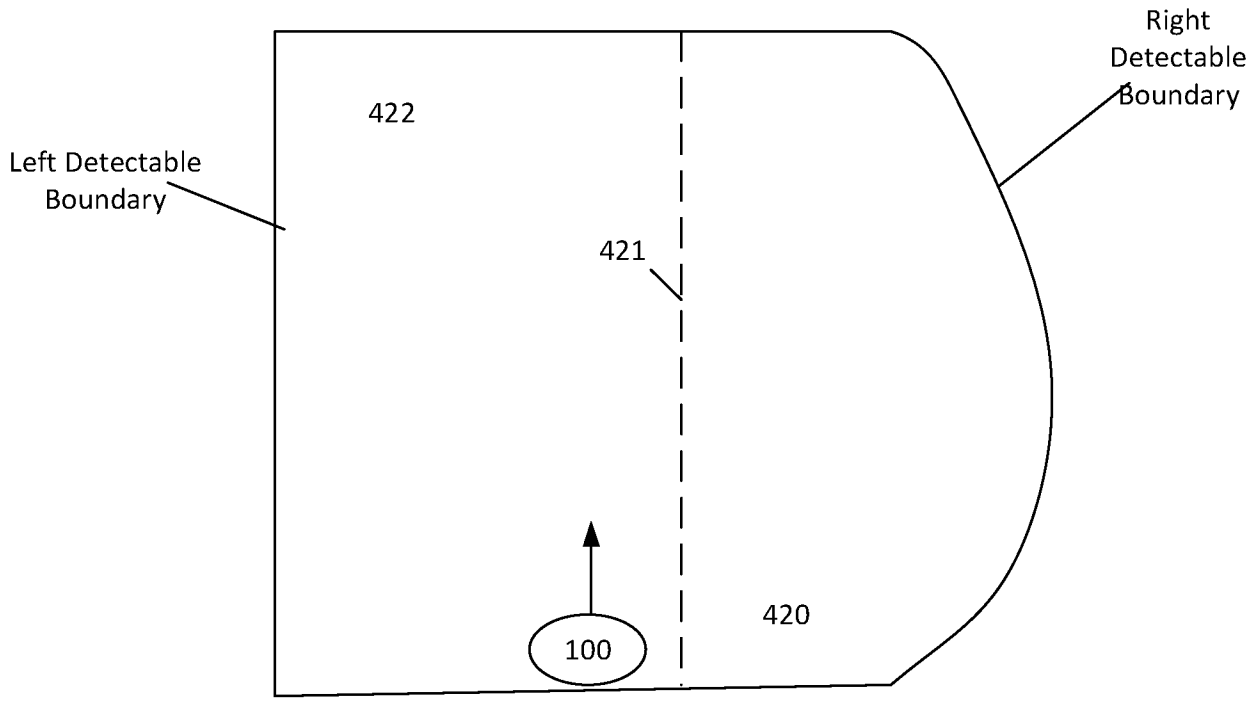

Right
Detectable
Boundary
422
Left Detectable
Boundary
421
420
100

FIG. 4G

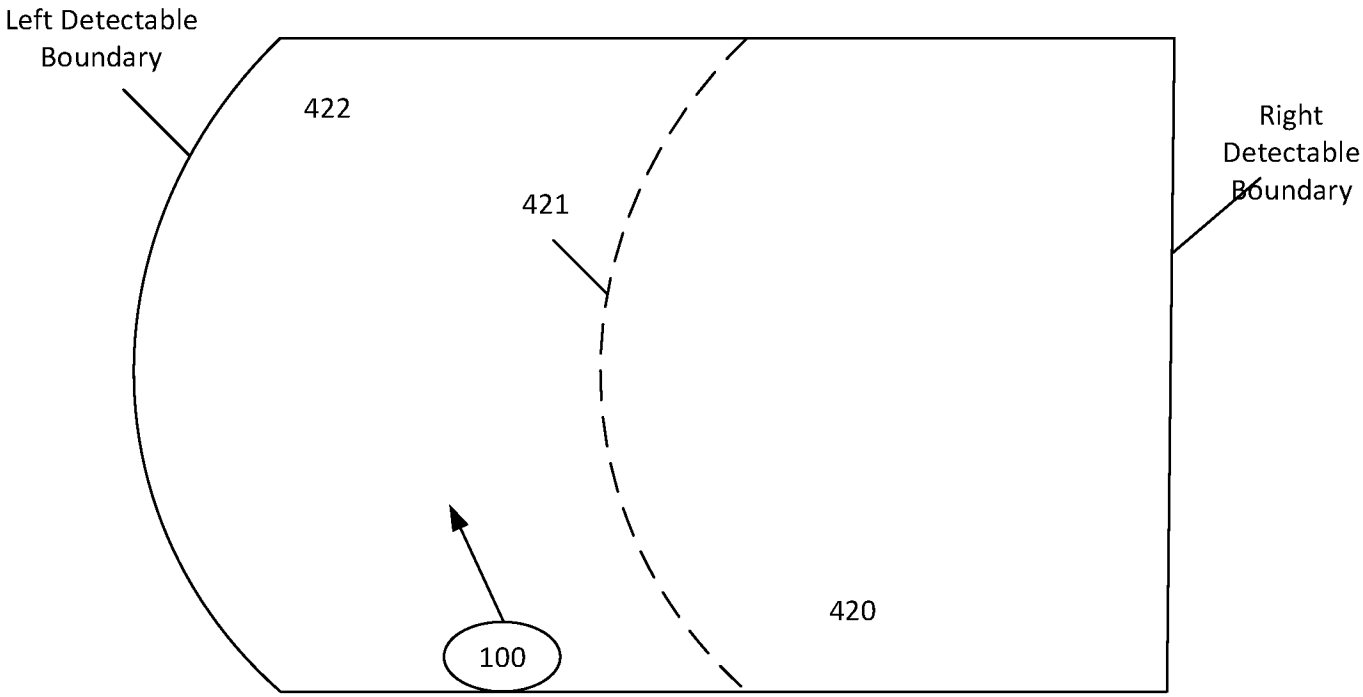

Left Detectable
Boundary
422
Right
Detectable
Boundary
421
420
100

FIG. 4H

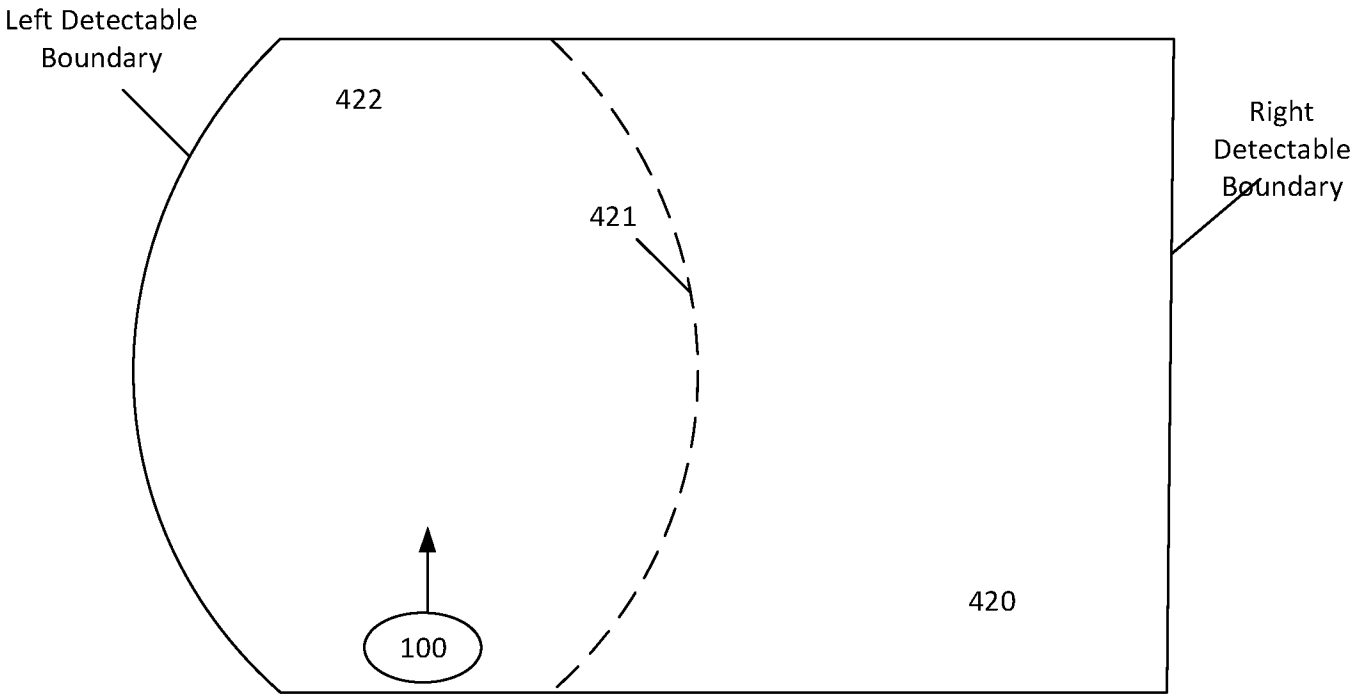

Left Detectable Boundary
422
421
Right Detectable Boundary
100
420

FIG. 4I

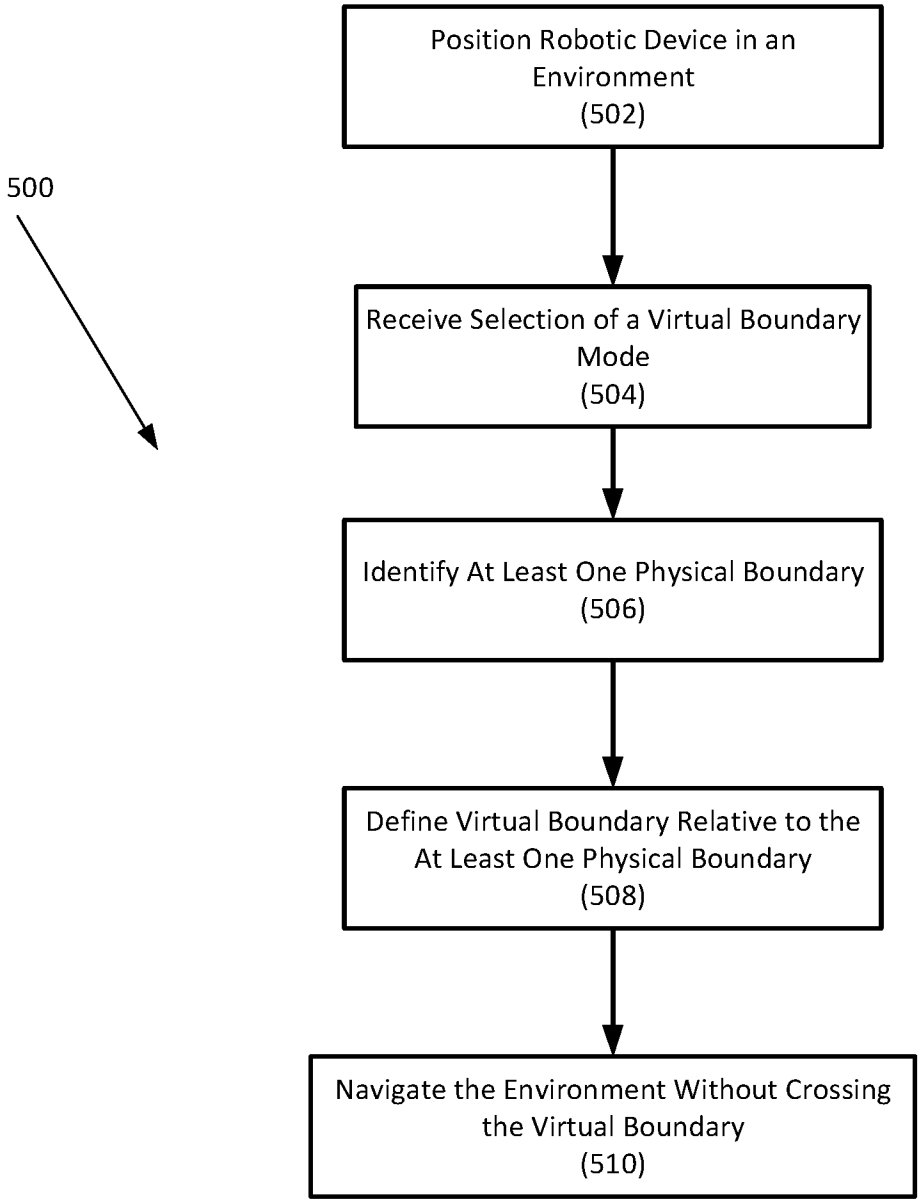

500
Position Robotic Device in an Environment (502)
Receive Selection of a Virtual Boundary Mode (504)
Identify At Least One Physical Boundary (506)
Define Virtual Boundary Relative to the At Least One Physical Boundary (508)
Navigate the Environment Without Crossing the Virtual Boundary (510)

FIG. 5

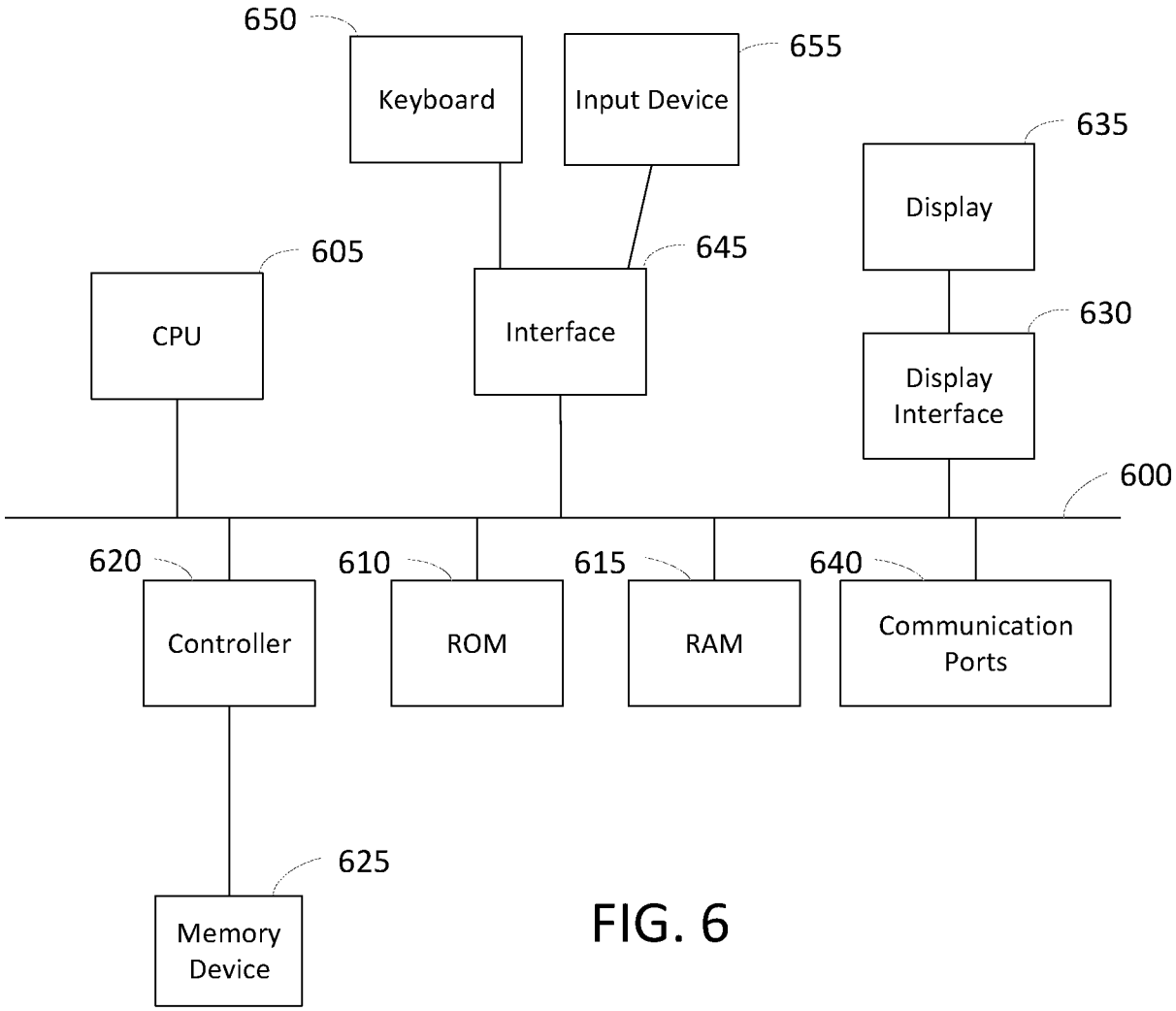

650
Keyboard
Input Device
655
635
Display
605
645
CPU
Interface
630
Display Interface
600
620
610
615
640
Controller
ROM
RAM
Communication Ports
625
Memory Device

FIG. 6