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Lisin et al.

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(54) **MAPPING STASIS FOR MOBILE CLEANING ROBOT**

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CPC ***G05D 1/246*** (2024.01); ***A47L 11/4011*** (2013.01); ***G05D 1/2437*** (2024.01);
(Continued)

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(Continued)

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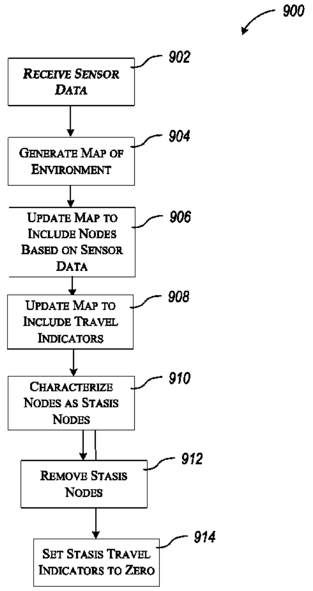
(57) **ABSTRACT**

A mobile cleaning robot configured to clean an environment. The mobile cleaning robot can include a body and a drivetrain operable to move the body within the environment. The robot can include a sensor connected to the body and configured to generate a sensor signal based on interactions between the mobile cleaning robot and the environment. The robot can include an image capture device connected to the body and configured to generate an image stream based on an optical field of view of the image capture device. The robot can include a controller connected to the body and configured to determine whether the mobile cleaning robot is in a stasis condition based on the image stream and the sensor signal. The controller can also update a map of the environment based on the stasis determination.

22 Claims, 13 Drawing Sheets


900
RECEIVE SENSOR DATA
902
GENERATE MAP OF ENVIRONMENT
904
UPDATE MAP TO INCLUDE NODES BASED ON SENSOR DATA
906
UPDATE MAP TO INCLUDE TRAVEL INDICATORS
908
CHARACTERIZE NODES AS STASIS NODES
910
REMOVE STASIS NODES
912
SET STASIS TRAVEL INDICATORS TO ZERO
914

(51) **Int. Cl.**

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G05D 1/648	(2024.01)
G05D 105/10	(2024.01)
G05D 107/40	(2024.01)

(52) **U.S. Cl.**
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(58) **Field of Classification Search**
CPC G05D 1/648; G05D 1/243; G05D 1/245; G05D 1/628; G05D 1/639; G05D 1/2464; G05D 2105/10; G05D 2107/40; G05D 2111/10; G05D 2111/54; G05D 2109/10; G06V 20/58
See application file for complete search history.

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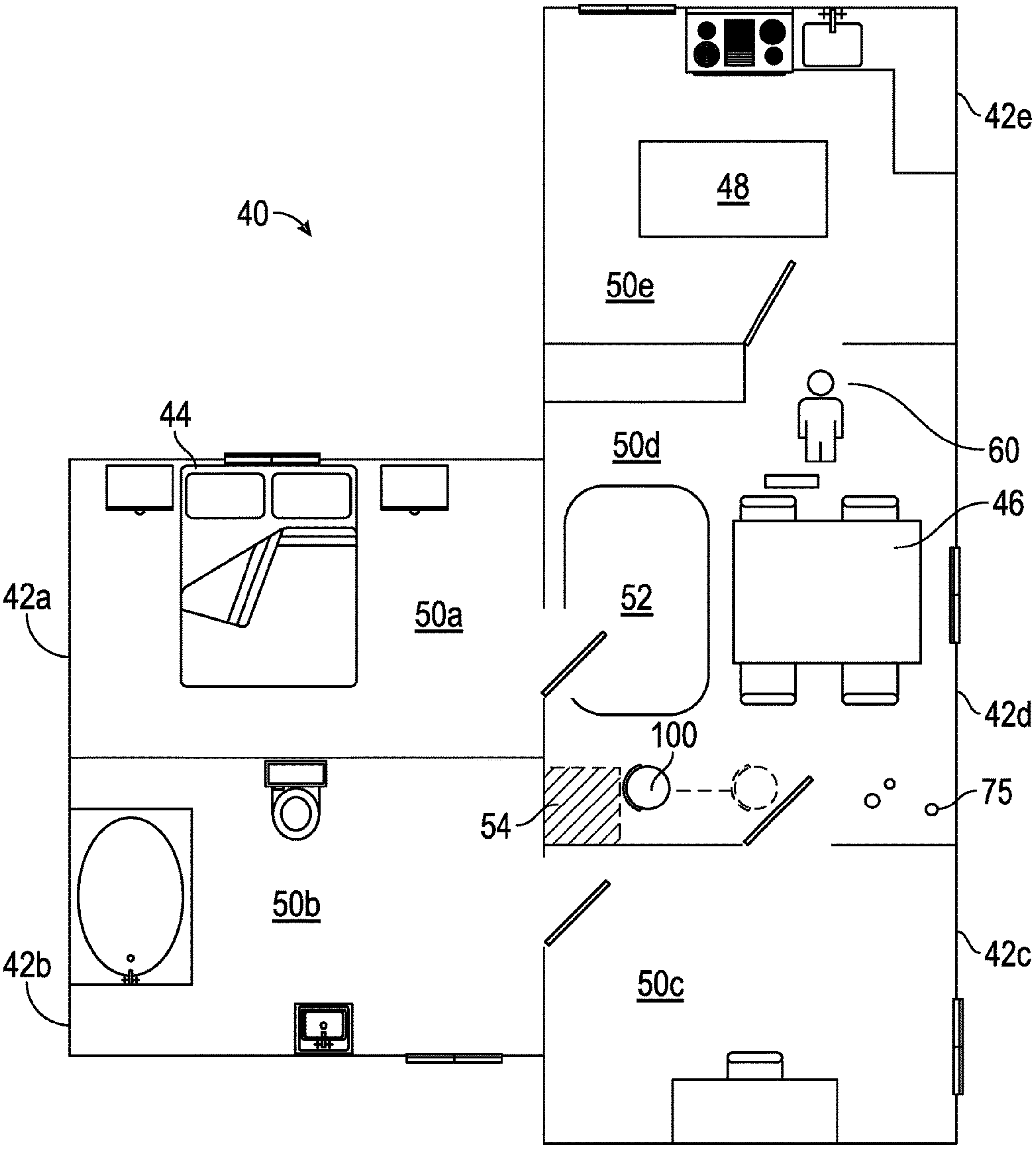

FIG. 1

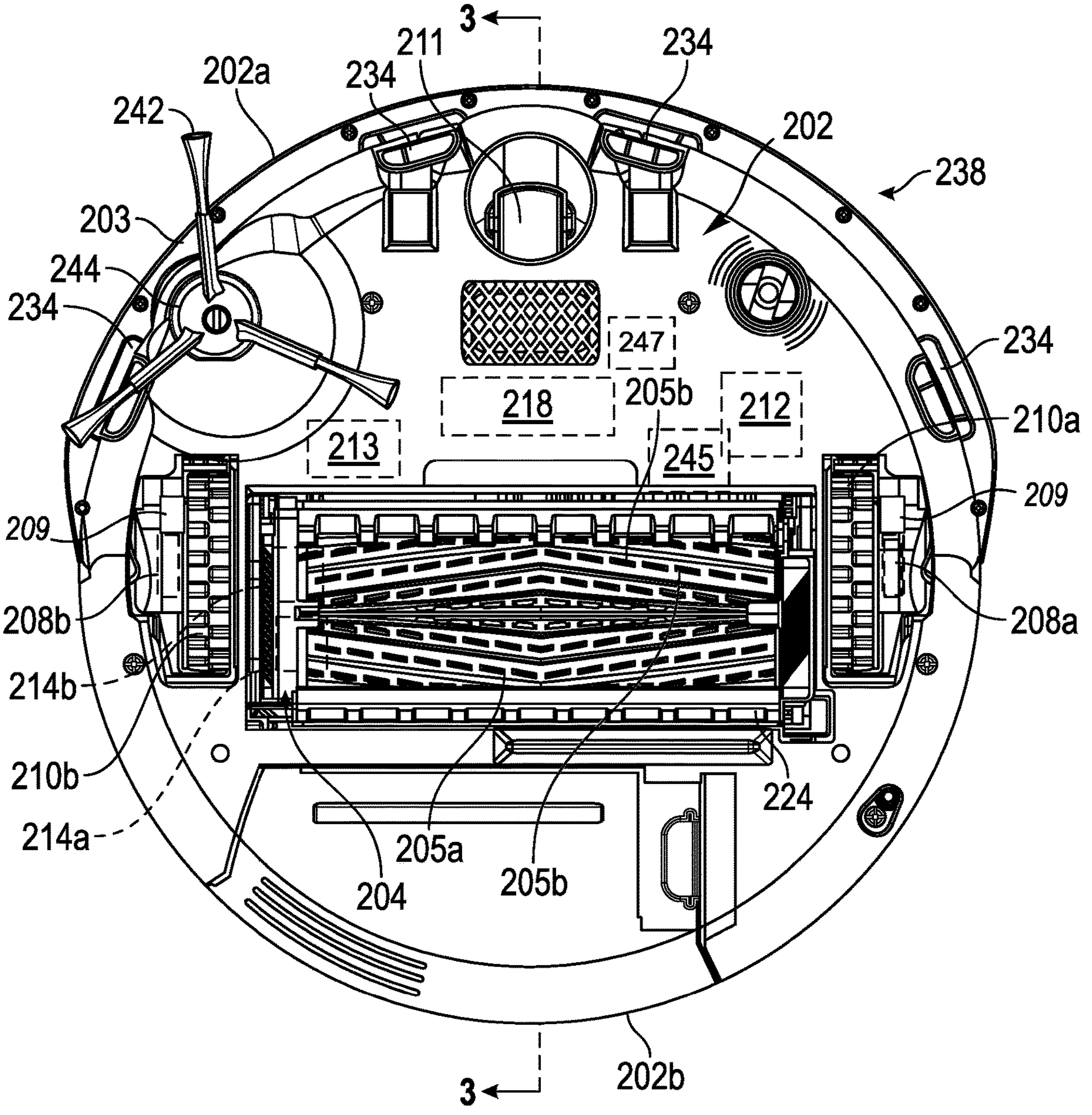
3
211
234
234
202a
242
202
238
203
244
234
247
234
218
205b
212
210a
213
245
209
209
208b
208a
214b
210b
224
214a
205a
204
205b
202b
3

FIG. 2A

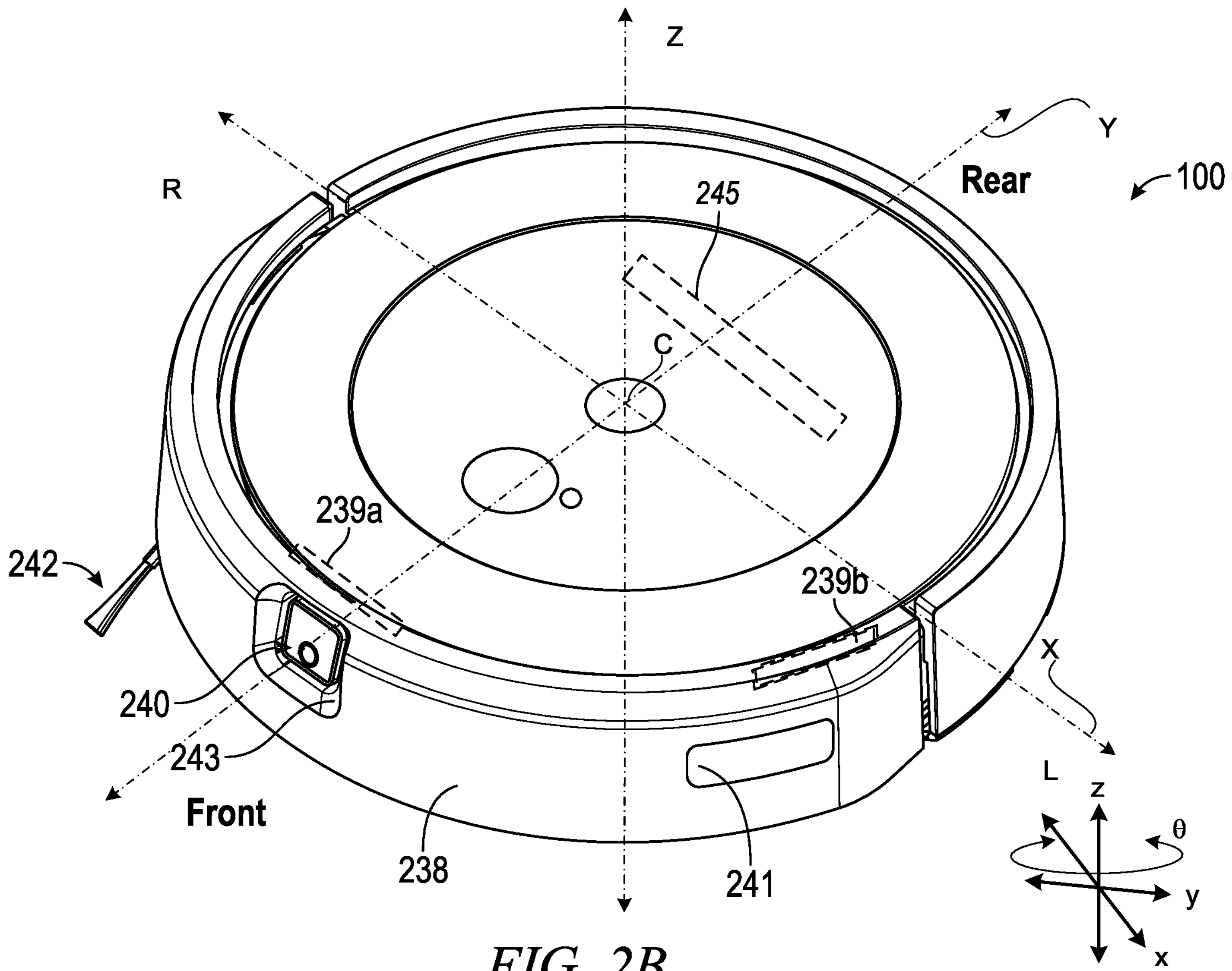

FIG. 2B

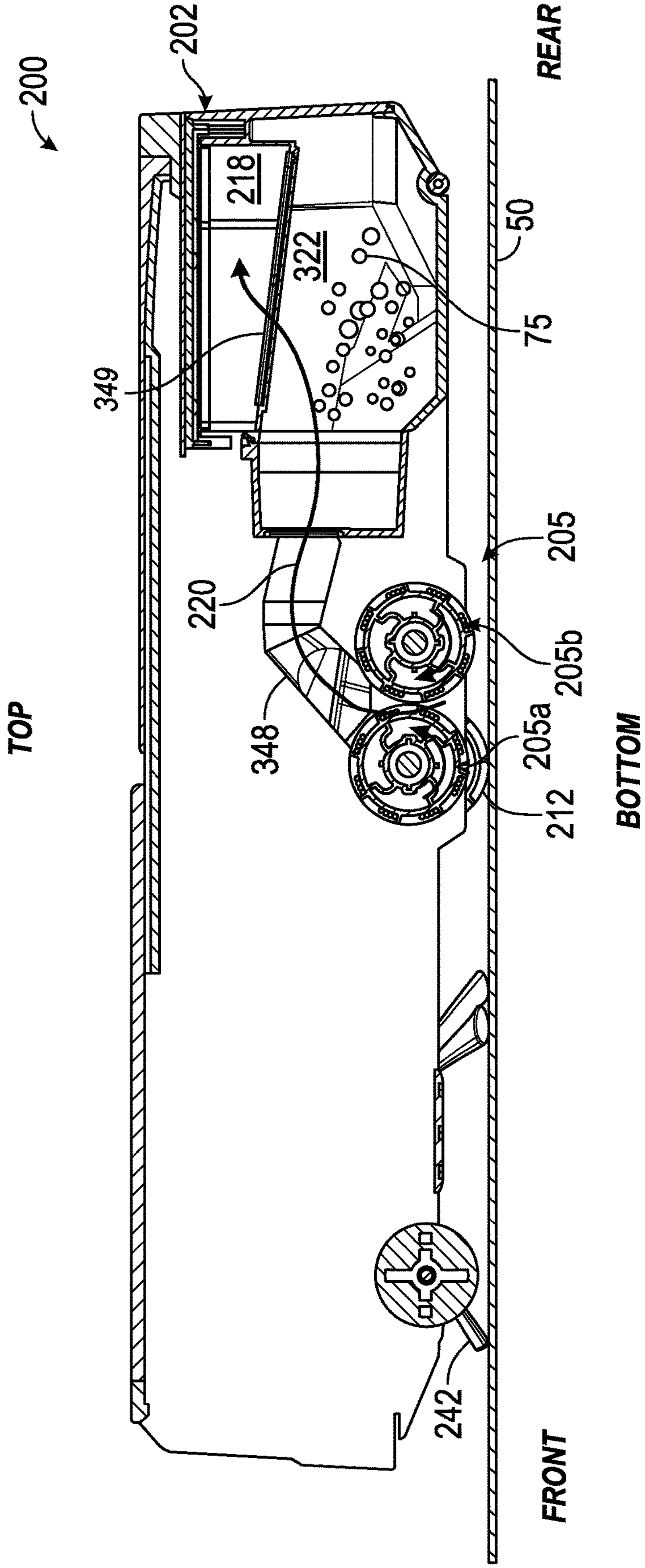
200
202
REAR
218
322
50
75
349
205
220
205b
348
205a
212
TOP
BOTTOM
242
FRONT

FIG. 3

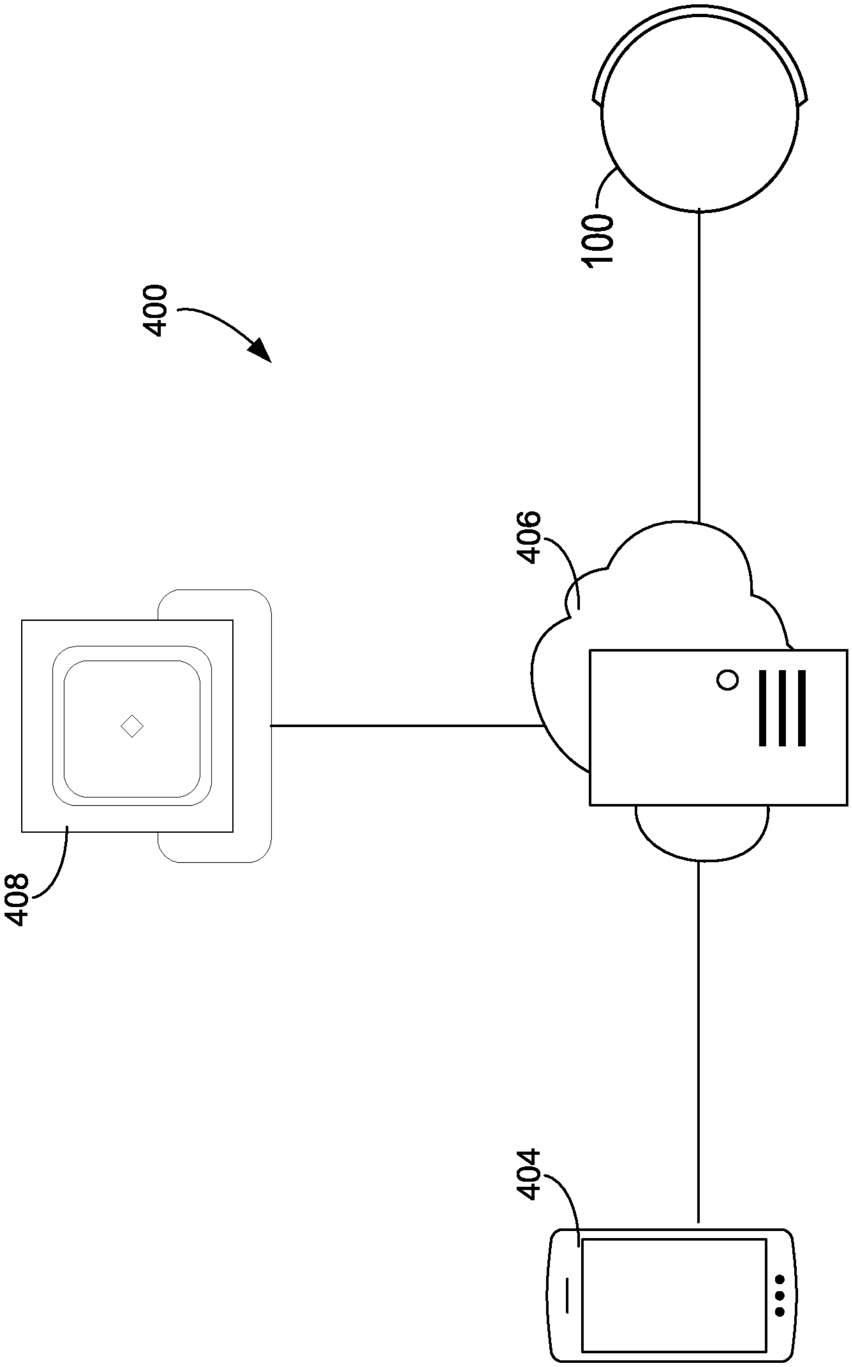

FIG. 4

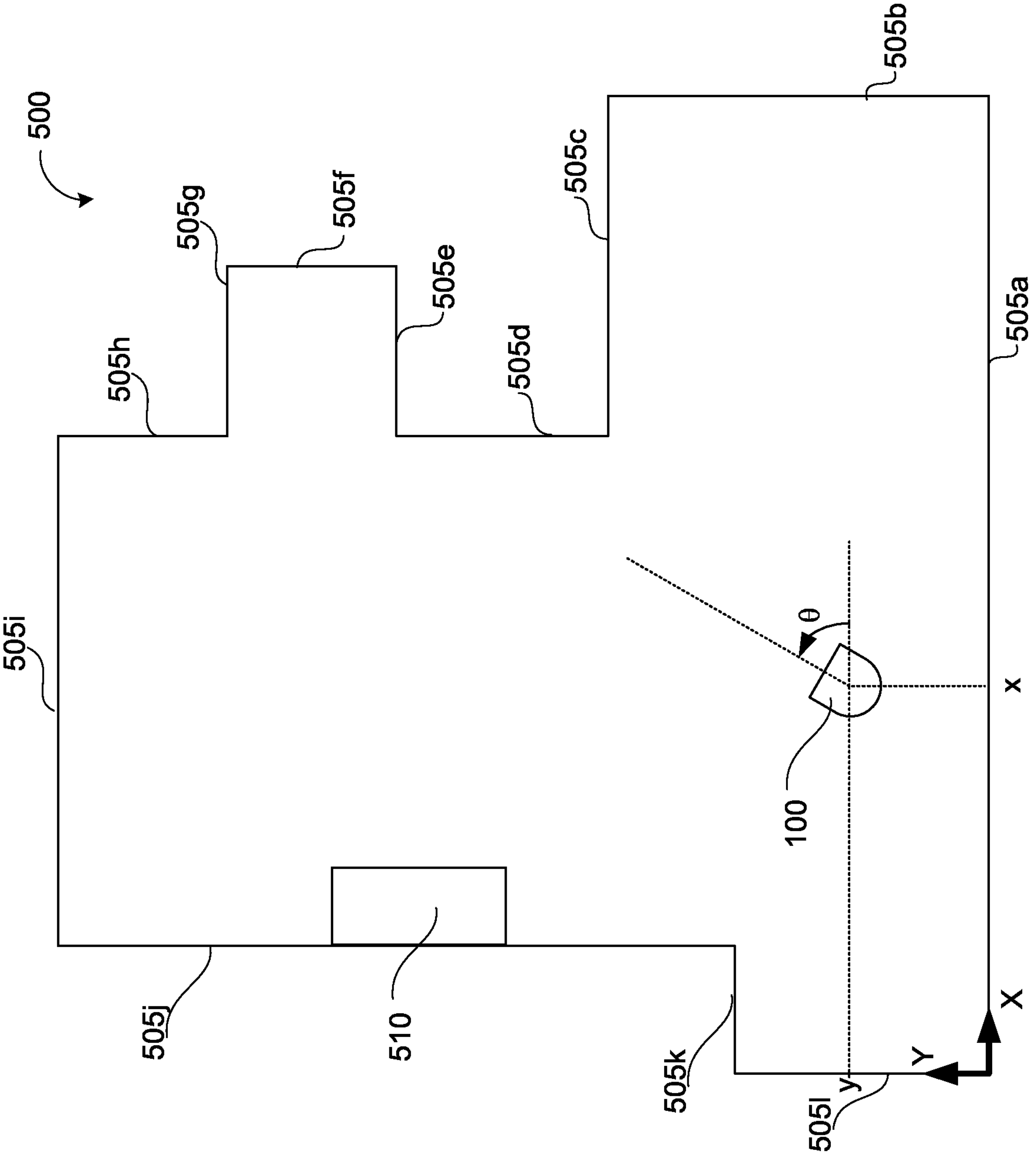
500
505a
505b
505c
505d
505e
505f
505g
505h
505i
505j
505k
505l
510
100
θ
x
y
X
Y

FIG. 5

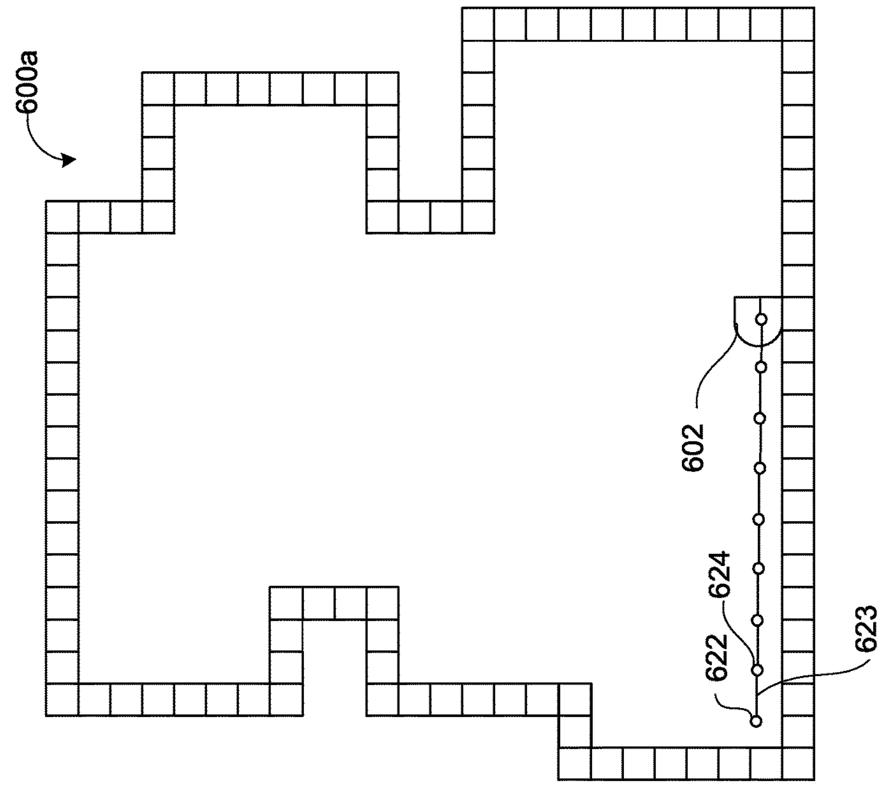
600a
602
624
622
623

FIG. 6B

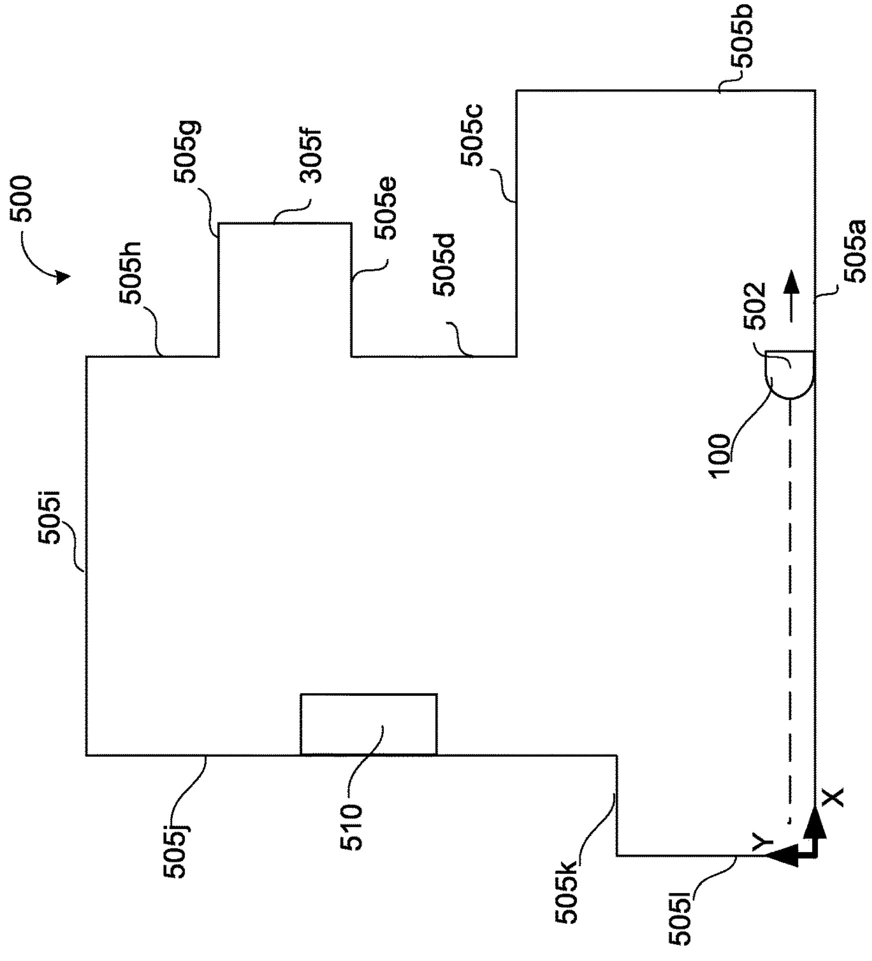
500
505b
505c
505g
305f
505e
505d
505h
505a
502
100
505i
510
505j
505k
505l
Y
X

FIG. 6A

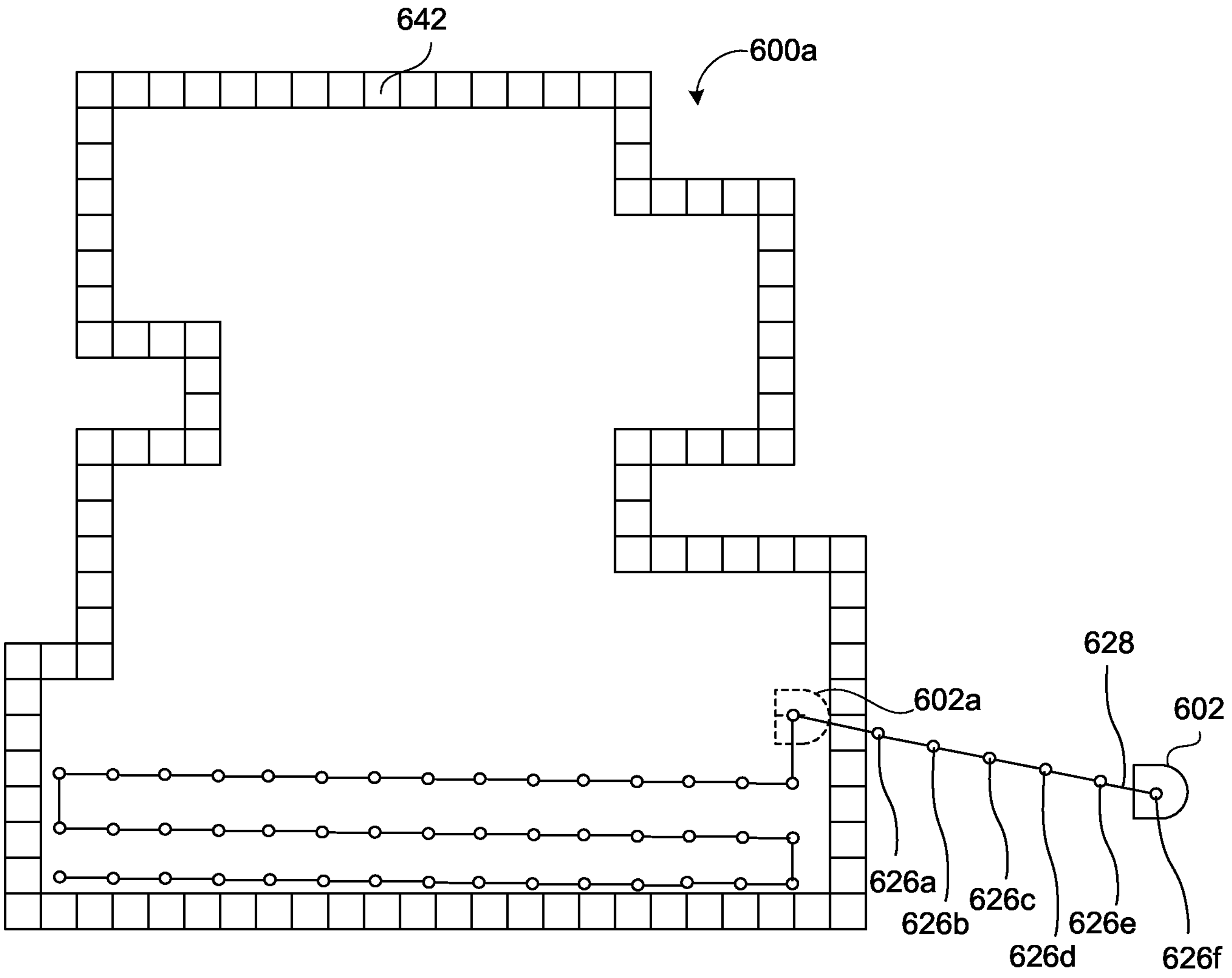

FIG. 7

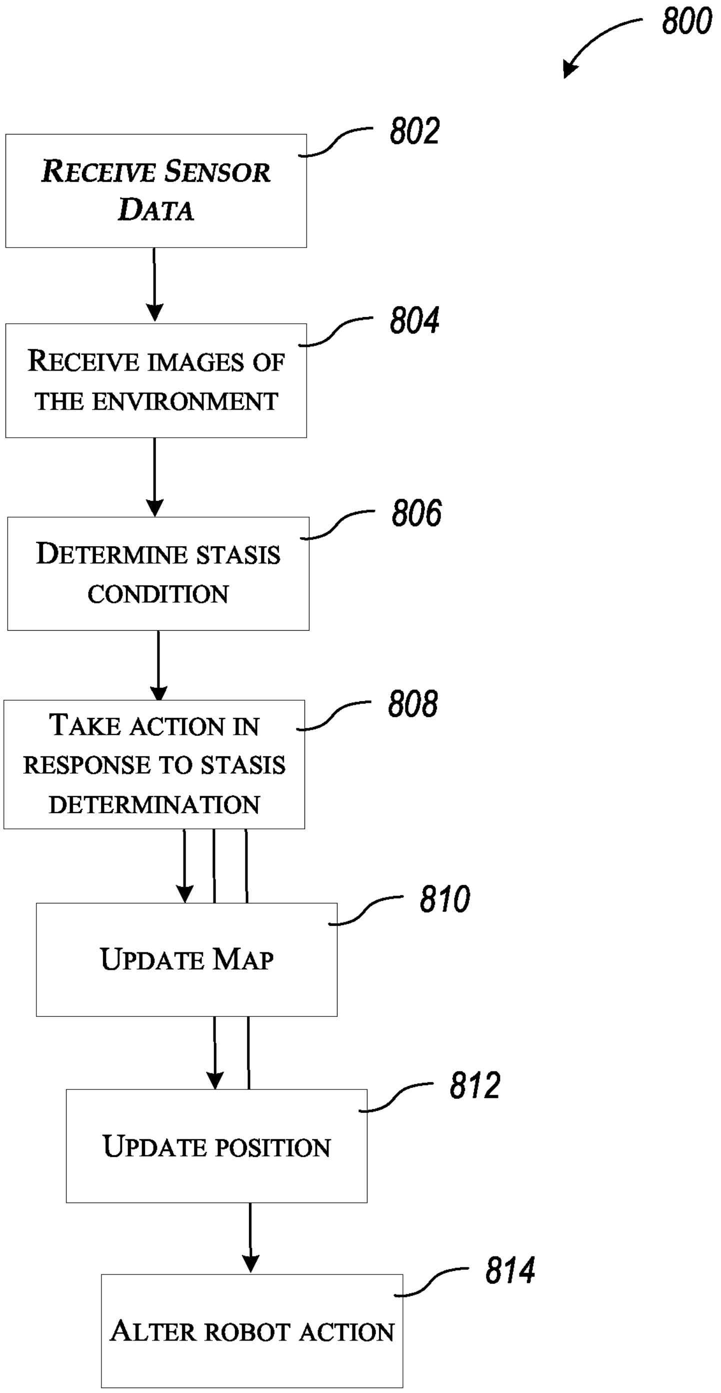
800
802
Receive Sensor Data
804
Receive images of the environment
806
Determine stasis condition
808
Take action in response to stasis determination
810
Update Map
812
Update position
814
Alter robot action

FIG. 8

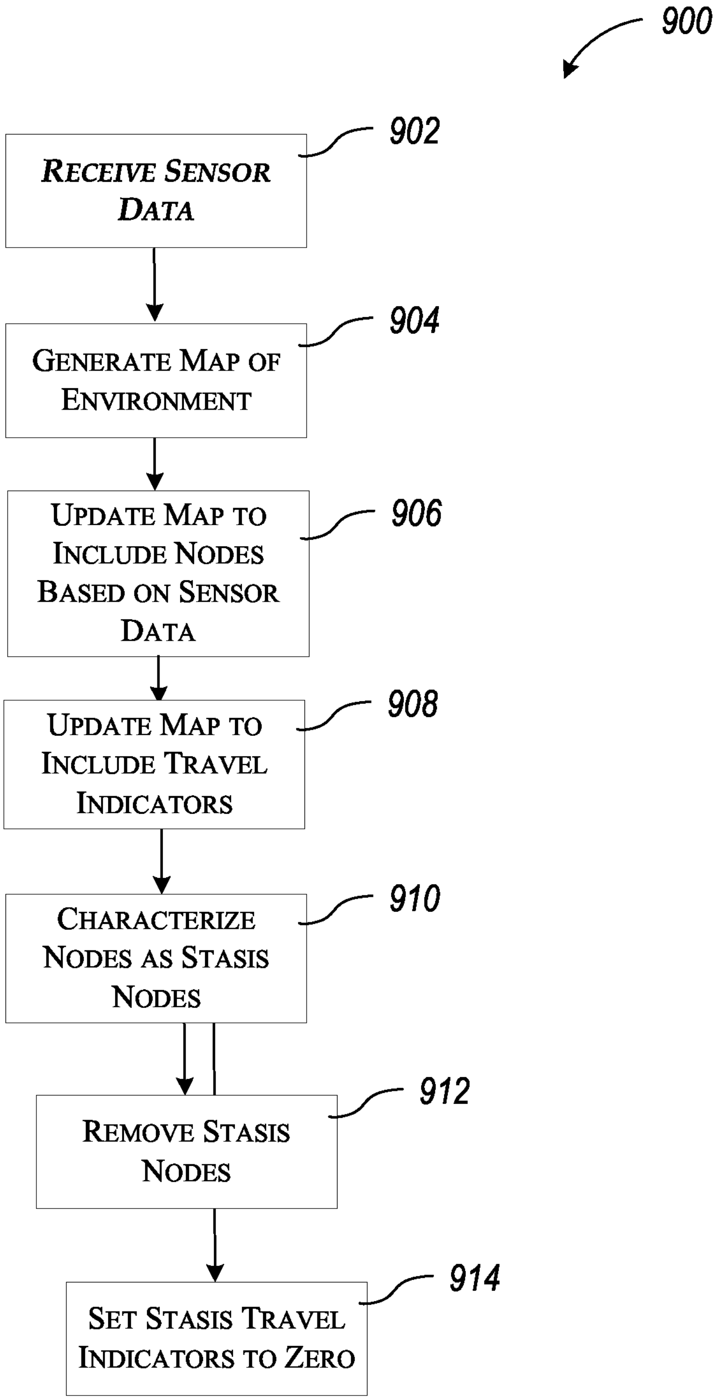
900
RECEIVE SENSOR DATA
902
GENERATE MAP OF ENVIRONMENT
904
UPDATE MAP TO INCLUDE NODES BASED ON SENSOR DATA
906
UPDATE MAP TO INCLUDE TRAVEL INDICATORS
908
CHARACTERIZE NODES AS STASIS NODES
910
REMOVE STASIS NODES
912
SET STASIS TRAVEL INDICATORS TO ZERO
914

FIG. 9

1000

I_1 vs I_2	I_2 vs I_3	I_3 vs I_4	...
I_1 vs I_3	I_2 vs I_4	I_3 vs I_5	...
I_1 vs I_4	I_2 vs I_5	I_3 vs I_6	...
...	...	...	...

FIG. 10

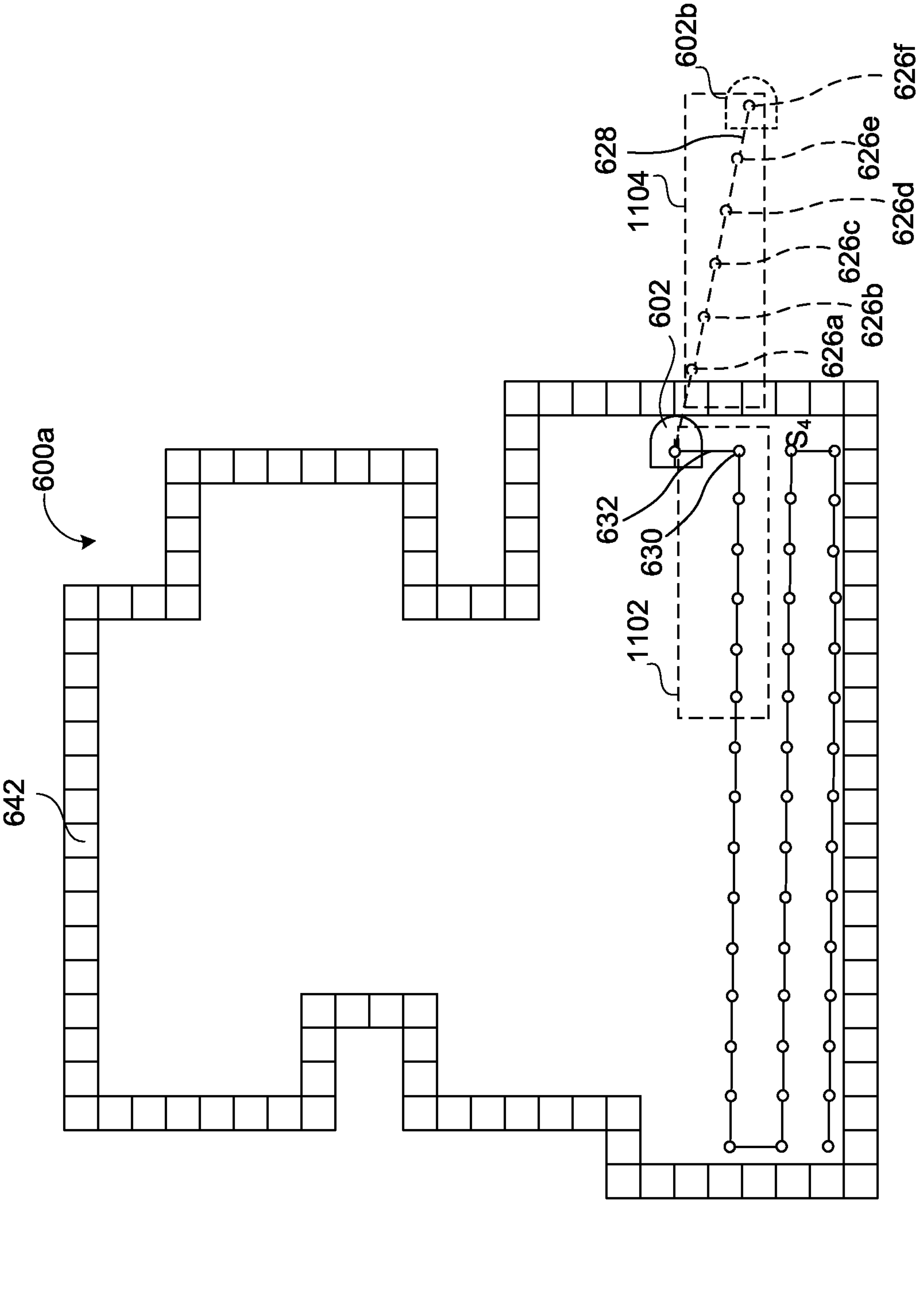
600a
642
602b
626f
628
626e
1104
626d
626c
602
626b
626a
S4
632
630
1102

FIG. 11

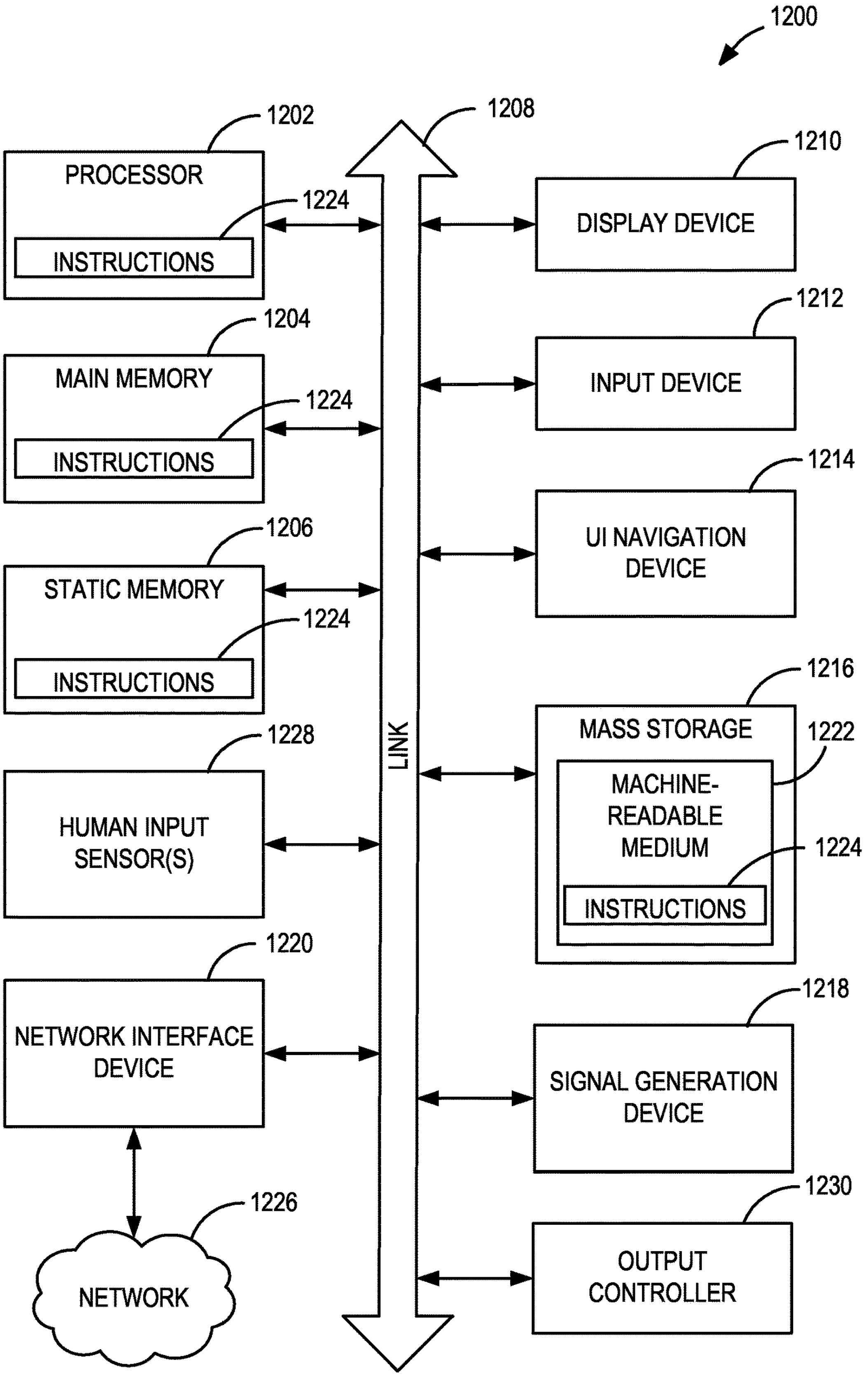
1200
1202
PROCESSOR
1224
INSTRUCTIONS
1204
MAIN MEMORY
1224
INSTRUCTIONS
1206
STATIC MEMORY
1224
INSTRUCTIONS
1228
HUMAN INPUT SENSOR(S)
1220
NETWORK INTERFACE DEVICE
1226
NETWORK
1208
LINK
1210
DISPLAY DEVICE
1212
INPUT DEVICE
1214
UI NAVIGATION DEVICE
1216
MASS STORAGE
1222
MACHINE-READABLE MEDIUM
1224
INSTRUCTIONS
1218
SIGNAL GENERATION DEVICE
1230
OUTPUT CONTROLLER

FIG. 12

MAPPING STASIS FOR MOBILE CLEANING ROBOT

BACKGROUND

Autonomous mobile cleaning robots can traverse floor surfaces to perform various operations in an environment, such as vacuuming of one or more rooms of the environment. A cleaning robot can include a controller configured to autonomously navigate the robot about an environment such that the robot can ingest debris as it moves. As an autonomous mobile robot traverses a floor surface, the robot can produce and record information about the environment and the robot, such as to generate a map of the environment for use in cleaning operations.

SUMMARY

Mobile cleaning robots can be used by users, such as homeowners, to perform ad hoc or scheduled cleaning missions. During missions, robots can autonomously navigate the environment and perform cleaning operations, such as vacuuming or mopping (or both). During navigation and cleaning, a robot can use its camera to detect objects within the environment, such as for odometry, avoidance, or scene understanding. This detection can help the robot to perform better cleaning operations, make and use a map of the environment, and avoid ingestion of non-debris items. Other sensors of the robot, including wheel encoders, optical sensors, or positioning sensors can also be used to develop and update the map. However, as the robot moves throughout the map it can become stuck. In some instances of being stuck or trapped, its wheels can still move leading the robot to incorrectly assume it is moving. During this period of stasis with moving wheels, the robot can record mapping data, such as locations, direction of travel, and distance traveled, which can be recorded on the map incorrectly due to the lack of actual movement of the robot.

This disclosure describes examples of devices, systems, and methods that can help to address this problem such as by using additional data collected by the robot to determine when the robot has entered stasis, such as by using one or more images (e.g., an image stream) of a camera of the robot. The images can be compared to make the stasis determination (such as using gradient comparison). When stasis is determined to be present, the map can be updated to remove some or all of the incorrectly mapped data, helping to increase the accuracy of the map over time.

For example, a mobile cleaning robot configured to clean an environment. The mobile cleaning robot can include a body and a drivetrain operable to move the body within the environment. The robot can include a sensor connected to the body and configured to generate a sensor signal based on interactions between the mobile cleaning robot and the environment. The robot can include an image capture device connected to the body and configured to generate an image stream based on an optical field of view of the image capture device. The robot can include a controller connected to the body and configured to determine whether the mobile cleaning robot is in a stasis condition based on the image stream and the sensor signal. The controller can also update a map of the environment based on the stasis determination.

The above discussion is intended to provide an overview of subject matter of the present patent application. It is not intended to provide an exclusive or exhaustive explanation of the invention. The description below is included to provide further information about the present patent application.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which are not necessarily drawn to scale, like numerals can describe similar components in different views. Like numerals having different letter suffixes can represent different instances of similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

FIG. **1** illustrates a plan view of a mobile cleaning robot in an environment.

FIG. **2**A illustrates a bottom view of a mobile cleaning robot.

FIG. **2**B illustrates an isometric view of a mobile cleaning robot.

FIG. **3** illustrates a cross-section view across indicators **3-3** of FIG. **2**A of a mobile cleaning robot.

FIG. **4** illustrates a diagram illustrating an example of a communication network in which a mobile cleaning robot operates and data transmission in the network.

FIG. **5** illustrates a plan view of a map of an environment.

FIG. **6**A illustrates a plan view of a map of an environment.

FIG. **6**B illustrates a plan view of a map of an environment.

FIG. **7** illustrates a plan view of a map of an environment.

FIG. **8** illustrates a schematic view of a process of developing or refining a map of an environment.

FIG. **9** illustrates a schematic view of a process of developing or refining a map of an environment.

FIG. **10** illustrates an example of a score array.

FIG. **11** illustrates a plan view of a map of an environment.

FIG. **12** illustrates a block diagram illustrating an example of a machine upon which one or more embodiments can be implemented.

DETAILED DESCRIPTION

FIG. **1** illustrates a plan view of a mobile cleaning robot **100** in an environment **40**, in accordance with at least one example of this disclosure. The environment **40** can be a dwelling, such as a home or an apartment, and can include rooms **42***a*-**42***e*. Obstacles, such as a bed **44**, a table **46**, and an island **48** can be located in one or more of the rooms **42** of the environment. Each of the rooms **42***a*-**42***e* can have a floor surface **50***a*-**50***e*, respectively. Some rooms, such as the room **42***d*, can include a rug, such as a rug **52**. The floor surfaces **50** can be of one or more types of flooring, such as hardwood, ceramic, low-pile carpet, medium-pile carpet, long (or high)-pile carpet, stone, or the like.

The mobile cleaning robot **100** can be operated, such as by a user **60**, to autonomously clean the environment **40** in a room-by-room fashion. In some examples, the robot **100** can clean the floor surface **50***a* of one room, such as the room **42***a*, before moving to the next room, such as the room **42***d*, to clean the surface of the room **42***d*. Different rooms can have different types of floor surfaces. For example, the room **42***e* (which can be a kitchen) can have a hard floor surface, such as wood or ceramic tile, and the room **42***a* (which can be a bedroom) can have a carpet surface, such as a medium pile carpet. Other rooms, such as the room **42***d* (which can be a dining room) can include multiple surfaces where the rug **52** is located within the room **42***d*.

During cleaning or traveling operations, the robot **100** can use data collected from various sensors and calculations (such as odometry and obstacle detection) to develop a map of the environment **40**. Once the map is created, the user **60** can define rooms or zones (such as the rooms **42**) within the map. The map can be presentable to the user **60** on a user interface, such as a mobile device, where the user **60** can direct or change cleaning preferences.

During operation, the robot **100** can detect surface types within each of the rooms **42**, which can be stored in the robot or another device. The robot **100** can update the map (or data related thereto) such as to include or account for surface types of the floor surfaces **50***a*-**50***e* of each of the respective rooms **42** of the environment. In some examples, the map can be updated to show the different surface types such as within each of the rooms **42**.

In some examples, the user **60** can define a behavior control zone **54** using, for example, the methods and systems described herein. In response to the user **60** defining the behavior control zone **54**, the robot **100** can move toward the behavior control zone **54** to confirm the selection. After confirmation, autonomous operation of the robot **100** can be initiated. In autonomous operation, the robot **100** can initiate a behavior in response to being in or near the behavior control zone **54**. For example, the user **60** can define an area of the environment **40** that is prone to becoming dirty to be the behavior control zone **54**. In response, the robot **100** can initiate a focused cleaning behavior in which the robot **100** performs a focused cleaning of a portion of the floor surface **50***d* in the behavior control zone **54**.

Components of the Robot

FIG. **2**A illustrates a bottom view of the mobile cleaning robot **100**. FIG. **2**B illustrates a top view of the mobile cleaning robot **100**. FIG. **3** illustrates a cross-section view across indicators **3-3** of FIG. **2**A of the mobile cleaning robot **100**. FIG. **3** also shows orientation indicators Front and Rear. FIGS. **2**A-**3** are discussed together below.

The cleaning robot **100** can be an autonomous cleaning robot that can autonomously traverse the floor surface **50** while ingesting the debris **75** from different parts of the floor surface **50**. As shown in FIGS. **2**A and **3**, the robot **100** can include a body **202** movable across the floor surface **50**. The body **202** can include multiple connected structures to which components of the cleaning robot **100** are mounted. The connected structures can include, for example, an outer housing to cover internal components of the cleaning robot **100**, a chassis or frame to which the drive wheels **210***a* and **210***b* and the cleaning rollers **205***a* and **205***b* (of a cleaning assembly **204**) are mounted, and a bumper **238**. The bumper **238** can be removably secured to the body **202** and can be movable relative to the body **202** while mounted thereto. In some examples, the bumper **238** can form part of the body **202**.

As shown in FIG. **2**A, the body **202** includes a front portion **202***a* that has a substantially semicircular shape and a rear portion **202***b* that has a substantially semicircular shape. These portions can have other shapes in other examples, such as a square front (or rounded square front). As shown in FIG. **2**A, the robot **100** can include a drive system including actuators **208***a* and **208***b*, which can be, for example, motors. The actuators **208***a* and **208***b* can be mounted in the body **202** and can be operably connected to the drive wheels **210***a* and **210***b*, which can be rotatably mounted to the body **202** to support the body **202** above the floor surface **50**. The actuators **208***a* and **208***b*, when driven, can rotate the drive wheels **210***a* and **210***b* to enable the robot **100** to autonomously move across the floor surface **50**. The robot **100** can also include encoders **209** that can be connected to the motors **208** and configured to generate a signal based on operation of the motors **208**, which can be used, e.g., by the controller **212** to determine a speed, direction of travel, or the like, of the robot **100**.

The controller (or processor) **212** can be located within the housing and can be a programmable controller, such as a single or multi-board computer, a direct digital controller (DDC), a programmable logic controller (PLC), or the like. In other examples the controller **212** can be any computing device, such as a handheld computer, for example, a smart phone, a tablet, a laptop, a desktop computer, or any other computing device including a processor, memory, and communication capabilities. The memory **213** can be one or more types of memory, such as volatile or non-volatile memory, read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. The memory **213** can be located within the body **202**, connected to the controller **212** and accessible by the controller **212**.

The controller **212** can operate the actuators **208***a* and **208***b* to autonomously navigate the robot **100** about the floor surface **50** during a cleaning operation. The actuators **208***a* and **208***b* can be operable to drive the robot **100** in a forward drive direction, in a backwards direction, or to turn the robot **100**. The robot **100** can include a caster wheel **211** that can support the body **202** above the floor surface **50**. The caster wheel **211** can support the front portion **202***a* of the body **202** above the floor surface **50**, and the drive wheels **210***a* and **210***b* can support the rear portion **202***b* of the body **202** above the floor surface **50**.

As shown in FIG. **3**, a vacuum assembly **218** can be located at least partially within the body **202** of the robot **100**, e.g., in the rear portion **202***b* of the body **202**. The controller **212** can operate the vacuum assembly **218** to generate an airflow that flows through the air gap near the cleaning rollers **205**, through the body **202**, and out of the body **202**. The vacuum assembly **218** can include, for example, an impeller that generates the airflow when rotated. The airflow and the cleaning rollers **205**, when rotated, can cooperate to ingest debris **75** into a suction duct **348** of the robot **100**. The suction duct **348** can extend down to or near a bottom portion of the body **202** and can be at least partially defined by the cleaning assembly **204**.

The suction duct **348** can be connected to the cleaning head **204** or cleaning assembly and can be connected to a cleaning bin **322**. The cleaning bin **322** can be mounted in the body **202** and can contain the debris **75** ingested by the robot **100**. A filter **349** can be located in the body **202**, which can help to separate the debris **75** from the airflow before the airflow **220** enters the vacuum assembly **218** and is exhausted out of the body **202**. In this regard, the debris **75** can be captured in both the cleaning bin **322** and the filter before the airflow **220** is exhausted from the body **202**.

The cleaning rollers **205***a* and **205***b* can be operably connected to one or more actuators **214***a* and **214***b*, e.g., motors, respectively. The cleaning head **204** and the cleaning rollers **205***a* and **205***b* can be positioned forward of the cleaning bin **322**. The cleaning rollers **205***a* and **205***b* can be mounted to a housing **224** of the cleaning head **204** and mounted, e.g., indirectly or directly, to the body **202** of the robot **100**. In particular, the cleaning rollers **205***a* and **205***b* can be mounted to an underside of the body **202** so that the cleaning rollers **205***a* and **205***b* engage debris **75** on the floor surface **50** during the cleaning operation when the underside faces the floor surface **50**.

The housing **224** of the cleaning head **204** can be mounted to the body **202** of the robot **100**. In this regard, the cleaning rollers **205***a* and **205***b* can also be mounted to the body **202** of the robot **100**, such as indirectly mounted to the body **202** through the housing **224**. Alternatively, or additionally, the cleaning head **204** can be a removable assembly of the robot **100** where the housing **224** (with the cleaning rollers **205***a* and **205***b* mounted therein) is removably mounted to the body **202** of the robot **100**.

A side brush **242** can be connected to an underside of the robot **100** and can be connected to a motor **244** operable to rotate the side brush **242** with respect to the body **202** of the robot **100**. The side brush **242** can be configured to engage debris to move the debris toward the cleaning assembly **205** or away from edges of the environment **40**. The motor **244** configured to drive the side brush **242** can be in communication with the controller **212**. The brush **242** can be a side brush laterally offset from a center of the robot **100** such that the brush **242** can extend beyond an outer perimeter of the body **202** of the robot **100**. Similarly, the brush **242** can also be forwardly offset of a center of the robot **100** such that the brush **242** also extends beyond the bumper **238** or an outer periphery of the body **202**.

The robot **100** can further include a sensor system with one or more electrical sensors. The sensor system can generate one or more signals indicative of a current location of the robot **100**, and can generate one or more signals indicative of locations of the robot **100** as the robot **100** travels along the floor surface **50**.

For example, cliff sensors **234** (shown in FIG. 2A) can be located along a bottom portion of the body **202**. The cliff sensors **234** can include an optical sensor that can be configured to detect a presence or absence of an object below the optical sensor, such as the floor surface **50**. The cliff sensors **234** can be connected to the controller **212**.

The bump sensors **239***a* and **239***b* (the bump sensors **239**) can be connected to the body **202** and can be engageable or configured to interact with the bumper **238**. The bump sensors **239** can include break beam sensors, Hall Effect sensors, capacitive sensors, switches, or other sensors that can detect contact between the robot **100** (e.g., the bumper **238**) and objects in the environment **40**. The bump sensors **239** can be in communication with the controller **212**.

An image capture device **240** can be connected to the body **202** and can extend at least partially through the bumper **238** of the robot **100**, such as through an opening **243** of the bumper **238**. The image capture device **240** can be a camera, such as a front-facing camera, configured to generate a signal based on imagery of the environment **40** of the robot **100**. The image capture device **240** can transmit the image capture signal to the controller **212** for use for navigation and cleaning routines.

Obstacle follow sensors **241** (shown in FIG. 2B) can include an optical sensor facing outward or downward from the bumper **238** that can be configured to detect the presence or the absence of an object adjacent to a side of the body **202**. The obstacle follow sensor **241** can emit an optical beam horizontally in a direction perpendicular (or nearly perpendicular) to the forward drive direction of the robot **100**. The optical emitter can emit an optical beam outward from the robot **100**, e.g., outward in a horizontal direction, and the optical detector detects a reflection of the optical beam that reflects off an object near the robot **100**. The robot **100**, e.g., using the controller **212**, can determine a time of flight of the optical beam and thereby determine a distance between the optical detector and the object, and hence a distance between the robot **100** and the object.

The robot **100** can also optionally include one or more dirt sensors **245** connected to the body **202** and in communication with the controller **212**. The dirt sensors **245** can be a microphone, piezoelectric sensor, optical sensor, or the like, and can be located in or near a flow path of debris, such as near an opening of the cleaning rollers **205** or in one or more ducts within the body **202**. This can allow the dirt sensor(s) **245** to detect how much dirt is being ingested by the vacuum assembly **218** (e.g., via the extractor **204**) at any time during a cleaning mission. Because the robot **100** can be aware of its location, the robot **100** can keep a log or record of which areas or rooms of the map are dirtier or where more dirt is collected. The robot **100** can also include a battery **247** operable to power one or more components (such as the motors) of the robot.

Operation of the Robot

In operation of some examples, the robot **100** can be propelled in a forward drive direction or a rearward drive direction. The robot **100** can also be propelled such that the robot **100** turns in place or turns while moving in the forward drive direction or the rearward drive direction. The robot **100** can move across a floor surface of a physical environment through various combinations of movements relative to three perpendicular axes defined by the body **102**: a transverse axis X, a fore-aft axis Y, and a central vertical axis Z. A forward drive direction along the fore-aft axis Y is designated Front, and an aft drive direction along the fore-aft axis Y is designated as Rear. The transverse axis X extends between a right side R and a left side L.

When the controller **212** causes the robot **100** to perform a mission, the controller **212** can operate the motors **208** to drive the drive wheels **210** and propel the robot **100** along the floor surface **50**. In addition, the controller **212** can operate the motors **214** to cause the rollers **205***a* and **205***b* to rotate, can operate the motor **244** to cause the brush **242** to rotate, or can operate the motor of the vacuum system **218** to generate airflow. The controller **212** can also execute software stored on the memory **213** to cause the robot **100** to perform various navigational and cleaning behaviors by operating the various motors or components of the robot **100**.

The various sensors of the robot **100** can be used to help the robot navigate and clean within the environment **40**. For example, the cliff sensors **234** can detect obstacles such as drop-offs and cliffs below portions of the robot **100** where the cliff sensors **234** are located. The cliff sensors **234** can transmit signals to the controller **212** so that the controller **212** can redirect the robot **100** based on signals from the cliff sensors **234**.

In some examples, the bump sensor **239***a* can be used to detect movement of the bumper **238** in one or more directions of the robot **100**. For example, the bump sensor **239***a* can be used to detect movement of the bumper **238** from front to rear or the bump sensors **239***b* can detect movement along one or more sides of the robot **100**. The bump sensors **239** can transmit signals to the controller **212** so that the controller **212** can redirect the robot **100** based on signals from the bump sensors **239**.

In some examples, the obstacle follow sensors **241** can detect detectable objects, including obstacles such as furniture, walls, persons, and other objects in the environment of the robot **100**. In some implementations, the sensors **241** can be located along a side surface of the body **202**, and the obstacle following sensor **241** can detect the presence or the absence an object adjacent to the side surface. The one or more obstacle following sensors **241** can also serve as obstacle detection sensors, similar to proximity sensors. The controller **212** can use the signals from the obstacle follow sensors **241** to follow along obstacles such as walls or cabinets.

The robot **100** can also include sensors for tracking a distance travelled by the robot **100**. For example, the sensor system can include encoders associated with the motors **208** for the drive wheels **210**, and the encoders can track a distance that the robot **100** has travelled. In some implementations, the sensor can include an optical sensor facing downward toward a floor surface. The optical sensor can be positioned to direct light through a bottom surface of the robot **100** toward the floor surface **50**. The optical sensor can detect reflections of the light and can detect a distance travelled by the robot **100** based on changes in floor features as the robot **100** travels along the floor surface **50**.

The image capture device **240** can be configured to generate a signal based on imagery of the environment **40** of the robot **100** as the robot **100** moves about the floor surface **50**. The image capture device **240** can transmit such a signal to the controller **212**. The image capture device **240** can capture images of wall surfaces of the environment so that features corresponding to objects on the wall surfaces can be used for localization.

The controller **212** can use data collected by the sensors of the sensor system to control navigational behaviors of the robot **100** during the mission. For example, the controller **212** can use the sensor data collected by obstacle detection sensors of the robot **100** (e.g., the cliff sensors **234**, the bump sensors **239**, and the image capture device **240**) to help the robot **100** avoid obstacles when moving within the environment of the robot **100** during a mission.

The sensor data can also be used by the controller **212** for simultaneous localization and mapping (SLAM) techniques in which the controller **212** extracts or interprets features of the environment represented by the sensor data and constructs a map of the floor surface **50** of the environment. The sensor data collected by the image capture device **240** can be used for techniques such as vision-based SLAM (VSLAM) in which the controller **212** can extract visual features corresponding to objects in the environment **40** and can construct the map using these visual features. As the controller **212** directs the robot **100** about the floor surface **50** during the mission, the controller **212** can use SLAM techniques to determine a location of the robot **100** within the map by detecting features represented in collected sensor data and comparing the features to previously stored features. The map formed from the sensor data can indicate locations of traversable and non-traversable space within the environment. For example, locations of obstacles can be indicated on the map as non-traversable space, and locations of open floor space can be indicated on the map as traversable space.

The sensor data collected by any of the sensors can be stored in the memory **213**. In addition, other data generated for the SLAM techniques, including mapping data forming the map, can be stored in the memory **213**. These data produced during the mission can include persistent data that are produced during the mission and that are usable during further missions. In addition to storing the software for causing the robot **100** to perform its behaviors, the memory **213** can store data resulting from processing of the sensor data for access by the controller **212**. For example, the map can be a map that is usable and updateable by the controller **212** of the robot **100** from one mission to another mission to navigate the robot **100** about the floor surface **50**.

The persistent data, including the persistent map, helps to enable the robot **100** to efficiently clean the floor surface **50**. For example, the map enables the controller **212** to direct the robot **100** toward open floor space and to avoid non-traversable space. In addition, for subsequent missions, the controller **212** can use the map to optimize paths taken during the missions to help plan navigation of the robot **100** through the environment **40**.

Mapping Examples

FIG. **4** is a diagram illustrating an example of a communication network **400** that can enable networking between the mobile robot **100** and one or more other devices, such as a mobile device **404**, a cloud computing system **406**, or another autonomous robot **408** separate from the mobile robot **100**. Using the communication network **400**, the robot **100**, the mobile device **404**, the robot **408**, and the cloud computing system **406** can communicate with one another to transmit and receive data from one another. In some examples, the robot **100**, the robot **408**, or both the robot **100** and the robot **408** communicate with the mobile device **404** through the cloud computing system **406**. Alternatively, or additionally, the robot **100**, the robot **408**, or both the robot **100** and the robot **408** communicate directly with the mobile device **404**. Various types and combinations of wireless networks (e.g., Bluetooth, radio frequency, optical based, etc.) and network architectures (e.g., mesh networks) can be employed by the communication network **400**.

In some examples, the mobile device **404** can be a remote device that can be linked to the cloud computing system **406** and can enable a user to provide inputs. The mobile device **404** can include user input elements such as, for example, one or more of a touchscreen display, buttons, a microphone, a mouse, a keyboard, or other devices that respond to inputs provided by the user. The mobile device **404** can also include immersive media (e.g., virtual reality) with which the user can interact to provide input. The mobile device **404**, in these examples, can be a virtual reality headset or a head-mounted display.

The user can provide inputs corresponding to commands for the mobile robot **100**. In such cases, the mobile device **404** can transmit a signal to the cloud computing system **406** to cause the cloud computing system **406** to transmit a command signal to the mobile robot **100**. In some implementations, the mobile device **404** can present augmented reality images. In some implementations, the mobile device **404** can be a smart phone, a laptop computer, a tablet computing device, or other mobile device.

According to some examples discussed herein, the mobile device **404** can include a user interface configured to display a map of the robot environment. A robot path, such as that identified by a coverage planner, can also be displayed on the map. The interface can receive a user instruction to modify the environment map, such as by adding, removing, or otherwise modifying a keep-out zone in the environment; adding, removing, or otherwise modifying a focused cleaning zone in the environment (such as an area that requires repeated cleaning); restricting a robot traversal direction or traversal pattern in a portion of the environment; or adding or changing a cleaning rank, among others.

In some examples, the communication network **400** can include additional nodes. For example, nodes of the communication network **400** can include additional robots. Also, nodes of the communication network **400** can include network-connected devices that can generate information about the environment **40**. Such a network-connected device can include one or more sensors, such as an acoustic sensor, an image capture system, or other sensor generating signals, to detect characteristics of the environment **40** from which features can be extracted. Network-connected devices can also include home cameras, smart sensors, or the like.

In the communication network **400**, the wireless links can utilize various communication schemes, protocols, etc., such as, for example, Bluetooth classes, Wi-Fi, Bluetooth-low-energy, also known as BLE, 802.15.4, Worldwide Interoperability for Microwave Access (WiMAX), an infrared channel, satellite band, or the like. In some examples, wireless links can include any cellular network standards used to communicate among mobile devices, including, but not limited to, standards that qualify as 1G, 2G, 3G, 4G, 5G, or the like. The network standards, if utilized, qualify as, for example, one or more generations of mobile telecommunication standards by fulfilling a specification or standards such as the specifications maintained by International Telecommunication Union. For example, the 4G standards can correspond to the International Mobile Telecommunications Advanced (IMT-Advanced) specification. Examples of cellular network standards include AMPS, GSM, GPRS, UMTS, LTE, LTE Advanced, Mobile WiMAX, and WiMAX-Advanced. Cellular network standards can use various channel access methods, e.g., FDMA, TDMA, CDMA, or SDMA.

Operations of the method **800** and other processes described herein, such one or more steps discussed below, can be executed in a distributed manner. For example, the cloud computing system **406**, the mobile robot **100**, and the mobile device **404** can execute one or more of the operations in concert with one another. Operations described as executed by one of the cloud computing system **406**, the mobile robot **100**, and the mobile device **404** are, in some implementations, executed at least in part by two or all of the cloud computing system **406**, the mobile robot **100**, and the mobile device **404**.

FIG. **5** illustrates a plan view of a map of an environment. FIG. **5** shows the robot **100** navigating through a room **500** with walls **505***a***-505***l* and a bookshelf **510**. A global coordinate system is defined by an X-axis and a Y-axis. The walls **505***a*, **505***c*, **505***e*, **505***g*, **505***i*, and **505***k* can be parallel to the X-axis, and the walls **505***b*, **505***d*, **505***f*, **505***h*, **505***j*, and **505***l* can be parallel to the Y-axis. The bookshelf **510** can be located against or near the wall **505***j*. The robot **100** can estimate its pose within the global coordinate system using the controller **212** as discussed with respect to FIG. 2A. The estimated pose can include a location of the robot within the room **500** and an orientation of the robot **100** relative to the room **500**. The location of the robot **100** within the global coordinate system can be defined by x and y. The orientation of the robot can be defined by θ, as measured relative to the X-axis.

FIG. **6**A shows the robot **100** in the room **500** of FIG. **5** as it travels along the wall **505***a*, such as according to a corresponding occupancy grid **600***a* of FIG. **6**B. The occupancy grid **600***a* can be a virtual map that the controller (e.g., the controller **212** of FIG. 2A) of the robot **100** or the cloud computing system **406** can generate, such as during a wall following behavior (e.g., the robot traces the traversable perimeter of the room **500** to develop a map of the outer edges of the room **500**). A virtual robot **602** can be a virtual representation of the robot **100** within the occupancy grid **600***a*. A center of the virtual robot **602** can represent an estimated (x, y) location of the robot **100**, and a line extending from the center of the virtual robot **602** and through a forward center of the virtual robot **602** can represent the estimated orientation θ of the robot **100**.

FIG. **6**B shows that the position **502** of the robot **100** within the room **500** can be estimated or determined (e.g., estimated or determined by the controller **212**) at least in part using dead reckoning (i.e., without an absolute determination of current position). For example, the position of the robot **100** can be assumed to match a determined position of the virtual robot **602**, or the position of the robot **100** can be determined to be within an error bound of the position of the virtual robot **602**. The position of the virtual robot can be determined (e.g., using the controller **212**) based upon one or more robot sensors or features (e.g., encoders **209**, cliff sensors **234**, bump sensors **239**, image capture device **240**, optical travel indicators, etc.).

As shown in FIG. **6**B, the virtual robot **602** can start at a starting node **622**, such as a specified, calibrated, or estimated position. The position of the starting node **622** can be determined with a specified level of accuracy, such as through user input, robot sensors, or the like. The starting node can include robot pose information, such as position or location and orientation. The starting node can be recorded in a memory, such as the memory **213**.

From the starting node **622**, the robot **100** can travel for a specified period of time where the virtual robot **602** can move within the occupancy grid **600***a* as the robot **100** moves a specified distance before recording a first node **624**. The first node **624** can include similar information to the starting node **622** (i.e., position, orientation), and can also be stored in memory. One or more pieces of information comprising the first node **624** can be determined using one or more pieces of the starting node **622** or a first travel indicator **623** (e.g., determined using dead reckoning). The first travel indicator **623** can include robot travel information, such as a determined or estimated distance that the virtual robot **602** has traveled since the virtual robot **602** left the starting node **622**. For example, the robot **100** can be able to determine a distance the robot has traveled (e.g., using the wheel encoders **209**, optical travel indicators, or the like) to determine a value of the first travel indicator **623**. Using the starting node **622** and the first travel indicator **623**, the robot **100** can determine the first node **624**, such as by adjusting a location of the first node **624** based upon the location and orientation of the starting node **622** and the distance of the first travel indicator **623** (e.g., determine the position of the first node **624** by adjusting the location of the starting node **622** by the length of the first travel indicator **623** in the direction of θ in the starting node **622**). The orientation of the robot **100** can be determined using a gyroscope mounted on the robot **100**, such as by using a dead reckoning technique. The orientation of the robot **100** can also be determined using one or more sensors, such as the encoders **209** (e.g., if the encoder on the drive wheel **210***a* indicates more travel than the encoder on the drive wheel **210***b*, calculate the turn of the robot **100**). The above dead reckoning technique (e.g., nodes and travel indicators) is an example of a method of determining position, but this disclosure is believed to apply to a variety of dead reckoning and position determination techniques.

By using a dead reckoning technique, such as the one discussed above, the position **502** of the robot **100** can be determined or estimated (e.g., using the controller **212**). The dead reckoning technique can be recalibrated, such as by determining a new starting node **622** with a higher degree of accuracy than the current dead reckoning node (e.g., the robot **100** recalibrates using user input, sensors, etc.). Periodically, the dead reckoning technique may include marginalizing one or more nodes or travel indicators, such as to reduce the amount of data storage required. Marginalization may include combining one or more nodes or one or more travel indicators. For example, five nodes connected by four travel indicators can be marginalized to two nodes connected with a single travel indicator. The starting and ending nodes can be in the same location, resulting in no loss of robot position information. The robot **100** can persist (i.e., record without deleting) a specified number of nodes or travel indicators before marginalization, such as may allow for the correction of incorrect nodes or travel indicators.

While the use of a dead reckoning technique can allow for position determination without absolute position information, an error or misinterpretation of data used to determine position information can result in an error in the determined position. For example, if the robot **100** is determined to be moving (e.g., the drive wheels **210** are spinning and turning the encoders **209**), but the robot is actually in a stasis condition (e.g., a stationary or abnormal condition), nodes and travel indicators can be generated that incorrectly reflect the position of the robot. Problematically, these nodes can be included on the occupancy grid **600***a*, creating inaccuracies in the occupancy grid **600***a*, which can cause future navigational problems. The systems and methods below help to address these issues.

FIG. **7** shows an example of a robot stasis condition resulting in inaccurate robot position information. FIG. **7** shows that the determined position of the virtual robot **602** is outside of traversable boundaries of the room (i.e., the robot would have to go through wall **505***b* to reach the determined position). The correct position of the virtual robot **602** is shown as correct position **602***a*. While executing a turn, such as during a cleaning mission, the robot **100** may have become stuck (e.g., stuck due to floor conditions, an obstacle, etc.) or disoriented (e.g., the determined pose of the robot is incorrect). After becoming stuck or disoriented, the robot **100** can attempt to continue the mission (e.g., keep driving drive wheels **210**), but the robot may not be able to move properly (e.g., because it is mechanically stuck, trying to drive through a wall, etc.). Additionally, the position of the robot **100** can continue to be determined using the dead reckoning technique. However, because the robot **100** is not actually moving as expected, the position(s) determined using the dead reckoning technique can be incorrect.

For example, the robot **100** (e.g., using the controller **212**) can generate nodes **626***a*-**626***f*, with travel indicators **628** between each of the nodes **626**. The nodes **626** can be located outside the traversable space of the environment **40**, e.g., beyond the map **642**. This incorrect position information can adversely affect the cleaning mission, such as by missing portions of an area to be cleaned, decreasing battery life, or forcing the robot to wait for user input. The incorrect position information may also adversely affect the map **642**, such as by updating the map **642** to indicate that the robot can travel to a non-traversable area.

FIG. **8** illustrates a schematic view of the method **800**, in accordance with at least one example of this disclosure. The method **800** can be a method of modifying a map of an environment (or of creating a map of an environment). The steps or operations of the method **800** are illustrated in a particular order for convenience and clarity; many of the discussed operations can be performed in a different sequence or in parallel without materially impacting other operations. The steps or operations of the method **800** can be omitted or can be performed multiple times. The method **800** as discussed includes operations that can be performed by multiple different actors, devices, and/or systems. It should be understood that subsets of the operations discussed in the method **800** can be attributable to a single actor, device, or system, or could be considered a separate standalone process or method.

The method **800** can be performed by one or more of the robot **100**, the cloud computing system **406**, or the mobile device **404**. The method **800** can begin at step **802**, where sensor data can be received. The sensor data can be received by the controller **212**, such as from one or more sensors on the robot **100**. The sensor data can include data based on the interaction between the robot **100** and the environment. The sensor data can be used, such as to determine a position of the robot **100** or generate a map **642**. The sensor data can be used in a dead reckoning technique, such as discussed above.

At step **804**, images of the environment can be received. The images of the environment can be captured by the image capture device **240** and received by the controller **212**. The image capture device **240** can be generally stationary with respect to the robot **100**, and therefore can capture images based on the position or orientation of the robot **100**. The image capture device **240** can be oriented towards the front portion **202***a* of the robot **100** and can capture features of the environment generally ahead of or generally above the robot **100**. One image can be received per node, such as an image captured at approximately the same time as the node is recorded. More than one image can be received between nodes, such as a continuous stream of images recorded at a specified interval, such as may not depend upon the recording of nodes. Optionally, one image can be received per node.

At step **806**, it can be determined whether the robot **100** is in a stasis condition, such as using the images received in step **804** and the sensor data received in step **802**. For example, the controller **212** can use a technique, such as an image processing technique, to determine if the robot is stationary or operating abnormally. When the robot is stuck against a wall or other obstruction and the drive wheels **210** are operating, the robot can wobble, rotate, or oscillate back and forth (e.g., the robot is not entirely stationary). The change in orientation(s) can result in little change in position or location but greater change in orientation. This change in orientation can cause the images to look different even though the robot **100** is in stasis. However, due to the oscillating motion of the robot **100**, images from farther ago in time can look similar to a present image. The robot **100** can compare one or more images to help determine if the robot is stationary, such as determining that the robot is in stasis if two images have a degree of similarity above a threshold. A technique for determining the stasis condition of the robot is discussed below. In an example, one or more of an optical sensor configured for detecting motion of the robot or the wheel encoders **209** can be used to determine if the robot is in a stasis condition. The optical sensor, wheel encoders **209**, or one or more images can be used to determine whether the robot is in stasis.

At step **808**, an action can be taken in response to the stasis determination. If the robot is determined to not be in stasis at step **806**, the stasis determination can continue recurrently without taking any actions in response to stasis until a stasis condition is determined. Examples of actions that can be taken in response to a stasis determination include updating the map **642** at step **810**, updating the determined position of the robot **100** at step **812**, or altering a robot action at step **814**. In an example, more than one of these actions can be taken. In an example, other actions can be taken alternatively or in addition to these actions.

At step **810**, updating the map **642** can include updating a previously generated map or updating a map that is currently being generated. For example, a previously generated map can include one or more non-traversable areas that the robot **100** attempts to access on missions but is unsuccessful in doing so, such as due to undetected stasis. If on a mission, stasis is detected, such as while attempting to access a portion of the map, the previously generated map can be updated to remove all or a portion of the incorrect data, such as poses, locations, travel indicators, or the like. If the map **642** is being generated, and the robot **100** detects a stasis condition, the map **642** can be generated to leave out a portion or all of the area that the virtual robot **602** traversed while the robot **100** was in stasis.

At step **812**, the determined location of the robot **100** can be updated, such as by updating the location of the virtual robot **602**. For example, the robot **100** can be attempting to complete a cleaning mission based upon a previously defined map **642**, and can enter a stasis condition. While in the stasis condition, the determined location of the robot **100** can become inaccurate, which can result in a portion of the remaining mission failing or being completed incorrectly (e.g., failing to clean the entire area that was to be cleaned). By updating the determined position of the robot **100** based upon the stasis determination to the correct position of the robot **100** or a more accurate position, the remaining mission can be completed successfully or more successfully (e.g., more of the area is cleaned correctly than if stasis was not determined and corrected for) and future missions using the map **642** can be completed more effectively or efficiently.

At step **814**, an action of the robot **100** can be altered. For example, the robot can take an action that it would not have taken if stasis was not detected. The action can be physical, such as an evasive maneuver to try to become unstuck (e.g., conducting a spin for a specified length of time) or redetermine or recalibrate a portion or all of a pose (e.g., travel to a recalibration point, such as a corner). The robot can also generate and transmit an alert that the robot is stuck. The robot can attempt to recalibrate the current position, such as by going to a calibration point. The action can also be a non-physical action, such as a change in recorded values, control flow, or system operations. For example, the robot can reduce a confidence level ascribed to one or more nodes or travel indicators.

FIG. **9** illustrates a schematic view of the method **900**, in accordance with at least one example of this disclosure. The method **900** can be a method of modifying a map of an environment, or of creating a map of an environment. The steps or operations of the method **900** are illustrated in a particular order for convenience and clarity; many of the discussed operations can be performed in a different sequence or in parallel without materially impacting other operations. The steps or operations of the method **900** can be omitted or can be performed multiple times. The method **900** as discussed includes operations that can be performed by multiple different actors, devices, and/or systems. It should be understood that subsets of the operations discussed in the method **900** can be attributable to a single actor, device, or system, or could be considered a separate standalone process or method.

The method **900** can be performed by one or more of the robot **100**, the cloud computing system **406**, or the mobile device **404**, and can include or can be part of one or more of the steps of the method **800** discussed above, such as step **810**, but can be part of any step of the method **800** or the method **900** can stand alone. The method **900** can begin at step **902**, where sensor data can be received. The sensor data can be received by the controller **212**, such as from one or more sensors on the robot **100**. The sensor data can include data based on the interaction between the robot **100** and the environment.

At step **904**, a map **642** of the environment can be generated, such as based on the received sensor data. The map **642** of the environment can be generated from scratch, or can be generated by updating a previously generated map. The map **642** can include one or more of a traversable perimeter map, a mission map (e.g., a map for the path to take while carrying out a cleaning mission), or the like. The map **642** can be created using SLAM or VSLAM, as discussed above. At step **906**, the map **642** can be updated to include one or more nodes (e.g., the nodes **622**-**626**) such as based on a location of the robot **100** in the environment, which can be determined using the sensor data received in step **902**.

At step **908**, the map **642** can be updated to include one or more travel indicators between adjacent nodes, such as the first travel indicator **623**. The travel indicators determined in step **908** can indicate a distance or angle between one or more nodes determined in step **906** (e.g., according to the dead reckoning technique discussed above).

At step **910**, one or more nodes can be characterized as stasis nodes, or one or more travel indicators can be characterized as stasis travel indicators when it is determined that the robot **100** is in a stasis condition. In an example, one or more nodes are characterized as stasis nodes and at least one travel indicator is characterized as a stasis travel indicator. The characterization can include flagging or otherwise marking the nodes or travel indicators as stasis nodes, and may not be required to include further action.

At step **912**, one or more of the stasis nodes or stasis travel indicators can be minimized (or optionally removed) such as by reducing the distance traveled including optionally reducing the distanced traveled to zero, which can result in a more accurate location determination of the robot **100** or a more accurate map **642**. For example, the dead reckoning technique can include removing travel information for times when the robot was determined to be in stasis. The nodes and travel indicators can be marked as stasis nodes and stasis travel indicators if it can be determined that the whole preceding travel indicator was generated when the robot **100** was in stasis. If stasis started in the middle of a travel indicator, the travel indicator may not be marked as a stasis travel indicator, or can be marked as a stasis travel indicator. Because the nodes and travel indicators can be treated as undividable elements, the coarseness of the stasis correction can be determined by the length of the travel indicators. For example, an entire travel indicator can either be preserved or discarded, even though stasis began in the middle of the travel indicator. This can result in an error regardless of whether the travel indicator is preserved or removed. Decreasing the length of time or distance between nodes can reduce the coarseness of the correction. In an example, a travel indicator can be divided into more than one travel indicator, including intermediate nodes, to attempt to reduce the coarseness of removing a travel indicator.

In an example, the stasis nodes and stasis travel indicators can be preserved or persisted, but a length of the stasis travel indicators can be reduced or can be set to zero at step **914**. This can have an effect of keeping the determined position of the robot **100** constant during stasis, or reducing the error in the position of the robot **100**.

The image processing technique used to determine stasis at step **806** can include comparing two or more images using one or more image processing techniques to determine if two or more of the two or more images were taken from the same position or approximately the same position. In an example, the image processing technique can include comparing one or more gradients of the two or more images. For example, a value (e.g., intensity at a specific color, overall intensity, etc.) for a pixel or group of pixels can be compared to a value of a neighboring pixel or group of pixels. The relative difference can define the gradient between pixels. Equation 1 defines a relative difference of gradient score of the positive gradient in the horizontal direction between a first image I_i and a second image I_j.

$$s^{x+}(I_i, I_j) = \frac{|(g^{x+}(I_i) - g^{x+}(I_j)_{>\theta}|}{|(g^{x+}(I_i)_{>\theta}|+|g^{x+}(I_j)_{>\theta}|} \qquad \text{Equation 1}$$

In equation 1, g^{x+} represents the positive gradient in the horizontal direction of the pixels in the images, and $|g>\theta|$represents the cardinality of the set of pixels in g with an absolute value larger than θ. For example, the portion of equation 1 above the division bar is equal to the number of gradients in the images that differ by an amount greater than θ. The portion of equation 1 below the division bar is equal to the sum of the gradients in the images alone that exceed θ. The value of θ can be specified or tuned, such as by using a machine learning method. In an example, θ can be 0.05, 0.1, 0.5, 1, 1.5 or 2. The domain of equation 1 ranges from 0 when the images are identical to 1 when none of the image gradients overlap.

Equation 2 can define a total relative difference of gradient score between a first image I_i and a second image I_j.

$$s(I_i, I_j) = \sqrt{(s^{x+})^2 + (s^{x-})^2 + (s^{y+})^2 + (s^{y-})^2} \qquad \text{Equation 2}$$

Equation 2 can define the total relative difference of gradient score as the root of the squares of each of the relative difference of gradient scores in the positive horizontal gradient (s^{x+}), the negative horizontal gradient (s^{x-}), the positive vertical gradient (s^{y+}), and the negative vertical gradient (s^{y-}). Positive can be defined as a light to dark transition or a dark to light transition of pixels, with negative being defined oppositely from positive. Each of the individual gradient scores can be calculated similarly to equation 1. The domain of the total relative difference of gradient scores can range from 0 when the images are identical to 2 (or 1 in other examples) when none of the gradients overlap.

The total relative difference in gradient score, such as determined according to Equation 2, can be compared to a threshold to determine whether the robot **100** is in stasis. Because a lower total relative difference of gradient score can correspond to a greater similarity between images, scores below the threshold can result in determining that the robot **100** is in stasis. The threshold can be determined empirically, such as through testing and calibration in different environments and conditions. The threshold can be determined through machine learning, such as can include training with samples and hard coding a threshold or machine learning during use, such as use by an end user in the end user's environment. The threshold can be adaptive, such as can result in the threshold increasing or decreasing based upon one or more conditions. In an example, the threshold can be increased or decreased based upon the overall ambient light detected by the robot **100**. For example, low light can make it more likely to detect a false positive of stasis, such as due to lower average image gradient, so the threshold can be lowered (i.e., the images must be more similar to determine the robot **100** is in stasis). In an example, stasis detection can be turned off or disabled if it is too dark. In an example, the threshold can be increased or decreased based upon the measurements of the gyroscope. For example, the gyroscope can detect more angular variation when the robot is oscillating against a while. Therefore, when the gyroscope detects more variation, it can be more likely that the robot is in a stasis condition, and the threshold can be increased (i.e., the images do not have to be as similar to determine the robot **100** is in stasis).

In an example, the method **800** can include generating a queue of images, such as corresponding to a specific time interval, with particular images being associated with one or more nodes. The queue of images can include N images. For example, the method **800** can include queuing 22 images corresponding to a specific time interval (e.g., images taken recurrently at a specified interval to achieve 22 images during the specified time interval), with each image corresponding to the generation of a node. In an example, the node generation may not be sequenced to image collection and a given image can be assigned to the previous node, the next node, or the nearest node in time. The method **800** can include comparing one or more of the 22 images to one or more of the remaining 21 images.

In an example, each of the 11 most recent images can be compared to the 11 images previous from each image. A 11-by-11 array of scores can be created to organize the values, with each column corresponding to one of the 11 most recent images and each column corresponding to the nth previous image. Respective array elements can correspond to the total relative difference of gradient scores for the image of the column and the image of the row. Comparing images to more than one other image can allow for one or more of increased accuracy (e.g., decreased false negative rate or decreased false positive rate), detection of conditions when the robot is stationary in position but oscillating in orientation (e.g., because the images do not overlap until the oscillation has made a partial or complete cycle and the image capture device **240** is aimed at the same or similar location as during a previous image capture).

Alternatively or additionally, the comparison of more than two images can allow for the robot **100** to continue operating during stasis determinations, such as by making the stasis determination a lower priority task or a recurrent or non-continuous task. For example, the robot **100** can prioritize other operations and only conduct stasis determinations when processing bandwidth allows. This can be benefitted by having a queue of images because each image may not be analyzed as it is received.

In an example, N can equal any number, such as 5, 10, 15, 20, 25, 30, 40, 50 or 100. In an example, one or more images can be compared with any one or more remaining images in the queue, and the resulting data may not generate a square array. For example, the first images can be compared to all the other images in the queue, the second image can be compared to all the earlier images, and so on to generate a stepped array. In an example, one or more comparisons can be skipped or conducted in a different way.

In one example, the robot **100** (or a controller **212** thereof) can generate the map **642** of the environment based on the sensor data. The robot **100** can update the map **642** to include one or more nodes (e.g., the nodes **622-626**) based on a location of the mobile cleaning robot **100** in the environment based on the sensor data. The robot **100** can update the map **642** to include one or more travel indicators

628 between adjacent nodes based on the sensor data. The robot **100** can characterize at least one of the one or more nodes as stasis nodes and characterize at least one of the travel indicators as stasis travel indicators when it is determined that the mobile cleaning robot **100** is in the stasis condition.

The robot **100** can also execute or generate instructions to further cause the processing circuitry (e.g., the controller **212**) to perform operations to remove the stasis nodes and the stasis travel indicators following the stasis determination to update the map **642**. The robot **100** can set a value of the one or more stasis travel indicators to zero following the stasis determination to update the map **642**. The robot **100** can generate a queue of the images over a time interval, particular images associated with one or more nodes. The robot **100** can characterize at least one of the images as a stasis image associated with at least one of the stasis nodes when it is determined that the mobile cleaning robot **100** is in the stasis condition. The robot **100** can delete the stasis image from the queue.

The robot **100** can persist remaining nodes, images, and travel indicators following removal of the stasis images from the queue. The robot **100** can compare a first gradient of a first image to a second gradient of a second image to determine whether the mobile cleaning robot is in a stasis condition.

Or, the robot **100** can determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images. The robot **100** can determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images. The robot **100** can determine whether the mobile cleaning robot **100** is in a stasis condition based on the first vertical gradient and the first horizontal gradient of one or more images of the first group of images and based on the second vertical gradient and the second horizontal gradient of one or more images of the second group of images.

The robot **100** can also determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images. The robot **100** can determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images. The robot **100** can assign a first score value to each image of the first group of images based on the first vertical gradient and the first horizontal gradient of that image. The robot **100** can assign a second score value to each image of the second group of images based on the second vertical gradient and the second horizontal gradient of that image. The robot **100** can compare the first score value of each of the images of the first group of images to the second score value of each of the images of the second group of images. The robot **100** can then determine whether the mobile cleaning robot **100** is in a stasis condition based on the comparison of the first score values to the second score values.

Optionally, the robot **100** can determine corresponding first gradients including first vertical gradients and a first horizontal gradients of one or more images of a first group of images. The robot **100** can determine corresponding second gradients including second vertical gradients and a second horizontal gradients of one or more images of a second group of images. The robot **100** can compare each of the first gradients to each of the second gradients to determine one or more score values corresponding to the one or more comparisons. The robot **100** can determine whether the mobile cleaning robot is in a stasis condition based on the one or more score values.

FIG. **10** illustrates an example of a score array **1000**. In FIG. **10**, I_1 represents the most recent image, I_2 represents the second most recent image, and so on. The first column contains the scores of comparisons involving the first image, the second column contains scores of comparisons involving the second image, and so on. A comparison (e.g., a comparison according to equation 2) is denoted with "vs," for example I_1 vs I_2 is a comparison of the first image and the second image. The score array **1000** can have a specified number of columns and a specified number of rows. The score array **1000** may not need to be square.

The stasis determination can be made by analyzing the score array **1000**. For example, the controller **212** can determine stasis using one or more of the minimum score of the first column, the maximum score of the first column, the mean of the minima of two or more of the columns (e.g., up to and including all the columns), or another array based operation. Other array-based operations can include a ratio of the high frequency components of the matrix to the overall magnitude of the matrix. In addition, the controller **212** can be trained to recognize arrays indicating stasis, such as through machine learning, or the controller can be hard-coded with data resulting from the training of another device.

In an example, the robot **100** can be determined to be in stasis if the maximum score of the first column is below a threshold. This can indicate that there is little variation between the most recent image and the past images. If the minimum score of the first column is below a threshold, the robot **100** can be determined to be in stasis. However, if some scores in the first column are above the threshold, this may indicate that the robot is oscillating, and only some of the images overlap sufficiently for the score to indicate stasis.

If the robot is oscillating, vibrating, or in another hard to detect stasis condition, it can be helpful to look beyond the first column of the matrix. For example, taking the mean of the minima of all the columns can allow for a broader comparison, or a comparison that looks farther back in time. A low mean of the minima of all columns can be indicative of stasis, however, this alone may not be sufficient to determine stasis. It can be helpful to also analyze the ratio of high frequency components in the matrix, and declare stasis if the high frequency ratio exceeds a threshold and the mean of minima is below a threshold.

In an example, if two adjacent images at one position in the queue (e.g., images eight and nine) have a score below the threshold and two images at a different position in the queue (e.g., images three and four) have a score below the threshold, one or more intermediate images (e.g., images four through eight) can be determined to be stasis images and treated as if their comparisons were below the threshold regardless of their determined scores. For example, if the robot is determined to be in stasis at one point in time, and a period of time later (e.g., 5 seconds) it is determined to be in stasis again, it can be determined that the robot was in stasis during the intermediate time, even if stasis was not detected.

An image can be characterized as a stasis image if its similarity with a previous image (e.g., such as determined using the score generated by equation 2) is less than the threshold. When an image is characterized as a stasis image, one or more nodes or travel indicators associated with the image can be characterized as stasis nodes or stasis travel indicators. Following the stasis determination, the stasis image can be deleted from the queue. Following the handling of the stasis nodes, stasis travel indicators, and stasis images, the remaining nodes can be marginalized. Marginalizing can be delayed until after the stasis determination is made and action is taken to allow for better handling of the stasis determination and actions (e.g., if nodes are marginalized before the stasis determination, the information necessary to remove stasis nodes may not be available).

FIG. **11** shows an example of a robot taking an action in response to the stasis condition shown in FIG. **7**. FIG. **10** shows that the robot **100** determined that one or more nodes **626***a*-**626***f* or travel indicators **628** in a region **1104** were stasis nodes or stasis travel indicators (e.g., determined stasis using one or more of the methods described herein). Following the stasis determination, the robot **100** removed or otherwise accounted for the one or more nodes or travel indicators in region **1104** (e.g., deleted nodes, deleted travel indicators, set travel indicator length to zero, etc.). Following the removal of the one or more nodes or travel indicators in region **1104**, the determined position of the virtual robot **602** can be moved towards the correct position **602***a* from the incorrect position **602***b*. The position of the virtual robot **602** can match the correct position **602***a*, or can differ from the correct position **602***a*, such as can be due to a delay in determining stasis or a granularity of the stasis correction. FIG. **10** shows that one or more nodes (e.g., persisted node **630**) or travel indicators (e.g., persisted travel indicator **632**) of region **1102** were determined not to be stasis nodes or travel indicators, and no action was taken with respect to these nodes and travel indicators.

FIG. **12** illustrates a block diagram of an example machine **1200** upon which any one or more of the techniques (e.g., methodologies) discussed herein can perform. Examples, as described herein, can include, or can operate by, logic or a number of components, or mechanisms in the machine **1200**. Circuitry (e.g., processing circuitry) is a collection of circuits implemented in tangible entities of the machine **1200** that include hardware (e.g., simple circuits, gates, logic, etc.). Circuitry membership can be flexible over time. Circuitries include members that may, alone or in combination, perform specified operations when operating. In an example, hardware of the circuitry can be immutably designed to carry out a specific operation (e.g., hardwired). In an example, the hardware of the circuitry can include variably connected physical components (e.g., execution units, transistors, simple circuits, etc.) including a machine readable medium physically modified (e.g., magnetically, electrically, moveable placement of invariant massed particles, etc.) to encode instructions of the specific operation. In connecting the physical components, the underlying electrical properties of a hardware constituent are changed, for example, from an insulator to a conductor or vice versa. The instructions enable embedded hardware (e.g., the execution units or a loading mechanism) to create members of the circuitry in hardware via the variable connections to carry out portions of the specific operation when in operation. Accordingly, in an example, the machine readable medium elements are part of the circuitry or are communicatively coupled to the other components of the circuitry when the device is operating. In an example, any of the physical components can be used in more than one member of more than one circuitry. For example, under operation, execution units can be used in a first circuit of a first circuitry at one point in time and reused by a second circuit in the first circuitry, or by a third circuit in a second circuitry at a different time. Additional examples of these components with respect to the machine **1200** follow.

In alternative embodiments, the machine **1200** can operate as a standalone device or can be connected (e.g., networked) to other machines. In a networked deployment, the machine **1200** can operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine **1200** can act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine **1200** can be a personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

The machine (e.g., computer system) **1200** can include a hardware processor **1202** (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory **1204**, a static memory (e.g., memory or storage for firmware, microcode, a basic-input-output (BIOS), unified extensible firmware interface (UEFI), etc.) **1206**, and mass storage **1216** (e.g., hard drive, tape drive, flash storage, or other block devices) some or all of which can communicate with each other via an interlink (e.g., bus) **1208**. The machine **1200** can further include a display unit **1210**, an alphanumeric input device **1212** (e.g., a keyboard), and a user interface (UI) navigation device **1214** (e.g., a mouse). In an example, the display unit **1210**, input device **1212** and UI navigation device **1214** can be a touch screen display. The machine **1200** can additionally include a storage device (e.g., drive unit) **1216**, a signal generation device **1218** (e.g., a speaker), a network interface device **1220**, and one or more sensors **1216**, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine **1200** can include an output controller **1230**, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

Registers of the processor **1202**, the main memory **1204**, the static memory **1206**, or the mass storage **1216** can be, or include, a machine readable medium **1222** on which is stored one or more sets of data structures or instructions **1224** (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions **1224** can also reside, completely or at least partially, within any of registers of the processor **1202**, the main memory **1204**, the static memory **1206**, or the mass storage **1216** [**1208**] during execution thereof by the machine **1200**. In an example, one or any combination of the hardware processor **1202**, the main memory **1204**, the static memory **1206**, or the mass storage **1216** can constitute the machine readable media **1222**. While the machine readable medium **1222** is illustrated as a single medium, the term "machine readable medium" can include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions **1224**.

The term "machine readable medium" can include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine **1200** and that cause the machine **1200** to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples can include solid-state memories, optical media, magnetic media, and signals (e.g., radio frequency signals, other photon based signals, sound signals, etc.). In an example, a non-transitory machine readable medium comprises a machine readable medium with a plurality of particles having invariant (e.g., rest) mass, and thus are compositions of matter. Accordingly, non-transitory machine-readable media are machine readable media that do not include transitory propagating signals. Specific examples of non-transitory machine readable media can include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks.

The instructions **1224** can be further transmitted or received over a communications network **1226** using a transmission medium via the network interface device **1220** utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks can include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®), IEEE 802.15.4 family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device **1220** can include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network **1226**. In an example, the network interface device **1220** can include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine **1200**, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software. A transmission medium is a machine readable medium.

NOTES AND EXAMPLES

The following, non-limiting examples, detail certain aspects of the present subject matter to solve the challenges and provide the benefits discussed herein, among others.

Example 1 is at least one non-transitory machine-readable medium, including instructions, which when executed, cause processing circuitry to perform operations to: receive sensor data from a mobile cleaning robot based on interaction between the mobile cleaning robot and an environment; receive images of the environment from an image capture device of the mobile cleaning robot; determine whether the mobile cleaning robot is in a stasis condition based on the images and the sensor data; and update a map of the environment based on the stasis determination.

In Example 2, the subject matter of Example 1 optionally includes the instructions to further cause the processing circuitry to perform operations to: generate the map of the environment based on the sensor data; update the map to include one or more nodes based on a location of the mobile cleaning robot in the environment based on the sensor data; update the map to include one or more travel indicators between adjacent nodes based on the sensor data; and characterize at least one of the one or more nodes as stasis nodes and characterize at least one of the travel indicators as stasis travel indicators when it is determined that the mobile cleaning robot is in the stasis condition.

In Example 3, the subject matter of Example 2 optionally includes the instructions to further cause the processing circuitry to perform operations to: remove the stasis nodes and the stasis travel indicators following the stasis determination to update the map.

In Example 4, the subject matter of any one or more of Examples 2-3 optionally include the instructions to further cause the processing circuitry to perform operations to: set a value of the one or more stasis travel indicators to zero following the stasis determination to update the map.

In Example 5, the subject matter of any one or more of Examples 2-4 optionally include the instructions to further cause the processing circuitry to perform operations to: generate a queue of the images over a time interval, particular images associated with one or more nodes; characterize at least one of the images as a stasis image associated with at least one of the stasis nodes when it is determined that the mobile cleaning robot is in the stasis condition; and delete the stasis image from the queue.

In Example 6, the subject matter of Example 5 optionally includes the instructions to further cause the processing circuitry to perform operations to: persist remaining nodes, images, and travel indicators following removal of the stasis images from the queue.

In Example 7, the subject matter of any one or more of Examples 1-6 optionally include the instructions to further cause the processing circuitry to perform operations to: compare a first gradient of a first image to a second gradient of a second image to determine whether the mobile cleaning robot is in a stasis condition.

In Example 8, the subject matter of any one or more of Examples 1-7 optionally include the instructions to further cause the processing circuitry to perform operations to: determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images; determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images; and determine whether the mobile cleaning robot is in a stasis condition based on the first vertical gradient and the first horizontal gradient of one or more images of the first group of images and based on the second vertical gradient and the second horizontal gradient of one or more images of the second group of images.

In Example 9, the subject matter of any one or more of Examples 1-8 optionally include the instructions to further cause the processing circuitry to perform operations to: determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images; determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images; assign a first score value to each image of the first group of images based on the first vertical gradient and the first horizontal gradient of that image; assign a second score value to each image of the second group of images based on the second vertical gradient and the second horizontal gradient of that image; compare the first score value of each of the images of the first group of images to the second score value of each of the images of the second group of images; and determine whether the mobile cleaning robot is in a stasis condition based on the comparison of the first score values to the second score values.

In Example 10, the subject matter of any one or more of Examples 1-9 optionally include the instructions to further cause the processing circuitry to perform operations to: determine corresponding first gradients including first vertical gradients and a first horizontal gradients of one or more images of a first group of images; determine corresponding second gradients including second vertical gradients and a second horizontal gradients of one or more images of a second group of images; compare each of the first gradients to each of the second gradients to determine one or more score values corresponding to the one or more comparisons; and determine whether the mobile cleaning robot is in a stasis condition based on the one or more score values.

In Example 11, the subject matter of any one or more of Examples 1-10 optionally include wherein the sensor data, for determining whether the mobile robot is in a stasis condition, are produced by one or more of an optical sensor of the mobile cleaning robot and a wheel encoder of the mobile cleaning robot.

Example 12 is a method of updating a map of an environment using a mobile cleaning robot, the method comprising: receiving sensor data from the mobile cleaning robot based on interactions between the mobile cleaning robot and the environment; receiving images of the environment from an image capture device of the mobile cleaning robot; determining whether the mobile cleaning robot is in a stasis condition based on the images; and updating a map of the environment based on the stasis determination.

In Example 13, the subject matter of Example 12 optionally includes generating the map of the environment based on sensor data from the mobile cleaning robot based on interactions between the mobile cleaning robot and the environment; updating the map to include one or more nodes based on a location of the mobile cleaning robot in the environment based on the sensor data; updating the map to include one or more travel indicators between adjacent nodes based on the sensor data; and characterizing at least one of the one or more nodes as stasis nodes and characterize at least one of the travel indicators as stasis travel indicators when it is determined that the mobile cleaning robot is in the stasis condition.

In Example 14, the subject matter of Example 13 optionally includes removing the stasis nodes and the stasis travel indicators following the stasis determination to update the map.

In Example 15, the subject matter of any one or more of Examples 13-14 optionally include comparing a first gradient of a first image to a second gradient of a second image to determine whether the mobile cleaning robot is in a stasis condition.

In Example 16, the subject matter of any one or more of Examples 13-15 optionally include determining a first vertical gradient and a first horizontal gradient of one or more images of a first group of images; determining a second vertical gradient and a second horizontal gradient of one or more images of a second group of images; assigning a first score value to each image of the first group of images based on the first vertical gradient and the first horizontal gradient of that image; assigning a second score value to each image of the second group of images based on the second vertical gradient and the second horizontal gradient of that image; comparing the first score value of each of the images of the first group of images to the second score value of each of the images of the second group of images; and determining whether the mobile cleaning robot is in a stasis condition based on the comparison of the first score values to the second score values.

Example 17 is a mobile cleaning robot configured to clean an environment, the mobile cleaning robot comprising: a body; a drivetrain operable to move the body within the environment; a sensor connected to the body and configured to generate a sensor signal based on interactions between the mobile cleaning robot and the environment; an image capture device connected to the body and configured to generate an image stream based on an optical field-of-view of the image capture device; and a controller connected to the body and configured to: determine whether the mobile cleaning robot is in a stasis condition based on the image stream and the sensor signal; and update a map of the environment based on the stasis determination.

In Example 18, the subject matter of Example 17 optionally includes the controller configured to: generate the map of the environment based on the sensor signal; update the map to include one or more nodes based on a location of the mobile cleaning robot in the environment based on the sensor signal; update the map to include one or more travel indicators between adjacent nodes based on the sensor signal; characterize at least one of the one or more nodes as stasis nodes and characterize at least one of the travel indicators as stasis travel indicators when it is determined that the mobile cleaning robot is in the stasis condition; and minimize the stasis nodes and the stasis travel indicators following the stasis determination to update the map.

In Example 19, the subject matter of Example 18 optionally includes the controller configured to: set a value of the one or more stasis travel indicators to zero following the stasis determination to update the map.

In Example 20, the subject matter of any one or more of Examples 17-19 optionally include the controller configured to: compare a first gradient of a first image to a second gradient of a second image to determine whether the mobile cleaning robot is in a stasis condition.

In Example 21, the subject matter of any one or more of Examples 17-20 optionally include the controller configured to: determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images; determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images; and determine whether the mobile cleaning robot is in a stasis condition based on the first vertical gradient and the first horizontal gradient of one or more images of the first group of images and based on the second vertical gradient and the second horizontal gradient of one or more images of the second group of images.

In Example 22, the subject matter of any one or more of Examples 17-21 optionally include the controller configured to: determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images; determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images; assign a first score value to each image of the first group of images based on the first vertical gradient and the first horizontal gradient of that image; assign a second score value to each image of the second group of images based on the second vertical gradient and the second horizontal gradient of that image; compare the first score value of each of the images of the first group of images to the second score value of each of the images of the second group of images;

and determine whether the mobile cleaning robot is in a stasis condition based on the comparison of the first score values to the second score values.

In Example 23, the subject matter of any one or more of Examples 1-22 optionally include wherein the map of the environment is produced using SLAM or VSLAM.

Example 24 is an apparatus comprising means to implement of any of Examples 1-23.

Example 25 is a system to implement of any of Examples 1-23.

Example 26 is a method to implement of any of Examples 1-23.

In Example 27, the system, apparatus(es), or method of any one or any combination of Examples 1-26 can optionally be configured such that all elements or options recited are available to use or select from.

The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments in which the invention can be practiced. These embodiments are also referred to herein as "examples." Such examples can include elements in addition to those shown or described. However, the present inventors also contemplate examples in which only those elements shown or described are provided. Moreover, the present inventors also contemplate examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

In the event of inconsistent usages between this document and any documents so incorporated by reference, the usage in this document controls. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, composition, formulation, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim.

In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, composition, formulation, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) can be used in combination with each other. Other embodiments can be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is provided to comply with 37 C.F.R. § 1.72(b), to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the

understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features can be grouped together to streamline the disclosure. This should not be interpreted as intending that an unclaimed disclosed feature is essential to any claim. Rather, inventive subject matter can lie in less than all features of a particular disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description as examples or embodiments, with each claim standing on its own as a separate embodiment, and it is contemplated that such embodiments can be combined with each other in various combinations or permutations. The scope of the invention should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

The invention claimed is:

1. At least one non-transitory machine-readable medium, including instructions, which when executed, cause processing circuitry to perform operations to:

receive sensor data from a mobile cleaning robot based on interaction between the mobile cleaning robot and an environment;

generate a map of the environment based on the sensor data;

update the map to include one or more nodes based on a location of the mobile cleaning robot in the environment based on the sensor data;

update the map to include one or more travel indicators between adjacent nodes based on the sensor data;

receive images of the environment from an image capture device of the mobile cleaning robot;

determine whether the mobile cleaning robot is in a stasis condition based on the images and the sensor data; and

update the map of the environment based on the stasis determination.

2. The at least one non-transitory machine-readable medium of claim **1**, the instructions to further cause the processing circuitry to perform operations to:

characterize at least one of the one or more nodes as stasis nodes and characterize at least one of the travel indicators as stasis travel indicators when it is determined that the mobile cleaning robot is in the stasis condition.

3. The at least one non-transitory machine-readable medium of claim **2**, the instructions to further cause the processing circuitry to perform operations to:

remove the stasis nodes and the stasis travel indicators following the stasis determination to update the map.

4. The at least one non-transitory machine-readable medium of claim **2**, the instructions to further cause the processing circuitry to perform operations to:

set a value of the one or more stasis travel indicators to zero following the stasis determination to update the map.

5. The at least one non-transitory machine-readable medium of claim **2**, the instructions to further cause the processing circuitry to perform operations to:

generate a queue of the images over a time interval, particular images associated with one or more nodes;

characterize at least one of the images as a stasis image associated with at least one of the stasis nodes when it is determined that the mobile cleaning robot is in the stasis condition; and

delete the stasis image from the queue.

6. The at least one non-transitory machine-readable medium of claim **5**, the instructions to further cause the processing circuitry to perform operations to:

persist remaining nodes, images, and travel indicators following removal of the stasis images from the queue.

7. The at least one non-transitory machine-readable medium of claim **1**, the instructions to further cause the processing circuitry to perform operations to:

compare a first gradient of a first image to a second gradient of a second image to determine whether the mobile cleaning robot is in a stasis condition.

8. The at least one non-transitory machine-readable medium of claim **1**, the instructions to further cause the processing circuitry to perform operations to:

determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images;

determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images; and

determine whether the mobile cleaning robot is in a stasis condition based on the first vertical gradient and the first horizontal gradient of one or more images of the first group of images and based on the second vertical gradient and the second horizontal gradient of one or more images of the second group of images.

9. The at least one non-transitory machine-readable medium of claim **1**, the instructions to further cause the processing circuitry to perform operations to:

determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images;

determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images;

assign a first score value to each image of the first group of images based on the first vertical gradient and the first horizontal gradient of that image;

assign a second score value to each image of the second group of images based on the second vertical gradient and the second horizontal gradient of that image;

compare the first score value of each of the images of the first group of images to the second score value of each of the images of the second group of images; and

determine whether the mobile cleaning robot is in a stasis condition based on the comparison of the first score values to the second score values.

10. The at least one non-transitory machine-readable medium of claim **1**, the instructions to further cause the processing circuitry to perform operations to:

determine corresponding first gradients including first vertical gradients and a first horizontal gradients of one or more images of a first group of images;

determine corresponding second gradients including second vertical gradients and a second horizontal gradients of one or more images of a second group of images;

compare each of the first gradients to each of the second gradients to determine one or more score values corresponding to the one or more comparisons; and

determine whether the mobile cleaning robot is in a stasis condition based on the one or more score values.

11. The at least one non-transitory machine-readable medium of claim **1**, wherein the sensor data, for determining whether the mobile robot is in a stasis condition, are produced by one or more of an optical sensor of the mobile cleaning robot and a wheel encoder of the mobile cleaning robot.

12. A method of updating a map of an environment using a mobile cleaning robot, the method comprising:

receiving sensor data from the mobile cleaning robot based on interactions between the mobile cleaning robot and the environment;

generating the map of the environment based on sensor data from the mobile cleaning robot based on interactions between the mobile cleaning robot and the environment;

updating the map to include one or more nodes based on a location of the mobile cleaning robot in the environment based on the sensor data;

updating the map to include one or more travel indicators between adjacent nodes based on the sensor data;

receiving images of the environment from an image capture device of the mobile cleaning robot;

determining whether the mobile cleaning robot is in a stasis condition based on the images; and

updating the map of the environment based on the stasis determination.

13. The method of claim **12**, comprising:

characterizing at least one of the one or more nodes as stasis nodes and characterizing at least one of the travel indicators as stasis travel indicators when it is determined that the mobile cleaning robot is in the stasis condition.

14. The method of claim **13**, comprising:

removing the stasis nodes and the stasis travel indicators following the stasis determination to update the map.

15. The method of claim **13**, comprising:

comparing a first gradient of a first image to a second gradient of a second image to determine whether the mobile cleaning robot is in a stasis condition.

16. The method of claim **13**, comprising:

determining a first vertical gradient and a first horizontal gradient of one or more images of a first group of images;

determining a second vertical gradient and a second horizontal gradient of one or more images of a second group of images;

assigning a first score value to each image of the first group of images based on the first vertical gradient and the first horizontal gradient of that image;

assigning a second score value to each image of the second group of images based on the second vertical gradient and the second horizontal gradient of that image;

comparing the first score value of each of the images of the first group of images to the second score value of each of the images of the second group of images; and

determining whether the mobile cleaning robot is in a stasis condition based on the comparison of the first score values to the second score values.

17. A mobile cleaning robot configured to clean an environment, the mobile cleaning robot comprising:

a body;

a drivetrain operable to move the body within the environment;

a sensor connected to the body and configured to generate a sensor signal based on interactions between the mobile cleaning robot and the environment;

an image capture device connected to the body and configured to generate an image stream based on an optical field-of-view of the image capture device; and

a controller connected to the body and configured to:

generate a map of the environment based on the sensor signal;

update the map to include one or more nodes based on a location of the mobile cleaning robot in the environment based on the sensor signal;

update the map to include one or more travel indicators between adjacent nodes based on the sensor signal;

determine whether the mobile cleaning robot is in a stasis condition based on the image stream and the sensor signal; and

update the map of the environment based on the stasis determination.

18. The mobile cleaning robot of claim **17**, the controller configured to:

characterize at least one of the one or more nodes as stasis nodes and characterize at least one of the travel indicators as stasis travel indicators when it is determined that the mobile cleaning robot is in the stasis condition; and

minimize the stasis nodes and the stasis travel indicators following the stasis determination to update the map.

19. The mobile cleaning robot of claim **18**, the controller configured to:

set a value of the one or more stasis travel indicators to zero following the stasis determination to update the map.

20. The mobile cleaning robot of claim **17**, the controller configured to:

compare a first gradient of a first image to a second gradient of a second image to determine whether the mobile cleaning robot is in a stasis condition.

21. The mobile cleaning robot of claim **17**, the controller configured to:

determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images;

determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images; and

determine whether the mobile cleaning robot is in a stasis condition based on the first vertical gradient and the first horizontal gradient of one or more images of the first group of images and based on the second vertical gradient and the second horizontal gradient of one or more images of the second group of images.

22. The mobile cleaning robot of claim **17**, the controller configured to:

determine a first vertical gradient and a first horizontal gradient of one or more images of a first group of images;

determine a second vertical gradient and a second horizontal gradient of one or more images of a second group of images;

assign a first score value to each image of the first group of images based on the first vertical gradient and the first horizontal gradient of that image;

assign a second score value to each image of the second group of images based on the second vertical gradient and the second horizontal gradient of that image;

compare the first score value of each of the images of the first group of images to the second score value of each of the images of the second group of images; and

determine whether the mobile cleaning robot is in a stasis condition based on the comparison of the first score values to the second score values.

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