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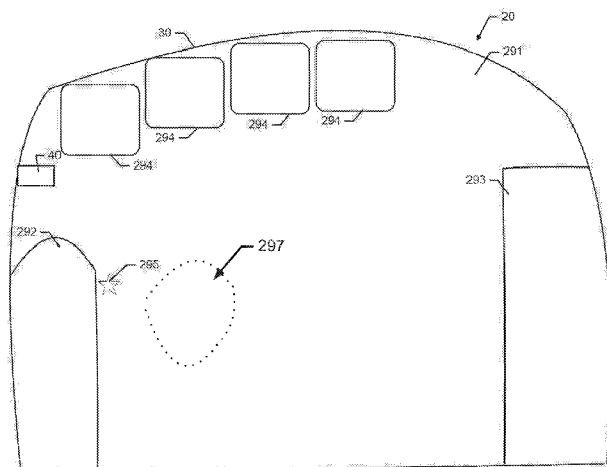


FIG. 4.

(57) Abstract: A robotic vehicle may include one or more functional components configured to execute a lawn care function, a sensor network comprising one or more sensors configured to detect conditions proximate to the robotic vehicle, a positioning module configured to determine robotic vehicle position using a first sensor of the sensor network, and a position quality analysis module configured to perform a qualitative assessment of position information determined via the first sensor. The position quality analysis module is further configured to determine whether the position information determined via the first sensor is indicative of an impaired area.



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ROBOTIC VEHICLE FOR DETECTING GPS SHADOW ZONES

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority to U.S. patent application number 62/093,689
5 filed December 18, 2014, which is expressly incorporated by reference in its entirety.

TECHNICAL FIELD

Example embodiments generally relate to robotic vehicles and, more particularly,
relate to a robotic vehicle that is configurable to operate within an area and identify GPS
10 shadow zones.

BACKGROUND

Yard maintenance tasks are commonly performed using various tools and/or machines
that are configured for the performance of corresponding specific tasks. Certain tasks, like
15 grass cutting, are typically performed by lawn mowers. Lawn mowers themselves may have
many different configurations to support the needs and budgets of consumers. Walk-behind
lawn mowers are typically compact, have comparatively small engines and are relatively
inexpensive. Meanwhile, at the other end of the spectrum, riding lawn mowers, such as lawn
tractors, can be quite large. More recently, robotic mowers and/or remote controlled mowers
20 have also become options for consumers to consider.

Robotic mowers are typically confined to operating on a parcel of land that is
bounded by some form of boundary wire. The robotic mower is capable of detecting the
boundary wire and operating relatively autonomously within the area defined by the
boundary wire. However, the laying of the boundary wire can be a time consuming and
25 difficult task, which operators would prefer to avoid, if possible. That said, to date it has
been difficult to try to provide a robotic mower that can truly operate without any need for a
boundary wire. Limitations on the accuracy of positioning equipment have played a large
role in making this problem difficult to solve.

Additionally, even if it were possible to accurately determine vehicle position, there is
30 currently no comprehensive way to ensure that the robotic vehicle only services the specific
areas of a garden or yard that are actually desired for servicing. Given that computing
devices are becoming more ubiquitous, it is to be expected that they may be employed to
assist in operation of lawn mowers. As such, many additional functionalities may be
provided or supported by the employment of computing devices on lawn mowers.

BRIEF SUMMARY OF SOME EXAMPLES

Some example embodiments may provide a robotic vehicle that is configured to incorporate multiple sensors to make the robotic vehicle capable of effectively identifying its position on a parcel using any of a number of positioning techniques including GPS. However, some example embodiments, may further enable GPS shadow zones or other impaired areas to be identified, and various remedial or other actions to be taken on the basis of the identification of such shadow zones.

In an example embodiment, a robotic vehicle may be provided. The robotic vehicle may include one or more functional components configured to execute a lawn care function, a sensor network comprising one or more sensors configured to detect conditions proximate to the robotic vehicle, a positioning module configured to determine robotic vehicle position using a first sensor of the sensor network, and a position quality analysis module configured to perform a qualitative assessment of position information determined via the first sensor. The position quality analysis module is further configured to determine whether the position information determined via the first sensor is indicative of an impaired area.

In another example embodiment, a method for identifying impairment areas or zones on a parcel based on operation of a robotic vehicle is provided. The method may include obtaining a plurality of instances of position information responsive to a robotic vehicle traversing a parcel via a first sensor, performing a qualitative assessment each instance of the position information, and determining whether the position information associated with the first sensor is indicative of an impaired area.

Some example embodiments may improve the ability of operators and/or fleet managers to make lawn mowers operate safely and/or efficiently.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 illustrates an example operating environment for a robotic mower;

FIG. 2 illustrates a block diagram of various components of control circuitry to illustrate some of the components that enable or enhance the functional performance of the robotic mower and to facilitate description of an example embodiment;

FIG. 3 illustrates a block diagram of some components that may be employed as part of a sensor network in accordance with an example embodiment;

FIG. 4 illustrates an example of a map view that may be generated or otherwise employed in accordance with an example embodiment;

FIG. 5 illustrates a control flow diagram regarding operation of a position quality analysis module according to an example embodiment; and

5 FIG. 6 illustrates a block diagram of one example of a method for operating a robotic mower in accordance with an example embodiment.

DETAILED DESCRIPTION

Some example embodiments now will be described more fully hereinafter with
10 reference to the accompanying drawings, in which some, but not all example embodiments are shown. Indeed, the examples described and pictured herein should not be construed as being limiting as to the scope, applicability or configuration of the present disclosure. Rather, these example embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like reference numerals refer to like elements throughout.
15 Furthermore, as used herein, the term “or” is to be interpreted as a logical operator that results in true whenever one or more of its operands are true. Additionally, the term "yard maintenance" is meant to relate to any outdoor grounds improvement or maintenance related activity and need not specifically apply to activities directly tied to grass, turf or sod care. As used herein, operable coupling should be understood to relate to direct or indirect connection
20 that, in either case, enables functional interconnection of components that are operably coupled to each other.

Robotic mowers, which are one example of a robotic vehicle of an example embodiment, typically mow an area that is defined by a boundary wire that bounds the area to be mowed. The robotic mower then roams within the bounded area to ensure that the entire
25 area is mowed, but the robotic mower does not go outside of the bounded area. Example embodiments are therefore described herein to provide various structural and control-related design features that can be employed to improve the capabilities of robotic vehicles (e.g., robotic mowers, mobile sensing devices, watering devices and/or the like) to be expanded and employed in an intelligent manner. Other structures may also be provided and other
30 functions may also be performed as described in greater detail below. Among the functions that may be performed by an example embodiment, GPS-based navigation may be practiced. Moreover, the robotic vehicle may be enabled to navigate the parcel and stay within boundaries defined based on GPS location. A robotic vehicle (e.g., a robotic mower) may therefore be provided that can operate without physical boundary wires and yet still stay

within boundaries that can be defined by any of a number of different ways.

However, GPS does not necessarily operate equally well in all locations and environments. Accordingly, the robotic vehicle of some example embodiments may be intelligent enough to identify specific areas in which GPS operation is degraded (e.g., shadow or impaired areas and/or the like). In some cases, the robotic vehicle may be further enabled to record, report and/or determine parameters regarding shadow zones to try to analyze (or at least facilitate analysis) to determine the cause of the GPS shadow zone. In some example embodiments, the robotic vehicle may take further actions based on the identification of the shadow zones, such as avoiding certain areas, or switching to backup or other methods of position determination in areas with GPS shadows. By enabling the robotic vehicle to accurately determine its position and the quality of its own positioning information in a more advanced way, some example embodiments may greatly expand the capabilities and the performance of robotic vehicles.

FIG. 1 illustrates an example operating environment for a robotic mower 10 that may be employed in connection with an example embodiment. However, it should be appreciated that example embodiments may be employed on numerous other robotic vehicles, so the robotic mower 10 should be recognized as merely one example of such a vehicle. The robotic mower 10 may operate to cut grass on a parcel 20 (i.e., a land lot or garden), the boundary 30 of which may be defined using one or more physical boundaries (e.g., a fence, wall, curb and/or the like), or programmed location based boundaries or combinations thereof. When the boundary 30 is detected, by any suitable means, the robotic mower 10 may be informed so that it can operate in a manner that prevents the robotic mower 10 from leaving or moving outside the boundary 30.

The robotic mower 10 may be controlled, at least in part, via control circuitry 12 located onboard. The control circuitry 12 may include, among other things, a positioning module and a sensor module (or sensor network), which will be described in greater detail below. Accordingly, the robotic mower 10 may utilize the control circuitry 12 to define a path for coverage of the parcel 20 in terms of performing a task over specified portions or the entire parcel 20. In this regard, the positioning module may be used to guide the robotic mower 10 over the parcel 20 and to ensure that full coverage (of at least predetermined portions of the parcel 20) is obtained, while the sensor module may detect objects and/or gather data regarding the surroundings of the robotic mower 10 while the parcel 20 is traversed.

If a sensor module is employed, the sensor module may include a sensors related to

positional determination (e.g., a GPS receiver, an accelerometer, a camera, a radar transmitter/detector, an ultrasonic sensor, a laser scanner and/or the like). Thus, for example, positional determinations may be made using GPS, inertial navigation, optical flow, radio navigation, visual location (e.g., VSLAM) and/or other positioning techniques or combinations thereof. Accordingly, the sensors may be used, at least in part, for determining the location of the robotic mower 10 relative to boundaries or other points of interest (e.g., a starting point or other key features) of the parcel 20, or determining a position history or track of the robotic mower 10 over time. The sensors may also detect collision, tipping over, or various fault conditions. In some cases, the sensors may also or alternatively collect data regarding various measurable parameters (e.g., moisture, temperature, soil conditions, etc.) associated with particular locations on the parcel 20.

In an example embodiment, the robotic mower 10 may be battery powered via one or more rechargeable batteries. Accordingly, the robotic mower 10 may be configured to return to a charge station 40 that may be located at some position on the parcel 20 in order to recharge the batteries. The batteries may power a drive system and a blade control system of the robotic mower 10. However, the control circuitry 12 of the robotic mower 10 may selectively control the application of power or other control signals to the drive system and/or the blade control system to direct the operation of the drive system and/or blade control system. Accordingly, movement of the robotic mower 10 over the parcel 20 may be controlled by the control circuitry 12 in a manner that enables the robotic mower 10 to systematically traverse the parcel while operating a cutting blade to cut the grass on the parcel 20. In cases where the robotic vehicle is not a mower, the control circuitry 12 may be configured to control another functional or working assembly that may replace the blade control system and blades.

In some embodiments, the control circuitry 12 and/or a communication node at the charge station 40 may be configured to communicate wirelessly with an electronic device 42 (e.g., a personal computer, a cloud based computer, server, mobile telephone, PDA, tablet, smart phone, and/or the like) of a remote operator 44 (or user) via wireless links 46 associated with a wireless communication network 48. The wireless communication network 48 may provide operable coupling between the remote operator 44 and the robotic mower 10 via the electronic device 42, which may act as a remote control device for the robotic mower 10 or may receive data indicative or related to the operation of the robotic mower 10. However, it should be appreciated that the wireless communication network 48 may include additional or internal components that facilitate the communication links and protocols

employed. Thus, some portions of the wireless communication network 48 may employ additional components and connections that may be wired and/or wireless. For example, the charge station 40 may have a wired connection to a computer or server that is connected to the wireless communication network 48, which may then wirelessly connect to the electronic device 42. As another example, the robotic mower 10 may wirelessly connect to the wireless communication network 48 (directly or indirectly) and a wired connection may be established between one or more servers of the wireless communication network 48 and a PC of the remote operator 44. In some embodiments, the wireless communication network 48 may be a data network, such as a local area network (LAN), a metropolitan area network (MAN), a wide area network (WAN) (e.g., the Internet), and/or the like, which may couple the robotic mower 10 to devices such as processing elements (e.g., personal computers, server computers or the like) or databases. Accordingly, communication between the wireless communication network 48 and the devices or databases (e.g., servers, electronic device 42, control circuitry 12) may be accomplished by either wireline or wireless communication mechanisms and corresponding protocols.

FIG. 2 illustrates a block diagram of various components of the control circuitry 12 to illustrate some of the components that enable or enhance the functional performance of the robotic mower 10 and to facilitate description of an example embodiment. In some example embodiments, the control circuitry 12 may include or otherwise be in communication with a vehicle positioning module 60, a detection module 70 (e.g., for detecting objects, borders and/or the like), and a position quality analyzer (PQA) module 80. As mentioned above, the vehicle positioning module 60, the detection module 70, and the PQA module 80 may work together to give the robotic mower 10 a comprehensive understanding of its environment, and enable it to be operated autonomously without boundary wires. However, in some embodiments, the detection module 70 may not be needed or desired. Thus, some embodiments may include only the vehicle positioning module 60 and the PQA module 80.

Any or all of the vehicle positioning module 60, the detection module 70 (if employed), and the PQA module 80 may be part of a sensor network 90 of the robotic mower 10. However, in some cases, any or all of the vehicle positioning module 60, the detection module 70, and the PQA module 80 may be separate from but otherwise in communication with the sensor network 90 to facilitate operation of each respective module.

In some examples, one or more of the vehicle positioning module 60, the detection module 70, and the PQA module 80 may further include or be in communication with a camera 95 other imaging device. However, the camera 95 is also not necessarily employed in

some embodiments. If employed, the camera 95 may be a part of the sensor network 90, part of any of the modules described above, or may be in communication with one or more of the modules to enhance, enable or otherwise facilitate operation of respective ones of the modules. The camera 95 may include an electronic image sensor configured to store captured
5 image data (e.g., in memory 114). Image data recorded by the camera 95 may be in the visible light spectrum or in other portions of the electromagnetic spectrum (e.g., IR camera). In some cases, the camera 95 may actually include multiple sensors configured to capture data in different types of images (e.g., RGB and IR sensors). The camera 95 may be configured to capture still images and/or video data and may be a single camera or multiple
10 cameras forming a camera assembly.

The robotic mower 10 may also include one or more functional components 100 that may be controlled by the control circuitry 12 or otherwise be operated in connection with the operation of the robotic mower 10. The functional components 100 may include a wheel assembly (or other mobility assembly components), one or more cutting blades and
15 corresponding blade control components, and/or other such devices for performing a yard maintenance or lawn care function. In embodiments where the robotic vehicle is not a mower, the functional components 100 may include equipment for performing various lawn care functions such as, for example, taking soil samples, operating valves, distributing water, seed, powder, pellets or chemicals, and/or other functional devices and/or components.

The control circuitry 12 may include processing circuitry 110 that may be configured to perform data processing or control function execution and/or other processing and management services according to an example embodiment of the present invention. In some embodiments, the processing circuitry 110 may be embodied as a chip or chip set. In other words, the processing circuitry 110 may comprise one or more physical packages (e.g., chips)
25 including materials, components and/or wires on a structural assembly (e.g., a baseboard). The structural assembly may provide physical strength, conservation of size, and/or limitation of electrical interaction for component circuitry included thereon. The processing circuitry 110 may therefore, in some cases, be configured to implement an embodiment of the present invention on a single chip or as a single “system on a chip.” As such, in some cases, a chip or
30 chipset may constitute means for performing one or more operations for providing the functionalities described herein.

In an example embodiment, the processing circuitry 110 may include one or more instances of a processor 112 and memory 114 that may be in communication with or otherwise control a device interface 120 and, in some cases, a user interface 130. As such,

the processing circuitry 110 may be embodied as a circuit chip (e.g., an integrated circuit chip) configured (e.g., with hardware, software or a combination of hardware and software) to perform operations described herein. However, in some embodiments, the processing circuitry 110 may be embodied as a portion of an on-board computer. In some embodiments, the processing circuitry 110 may communicate with electronic components and/or sensors of the robotic mower 10 via a single data bus. As such, the data bus may connect to a plurality or all of the switching components, sensory components and/or other electrically controlled components of the robotic mower 10.

The processor 112 may be embodied in a number of different ways. For example, the processor 112 may be embodied as various processing means such as one or more of a microprocessor or other processing element, a coprocessor, a controller or various other computing or processing devices including integrated circuits such as, for example, an ASIC (application specific integrated circuit), an FPGA (field programmable gate array), or the like. In an example embodiment, the processor 112 may be configured to execute instructions stored in the memory 114 or otherwise accessible to the processor 112. As such, whether configured by hardware or by a combination of hardware and software, the processor 112 may represent an entity (e.g., physically embodied in circuitry – in the form of processing circuitry 110) capable of performing operations according to embodiments of the present invention while configured accordingly. Thus, for example, when the processor 112 is embodied as an ASIC, FPGA or the like, the processor 112 may be specifically configured hardware for conducting the operations described herein. Alternatively, as another example, when the processor 112 is embodied as an executor of software instructions, the instructions may specifically configure the processor 112 to perform the operations described herein.

In an example embodiment, the processor 112 (or the processing circuitry 110) may be embodied as, include or otherwise control the vehicle positioning module 60, the detection module 70, and the PQA module 80. As such, in some embodiments, the processor 112 (or the processing circuitry 110) may be said to cause each of the operations described in connection with the vehicle positioning module 60, the detection module 70, and the PQA module 80 by directing the vehicle positioning module 60, the detection module 70, and the PQA module 80, respectively, to undertake the corresponding functionalities responsive to execution of instructions or algorithms configuring the processor 112 (or processing circuitry 110) accordingly. These instructions or algorithms may configure the processing circuitry 110, and thereby also the robotic mower 10, into a tool for driving the corresponding physical components for performing corresponding functions in the physical world in accordance with

the instructions provided.

In an exemplary embodiment, the memory 114 may include one or more non-transitory memory devices such as, for example, volatile and/or non-volatile memory that may be either fixed or removable. The memory 114 may be configured to store information, data, applications, instructions or the like for enabling the vehicle positioning module 60, the detection module 70, and the PQA module 80 to carry out various functions in accordance with exemplary embodiments of the present invention. For example, the memory 114 could be configured to buffer input data for processing by the processor 112. Additionally or alternatively, the memory 114 could be configured to store instructions for execution by the processor 112. As yet another alternative, the memory 114 may include one or more databases that may store a variety of data sets responsive to input from various sensors or components of the robotic mower 10. Among the contents of the memory 114, applications may be stored for execution by the processor 112 in order to carry out the functionality associated with each respective application.

The applications may include applications for controlling the robotic mower 10 relative to various operations including determining an accurate position of the robotic mower 10 (e.g., using one or more sensors of the vehicle positioning module 60). Alternatively or additionally, the applications may include applications for controlling the robotic mower 10 relative to various operations including determining the existence and/or position of obstacles (e.g., static or dynamic) and borders relative to which the robotic mower 10 must navigate (e.g., using one or more sensors of the detection module 70). Alternatively or additionally, the applications may include applications for determining a quality rating or other qualitative assessment regarding position information gathered via the vehicle positioning module 60 (e.g., using the PQA module 80). Alternatively or additionally, the applications may include applications for controlling aspects of the operation of the robotic mower 10 based on the qualitative assessment regarding position information.

The user interface 130 (if implemented) may be in communication with the processing circuitry 110 to receive an indication of a user input at the user interface 130 and/or to provide an audible, visual, mechanical or other output to the user. As such, the user interface 130 may include, for example, a display, one or more buttons or keys (e.g., function buttons), and/or other input/output mechanisms (e.g., microphone, speakers, cursor, joystick, lights and/or the like).

The device interface 120 may include one or more interface mechanisms for enabling communication with other devices either locally or remotely. In some cases, the device

interface 120 may be any means such as a device or circuitry embodied in either hardware, or a combination of hardware and software that is configured to receive and/or transmit data from/to sensors or other components in communication with the processing circuitry 110. In some example embodiments, the device interface 120 may provide interfaces for communication of data to/from the control circuitry 12, the vehicle positioning module 60, the detection module 70, the PQA module 80, the sensor network 90, the camera 95 and/or other functional components 100 via wired or wireless communication interfaces in a real-time manner, as a data package downloaded after data gathering or in one or more burst transmission of any kind.

Each of the vehicle positioning module 60, the detection module 70, and the PQA module 80 may be any means such as a device or circuitry embodied in either hardware, or a combination of hardware and software that is configured to perform the corresponding functions described herein. Thus, the modules may include hardware and/or instructions for execution on hardware (e.g., embedded processing circuitry) that is part of the control circuitry 12 of the robotic mower 10. The modules may share some parts of the hardware and/or instructions that form each module, or they may be distinctly formed. As such, the modules and components thereof are not necessarily intended to be mutually exclusive relative to each other from a compositional perspective.

The vehicle positioning module 60 (or "positioning module") may be configured to utilize one or more sensors (e.g., of the sensor network 90) to determine a location of the robotic mower 10 and direct continued motion of the robotic mower 10 to achieve appropriate coverage of the parcel 20. As such, the robotic mower 10 (or more specifically, the control circuitry 12) may use the location information to determine a mower track and/or provide full coverage of the parcel 20 to ensure the entire parcel is mowed (or otherwise serviced). The vehicle positioning module 60 may therefore be configured to direct movement of the robotic mower 10, including the speed and direction of the robotic mower 10. The vehicle positioning module 60 may also employ such sensors to attempt to determine an accurate current location of the robotic mower 10 on the parcel 20 (or generally).

Various sensors of sensor network 90 of the robotic mower 10 may be included as a portion of, or otherwise communicate with, the vehicle positioning module 60 to, for example, determine vehicle speed/direction, vehicle location, vehicle orientation and/or the like. Sensors may also be used to determine motor run time, machine work time, and other operational parameters. In some embodiments, positioning and/or orientation sensors (e.g., global positioning system (GPS) receiver and/or accelerometer) may be included to monitor,

display and/or record data regarding vehicle position and/or orientation as part of the vehicle positioning module 60.

In an example embodiment, the detection module 70 (if employed) may be configured to utilize one or more sensors (e.g., of the sensor network 90) to detect objects and/or boundaries that are located in the area around the robotic mower 10 to enable the robotic mower 10 to identify the objects or boundaries without physically contacting them. Thus, the detection module 70 may enable object avoidance as well as allow the robotic mower 10 to avoid contact with boundaries, buildings, fences, and/or the like while covering the parcel 20. As such, the robotic mower 10 (or more specifically, the control circuitry 12) may object/boundary detection information to alter a mower track and/or report impediments to providing full coverage of the parcel 20. The detection module 70 may therefore be configured to detect static (i.e., fixed or permanent) and/or dynamic (i.e., temporary or moving) objects in the vicinity of the robotic mower 10. In some cases, the detection module 70 may be further configured to classify or identify the objects detected (e.g., by type, as known or unknown, as static or dynamic objects, as specific objects, and/or the like). Moreover, in some cases, the detection module 70 may interact with the vehicle positioning module 60 to utilize one or more objects to facilitate positioning or boundary definition for the robotic mower 10.

Various sensors of sensor network 90 of the robotic mower 10 may be included as a portion of, or otherwise communicate with, the detection module 70 to, for example, determine the existence of objects, determine range to objects, determine direction to objects, classify objects, and/or the like.

In an example embodiment, the PQA module 80 may be configured to interact with the positioning module 60 to analyze the position information determined thereby. The analysis may include performing a qualitative assessment of the position information. In some cases, the PQA module 80 may be configured to analyze the quality of GPS position information (and/or data associated with generating such information) to determine whether the corresponding location at which such position information was determined lies within a shadow zone (i.e., an impaired area) or otherwise in a zone in which GPS information appears to be degraded. In some embodiments, the PQA module 80 may be further configured to classify or attempt to make a causal determination regarding the shadow zone and/or a descriptive assessment of the shadow zone. For example, the PQA module 80 may be configured to analyze the data (and/or use other sensors in cooperation with the detection module 70) to determine whether the shadow zone is caused by a particular obstacle and, if

so, the size, shape and/or location of the obstacle causing the shadow zone. Furthermore, in some cases, the shadow zone may have a temporal aspect associated therewith, such that, for example, the shadow zone is present at particular times of the day, week, month or year. These types of determinations are examples of a causal determination. A descriptive assessment of the shadow zone may include using the data to determine the size, shape and/or location of the shadow zone itself, and/or of other shadow zones. If applicable, the descriptive assessment may also include a temporal component so that the corresponding shadow zone can be avoided during times when the impacts are present or present above a threshold impairment level. Descriptive assessments of each shadow zone may further include a degree of impairment (e.g., minor, moderate or major), which is meant to indicate whether the impairment renders the corresponding position information useable in spite of the impairment or unreliable.

If, for example, the descriptive assessment for a particular zone indicates that the particular zone has minor impairment, information, some embodiments may continue to use GPS position information in the corresponding zone as a primary location source. However, for example, if the descriptive assessment for a certain zone indicates that the certain zone has major impairment, then the positioning module 60 may be informed to ignore GPS position information in the certain zone and instead rely on another source for position information determinations.

In some embodiments, the PQA module 80 may be configured to export shadow zone information (e.g., qualitative assessment information, causal determinations, descriptive assessments, degree of impairment, and/or the like) to external mapping agents, so that any maps of the parcel 20 may be generated or updated to reflect the shadow zones. As such, for example, the zones may be identified and may provide accessible information to the operator to indicate cause and/or degree of impairment for the corresponding zone. Thus, for example, the PQA module 80 may enable data gathered to be used to generate or update a map to, for example, build a graphical display of the parcel 20 and the various objects, boundaries, zones or other differentiating features of the parcel 20 in such a way that the zones identify any applicable shadow zones. As such, the graphical display can be used for future operation (or current operation) of the robotic mower 10 in a manner that considers shadow zones relative to managing the location and navigation of the robotic mower 10.

In an example embodiment, the sensor network 90 may provide data to the modules described above to facilitate execution of the functions described above, and/or any other functions that the modules may be configurable to perform. In some cases, the sensor

network 90 may include (perhaps among other things) any or all of inertial measurement unit (IMU) 150, a GPS receiver 152, and the camera 95, as shown in FIG. 3. In this regard, FIG. 3 illustrates a block diagram of some components that may be employed as part of the sensor network 90 in accordance with an example embodiment.

5 The sensor network 90 may include independent devices with on-board processing that communicate with the processing circuitry 110 of the control circuitry 12 via a single data bus, or via individual communication ports. However, in some cases, one or more of the devices of the sensor network 90 may rely on the processing power of the processing circuitry 110 of the control circuitry 12 for the performance of their respective functions. As
10 such, in some cases, one or more of the sensors of the sensor network 90 (or portions thereof) may be embodied as portions of the detection module 70, and/or the positioning module 60, and any or all of such sensors may employ the camera 95.

 The IMU 150 may include one or more and any or all of combinations of accelerometers, odometers, gyroscopes, magnetometers, compasses, and/or the like. As such,
15 the IMU 150 may be configured to determine velocity, direction, orientation and/or the like so that dead reckoning and/or other inertial navigation determinations can be made by the control circuitry 12. The IMU 150 may be enabled to determine changes in pitch, roll and yaw to further facilitate determining terrain features and/or the like.

 Inertial navigation systems may suffer from integration drift over time. Accordingly,
20 inertial navigation systems may require a periodic position correction, which may be accomplished by getting a position fix from another more accurate method or by fixing a position of the robotic mower 10 relative to a known location. For example, navigation conducted via the IMU 150 may be used for robotic mower 10 operation for a period of time, and then a correction may be inserted when a GPS fix is obtained on robotic mower position.
25 As an example alternative, the IMU 150 determined position may be updated every time the robotic mower 10 returns to the charge station 40 (which may be assumed to be at a fixed location). In still other examples, known reference points may be disposed at one or more locations on the parcel 20 and the robotic mower 10 may get a fix relative to any of such known reference points when the opportunity presents itself. The IMU 150 determined
30 position may then be updated with the more accurate fix information.

 In some embodiments, the GPS receiver 152 may be embodied as a real time kinematic (RTK) – GPS receiver. As such, the GPS receiver 152 may employ satellite based positioning in conjunction with GPS, GLONASS, Galileo, GNSS, and/or the like to enhance accuracy of the GPS receiver 152. In some cases, carrier-phase enhancement may be

employed such that, for example, in addition to the information content of signals received, the phase of the carrier wave may be examined to provide real-time corrections that can enhance accuracy.

In the context of some example embodiments, the IMU 150 should be understood to represent one example of a backup or secondary source of obtaining position information relative to the GPS receiver 152. Thus, it should be understood that other alternative or additional backup sources could be provided in other examples. For example, in some cases, a radio receiver may be provided to include an ultra wide band (UWB), or other radio beacon for transmitting radio information that can be received and processed at the robotic mower 10 for positioning purposes. The camera 95 may also assist with positioning techniques employing optical flow or other image analysis techniques.

The camera 95 may also be used to assist with identifying and/or classifying objects that may be causative of shadow zones. Thus, for example, the camera 95 may be used to exemplify one mechanism by which the detection module 70 (if employed) may obtain information that may facilitate the making of causal determinations and/or descriptive assessments. However, it should be appreciated that other sensors could also or alternatively be employed in other example embodiments. For example, a 2.5D sensor (e.g., a LIDAR (laser imaging detection and ranging) device or a LEDDAR (light emitting diode detection and ranging) device) or other time-of-flight ranging device or contactless detector may be employed in some cases.

By incorporating the sensor network 90 and the modules described above, the robotic mower 10 may be enabled to perform a plurality of functions without reliance upon a boundary wire and without necessarily bumping into objects. Accordingly, the robotic mower 10 may be substantially contactless robotic vehicle that can operate in defined boundaries without a boundary wire while performing a number of useful functions. Moreover, the robotic mower 10 may be enabled to identify any particular areas in which GPS shadow zones are present so that the robotic mower 10 can shift reliance for positioning information to another (presumably better) sensor when in shadow zones. However, the information may also be used to inform the operator so that if certain obstacles can be identified, the operator can take corrective action to improve the GPS environment. For example, certain objects could be moved, removed, or altered to improve the GPS environment. In this regard, for example, branches could be pruned or trimmed, trees could be removed, and/or other objects could be moved when practicable or desirable.

In an example embodiment, the qualitative assessment performed by the PQA module

80 may include the ability to detect or analyze any or all of the user equivalent range errors that are known to exist for GPS systems. Thus, for example, the PQA module 80 may be configured to detect or analyze signal arrival time measurement errors, ionospheric effects, ephemeris errors, satellite clock errors, multipath distortion, tropospheric effects, and/or the like. However, since objects impacting GPS accuracy are most likely to be a factor for multipath distortion and signal arrival time measurement errors, some embodiments may focus primarily on either or both of these potential errors. Thus, for example, the PQA module 80 may be configured to detect areas where signals from particular satellites are blocked or degraded based on detection of these effects and note the same for a given location while the robotic mower 10 is operating. In some cases, specific data regarding errors experienced at each location may be noted and/or stored. Contours and/or locations of shadow zones may then be identified based on the errors detected or detectable from the data recorded.

FIG. 4 illustrates a graphical representation of the parcel 20 generated into a map view in accordance with an example embodiment. The graphical representation of FIG. 4 is a 2D representation similar to a map view, showing a variety of different work zones defined based on desires of the operator. In this regard, the work zones may include a work area 291 defined along with a first exclusion area 292 and a second exclusion area 293. The first and second exclusion areas 292 and 293 may be designated by the operator as cultivated areas, or areas that are otherwise not grass and that the robotic mower 10 is to avoid. However, the work area 291 may be defined as an area that is to be mowed in its entirety. Various structures (e.g., bushes 294) are also represented, and may be appreciated by the robotic mower 10 as inaccessible areas due to the existence of a structure at the location.

The bushes 294 may be known objects. Similarly, in some cases, the first and/or second exclusion areas 292 and 293 may have borders defined by wooden, stone or other structures that may be known objects. One or more portions of the boundary 30 may also comprise known objects. However, other objects may also be encountered and/or displayed on the map. In this regard, a tree trunk 295 is also shown in FIG. 4. As can easily be appreciated from FIG. 4, the tree that corresponds to tree trunk 295 may interfere with GPS signaling on the work area 291. Accordingly, the robotic mower 10 may experience a shadow zone 297 while transiting the parcel. The location of the shadow zone 297 may be experientially determined based on detecting degraded GPS performance in the shadow zone 297. As such, the experiential determination may be an example of performing a qualitative assessment of the position information gathered in the shadow zone 297. By identifying the

edges of the shadow zone, and identifying the nature of the degradation, the PQA module 80 may have effectively performed a descriptive assessment of the shadow zone 297, and such data may be recorded and/or provided in a way that can be extracted from the map view of FIG. 4. After the shadow zone 297 has been experienced and identified by the PQA module 80, the PQA module 80 may be further configured to attempt to determine a cause. In making a causal determination, the PQA module 80 may be configured to correlate the shadow zone 297 to any known objects that are classified as potential causes. For example, buildings, trees, or other large structures may be identified as potential causes. Thus, having a known object (i.e., tree trunk 295) nearby, the PQA module 80 may be configured to correlate the shadow zone 297 to the tree trunk 295 as a likely cause for the shadow zone 297. The operator may be informed of the shadow zone 297 and potential cause by a message or by an indication provided on a map view (such as the map view of FIG. 4). Finally, the PQA module 80 may be configured to determine the degree of impairment based on the amount of signal degradation experienced. In some cases, a label such as minor, moderate or major may be provided on the map view of FIG. 4 to illustrate the degree of impairment. As mentioned above, with major impairment in the shadow zone 297, the positioning module 60 may shift to using the IMU 150 as a primary positioning source.

Accordingly, the robotic mower 10 (or other robotic vehicle) may be provided with the positioning module 60, the detection module 70, and the PQA module 80 to process sensor data received from the sensor network 90. The robotic mower 10 may therefore be capable of accurately determining its position and gathering information about its surroundings to further perform a qualitative assessment of position information determined for the robotic mower 10. With accurate position determining capabilities, and the ability to qualitatively assess positioning information, the robotic mower 10 can strategically shift between positioning sources to obtain the most accurate positioning to achieve quality coverage of the parcel 20 within boundaries that are not necessarily provided by wire means. The robotic mower 10 may therefore be more capable of being programmed to perform autonomous activities of various kinds and the value proposition for owners and operators may be greatly enhanced.

Embodiments of the present invention may therefore be practiced using an apparatus such as the one described in reference to FIGS 1-4. However, it should also be appreciated that some embodiments (or aspects thereof) may be practiced in connection with a computer program product for performing embodiments of the present invention. As such, for example, each block or step of the flowcharts of FIGS. 5 and 6, and combinations of blocks

in the flowcharts, may be implemented by various means, such as hardware, firmware, processor, circuitry and/or another device associated with execution of software including one or more computer program instructions. Thus, for example, one or more of the procedures described above may be embodied by computer program instructions, which may
5 embody the procedures described above and may be stored by a storage device (e.g., memory 114) and executed by processing circuitry (e.g., processor 112).

As will be appreciated, any such stored computer program instructions may be loaded onto a computer or other programmable apparatus (i.e., hardware) to produce a machine, such that the instructions which execute on the computer or other programmable apparatus
10 implement the functions specified in the flowchart block(s) or step(s). These computer program instructions may also be stored in a computer-readable medium comprising memory that may direct a computer or other programmable apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instructions to implement the function specified in the flowchart
15 block(s) or step(s). The computer program instructions may also be loaded onto a computer or other programmable apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions specified in the flowchart block(s) or step(s).

FIG. 5 illustrates a control flow diagram of one example of how the robotic mower 10 can be operated in relation to using the sensors thereon to qualitatively assess positioning information in accordance with an example embodiment. As shown in FIG. 5, operation may begin with commencement of parcel traversal by the robotic mower 10 at operation 400. During such operation, position information may be obtained using a current (or first)
25 positioning source at operation 402. The current (or first) positioning source may be a first sensor of the sensor network (e.g., a GPS receiver, RTK-GPS receiver, and/or the like). The position information may be subject to a qualitative assessment of each fix or of a sequence of position fixes or other position information at operation 404. The qualitative assessment 404 may include the analysis and/or recording of data associated with gathering the position
30 information that is indicative of the quality of the corresponding position information. A determination may then be made as to whether the qualitative assessment indicates that the position information corresponds to an impaired area (or shadow zone) at operation 406. The determination at operation 406 may include a comparison of signal strength values, noise figure values, multipath distortion errors, signal arrival time measurement errors, and/or the

like to specified thresholds to determine whether such values are above (or below) the specified thresholds that correspond to impaired area status. However, in some cases, the determination at operation 406 may include a comparison of subsequent signal strength values, noise figure values, multipath distortion errors, signal arrival time measurement errors, and/or the like to each other to determine a change has occurred above (or below) specified thresholds relative to immediately or more distant prior corresponding values to see if the magnitude of the change corresponds to impaired area status. Other possible determining criteria could also be employed.

If there is no indication of a possible impaired area, then flow may return to operation 402. However, if the area appears to be impaired, then any or both of two additional determinations may be employed at operations 408 and 416, and it should be appreciated that such operations could be employed in any order. One of the determinations (operation 408) may be a causal determination. The causal determination may attempt to see if the impaired area can be correlated to or explained by an object nearby. The object may also be identified, if possible. If no cause can be determined, the descriptive assessment for the impaired area may be recorded at operation 410. The descriptive assessment may include the location associated with the impaired area and any data indicating the potential for impaired status.

A determination may then be made, at operation 412, as to whether the degree of impairment is above a threshold. If the degree of impairment is not above the threshold, then flow may return to operation 402 and continued analysis may be conducted that may (if still in the impaired area) allow different or updated results from operations 408 and/or 416. If the degree of impairment is above the threshold, then the positioning source may be switched at operation 414 before returning to operation 402. Thus, the next positioning source (e.g., a second sensor of the sensor network 90) may be used to provide further position information. This position information may (or may not) also be subject to qualitative assessment in accordance with this method.

Returning to operation 406, if the area is impaired an effort may be made to include a description of the size and/or shape of the impaired area (and any applicable temporal component) at operation 416. The determinations of operations 408 and 416 may be made in parallel or in any desirable sequence relative to each other. In any case, if the size and/or shape of the impaired area is not determinable via a current cycle of the method, then the descriptive assessment may be recorded (with corresponding cause if one was determinable) at operation 418 before the impairment degree check is performed at operation 412. As mentioned above, further cycles may gain more information that may eventually lead to the

size and/or shape of the impaired area (along with any applicable temporal component) being determinable. Once the size and/or shape are determinable as a result of operation 416, then the corresponding descriptive assessment may be made at operation 420 before the impairment degree check is performed at operation 412.

5 Of note, the processes above may incorporate some or all of mapping, position determining and object detection, which can be accomplished based on the inclusion of the sensor network 90 and the modules described above. As such, in some cases, the robotic mower 10 may generally operate in accordance with a control method that combines the modules described above to provide a functionally robust robotic vehicle. In this regard, a
10 method according to example embodiments of the invention may include any or all of the operations shown in FIG. 5. Moreover, other methods derived from the descriptions provided herein may also be performed responsive to execution of steps associated with such methods by a computer programmed to be transformed into a machine specifically configured to perform such methods.

15 Of note, the processes above may incorporate all of position determining, data gathering and qualitative assessment, which can be accomplished based on the inclusion of the sensor network 90 and the modules described above. As such, in some cases, the robotic mower 10 may generally operate in accordance with a control method that combines the modules described above to provide a functionally robust robotic vehicle. In this regard, a
20 method according to example embodiments of the invention may include any or all of the operations shown in FIG. 5. Moreover, other methods derived from the descriptions provided herein may also be performed responsive to execution of steps associated with such methods by a computer programmed to be transformed into a machine specifically configured to perform such methods.

25 In an example embodiment, a method for identifying impairment areas or zones on a parcel based on operation of a robotic vehicle (e.g., a mower or watering device), as shown in FIG. 6, may include obtaining a plurality of instances of position information responsive to a robotic vehicle traversing a parcel via a first sensor at operation 500, performing a qualitative assessment each instance of the position information at operation 510, and determining
30 whether the position information associated with the first sensor is indicative of an impaired area at operation 520.

 In some cases, the method may further include additional optional operations, some examples of which are shown in dashed lines in FIG. 6. In this regard, for example, the method may further include determining a descriptive assessment of the impaired area at

operation 530. In some cases, the method may further include making a causal determination regarding the impaired area at operation 540. In an example embodiment, the method may further include determining a degree of impairment associated with the impaired area at operation 550. The method may further include switching to determining robotic vehicle
5 position using a second sensor of the sensor network responsive to the degree of impairment exceeding a predetermined threshold at operation 560. In some cases, the method may further include providing the qualitative assessment to a graphical display at operation 570. The optional operations 530-570 may be added in any desirable combination with the operations 500-520.

10 Furthermore, the operations 500-570 may also be modified, augmented or amplified in some cases. For example, in some embodiments, determining the descriptive assessment may include determining a size or shape of the impaired area. In an example embodiment, making the causal determination may include determining whether the impaired area is associated with a nearby obstacle. In some cases, making the causal determination may
15 include determining a size, shape and location of the obstacle.

In an example embodiment, an apparatus for performing the method of FIGS. 5 and 6 above may comprise a processor (e.g., the processor 112) configured to perform some or each of the operations (400-570) described above. The processor 112 may, for example, be configured to perform the operations (400-570) by performing hardware implemented logical
20 functions, executing stored instructions, or executing algorithms for performing each of the operations. Alternatively, the apparatus may comprise means for performing each of the operations described above. In this regard, according to an example embodiment, examples of means for performing operations 400-570 may comprise, for example, the control circuitry 12. Additionally or alternatively, at least by virtue of the fact that the processor 112 may be
25 configured to control or even be embodied as the control circuitry 12, the processor 112 and/or a device or circuitry for executing instructions or executing an algorithm for processing information as described above may also form example means for performing operations 400-570.

Many modifications and other embodiments of the inventions set forth herein will
30 come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Moreover, although the foregoing descriptions and the

associated drawings describe exemplary embodiments in the context of certain exemplary combinations of elements and/or functions, it should be appreciated that different combinations of elements and/or functions may be provided by alternative embodiments without departing from the scope of the appended claims. In this regard, for example, 5 different combinations of elements and/or functions than those explicitly described above are also contemplated as may be set forth in some of the appended claims. In cases where advantages, benefits or solutions to problems are described herein, it should be appreciated that such advantages, benefits and/or solutions may be applicable to some example embodiments, but not necessarily all example embodiments. Thus, any advantages, benefits 10 or solutions described herein should not be thought of as being critical, required or essential to all embodiments or to that which is claimed herein. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

THAT WHICH IS CLAIMED:

1. A robotic vehicle comprising:
one or more functional components configured to execute a lawn care function;
5 a sensor network comprising one or more sensors configured to detect conditions proximate to the robotic vehicle;
a positioning module configured to determine robotic vehicle position using a first sensor of the sensor network; and
a position quality analysis module configured to perform a qualitative assessment of
10 position information determined via the first sensor, the position quality analysis module being further configured to determine whether the position information determined via the first sensor is indicative of an impaired area.
2. The robotic vehicle of claim 1, wherein the position quality analysis module is
15 further configured to determine a descriptive assessment of the impaired area.
3. The robotic vehicle of claim 2, wherein the descriptive assessment comprises a size or shape of the impaired area.
- 20 4. The robotic vehicle of claim 2 or 3, wherein the descriptive assessment comprises a temporal component.
5. The robotic vehicle of claim 1, wherein the position quality analysis module is configured to make a causal determination regarding the impaired area.
25
6. The robotic vehicle of claim 5, wherein the position quality analysis module is configured to make the causal determination by determining whether the impaired area is associated with a nearby obstacle.
- 30 7. The robotic vehicle of claim 6, wherein making the causal determination comprises determining a size, shape and location of the obstacle.
8. The robotic vehicle of claim 1, wherein the position quality analysis module is configured to determine a degree of impairment associated with the impaired area.

9. The robotic vehicle of claim 8, wherein, responsive to the degree of impairment exceeding a predetermined threshold, the positioning module is configured to switch to determining robotic vehicle position using a second sensor of the sensor network.

5

10. The robotic vehicle of claim 1, wherein the position quality analysis module is configured to provide the qualitative assessment to a graphical display.

11. The robotic vehicle of any preceding claim, wherein the first sensor comprises a real time kinematic (RTK) – GPS receiver.

10

12. A method comprising:
obtaining a plurality of instances of position information responsive to a robotic vehicle traversing a parcel via a first sensor;
performing a qualitative assessment each instance of the position information; and
determining whether the position information associated with the first sensor is indicative of an impaired area.

15

13. The method of claim 12, further comprising determining a descriptive assessment of the impaired area.

20

14. The method of claim 13, wherein determining the descriptive assessment comprises determining a size or shape of the impaired area.

15. The method of claim 13 or 14, wherein determining the descriptive assessment further comprises determining a temporal component associated with the impaired area.

25

16. The method of claim 12, further comprising making a causal determination regarding the impaired area.

30

17. The method of claim 16, wherein making the causal determination comprises determining whether the impaired area is associated with a nearby obstacle.

18. The method of claim 17, wherein making the causal determination comprises determining a size, shape and location of the obstacle.

5 19. The method of claim 12, further comprising determining a degree of impairment associated with the impaired area.

10 20. The method of claim 19, further comprising, responsive to the degree of impairment exceeding a predetermined threshold, switching to determining robotic vehicle position using a second sensor of the sensor network.

21. The method of claim 12, further comprising providing the qualitative assessment to a graphical display.

15 22. The method of any of claims 12-21, wherein the first sensor comprises a real time kinematic (RTK) – GPS receiver.

1/6

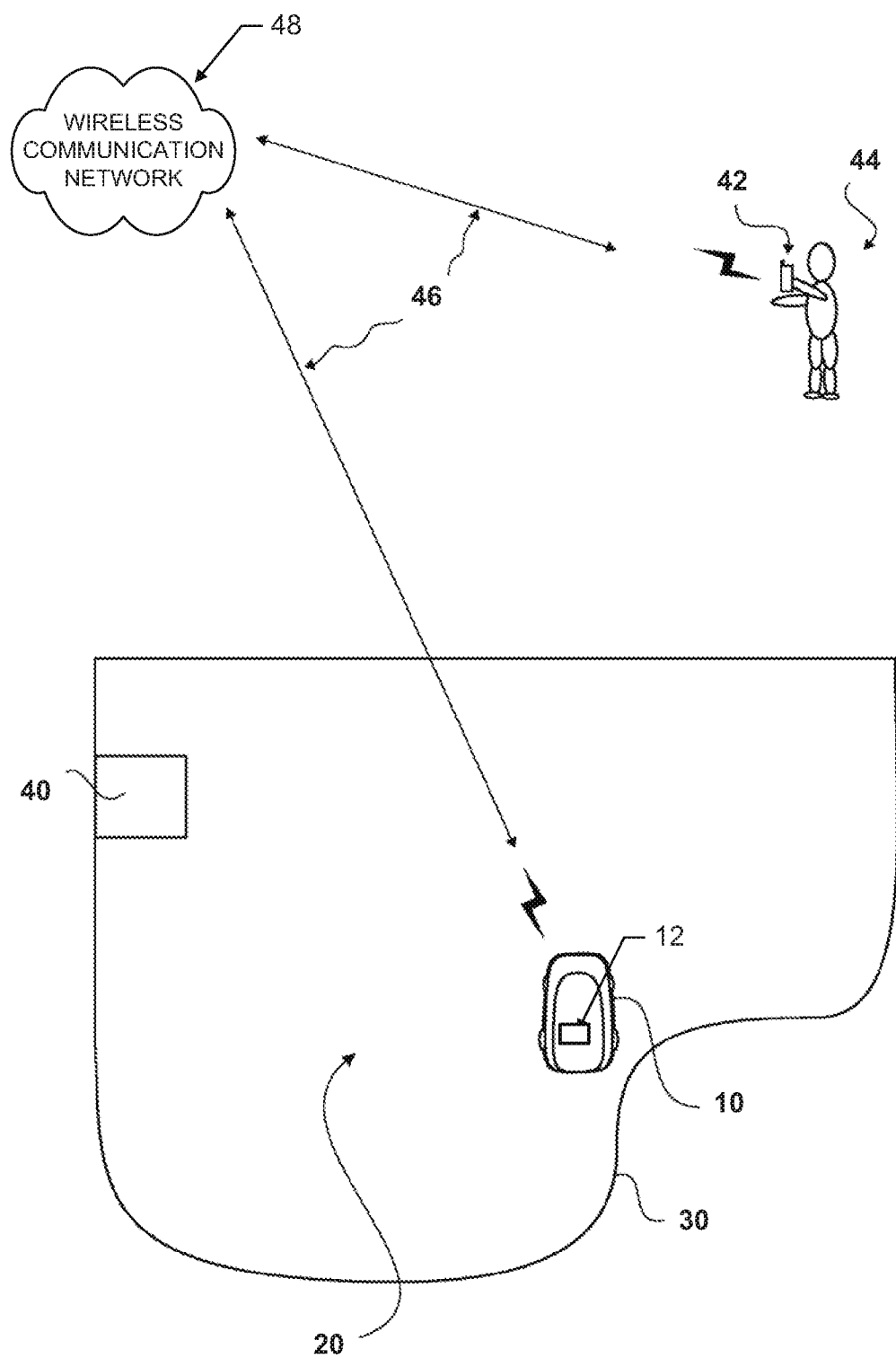


FIG. 1.

2/6

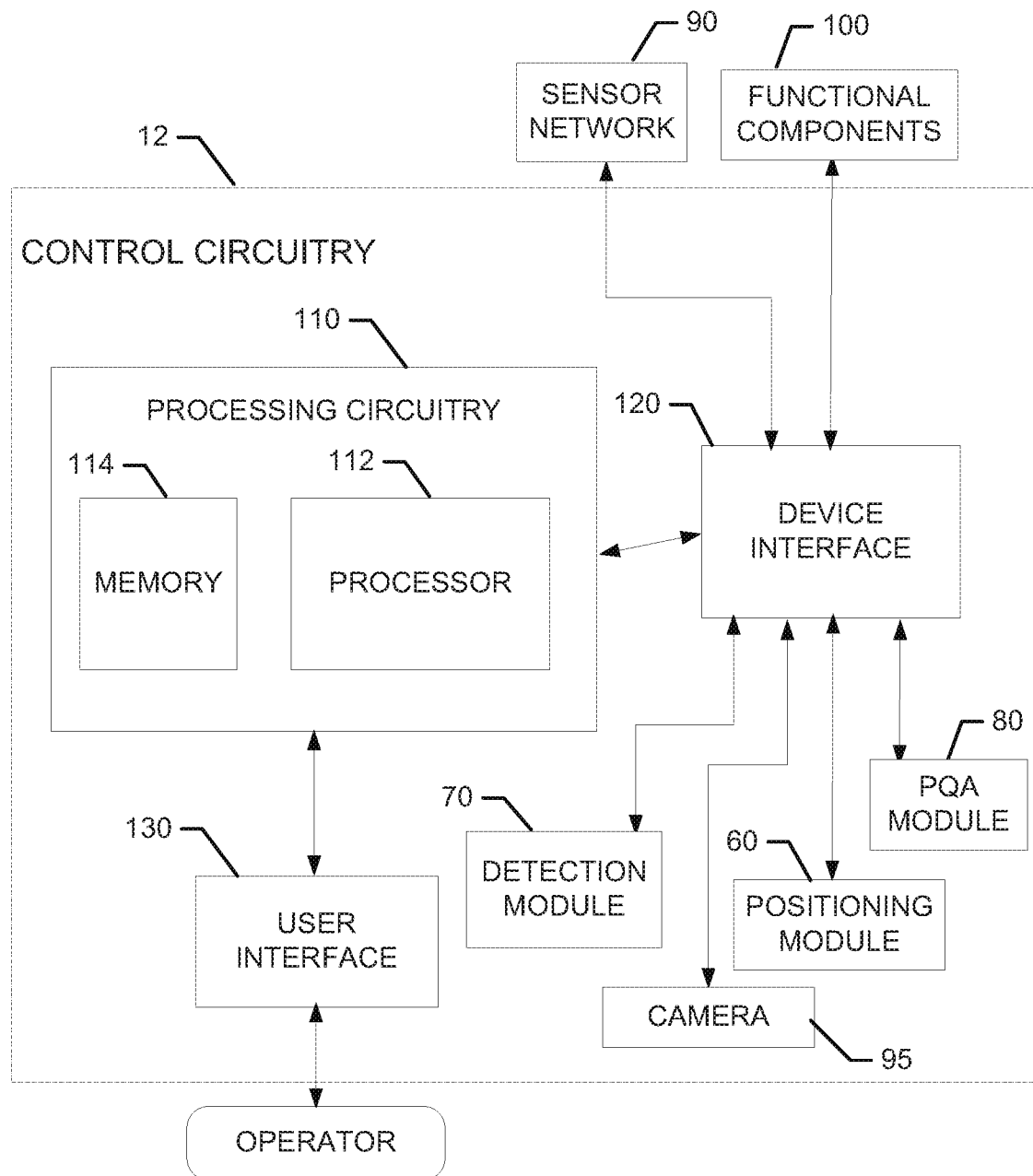


FIG. 2.

3/6

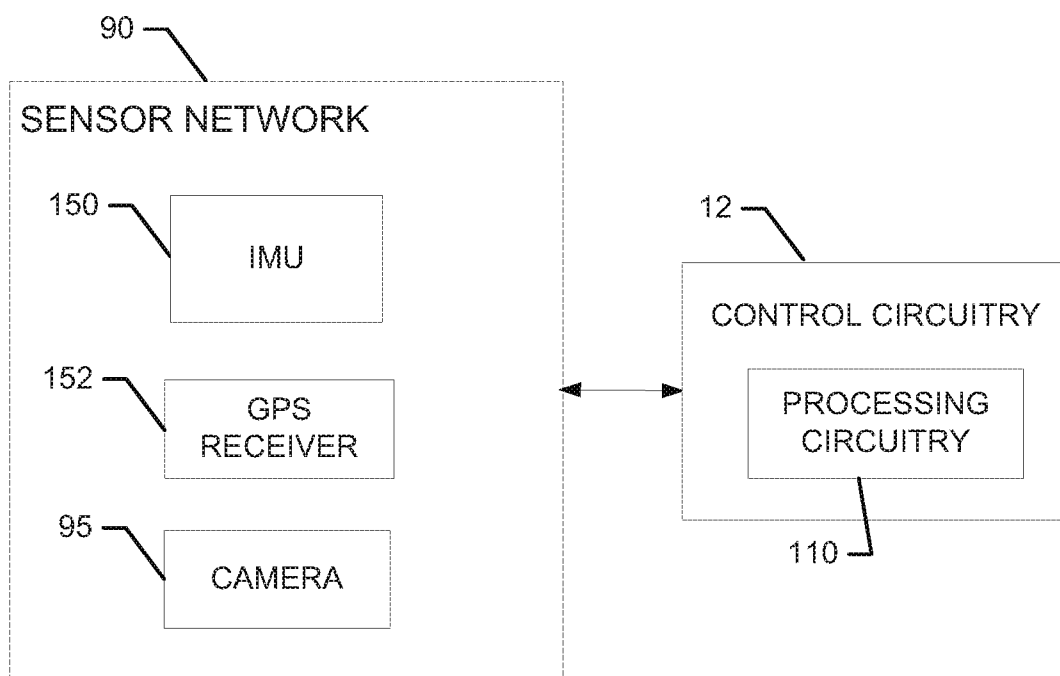


FIG. 3.

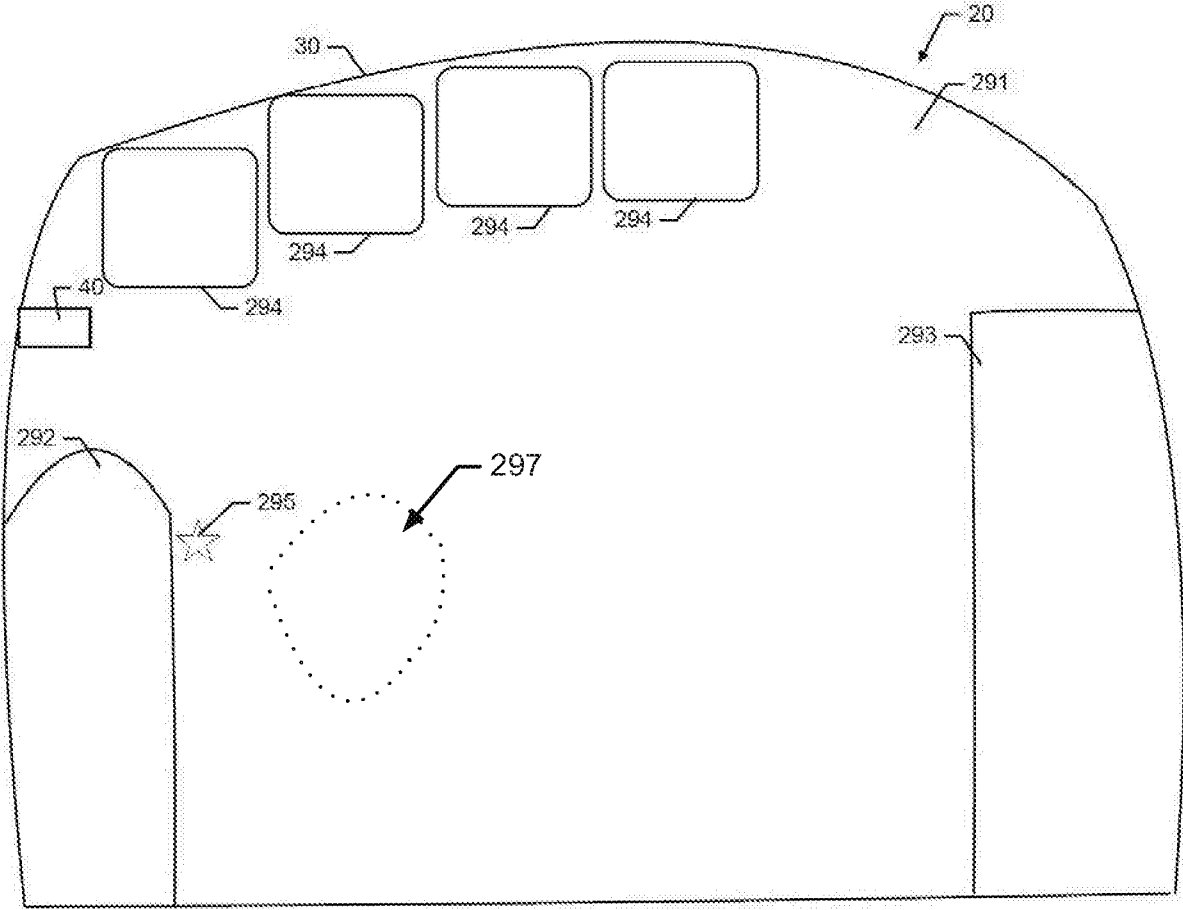


FIG. 4.

5/6

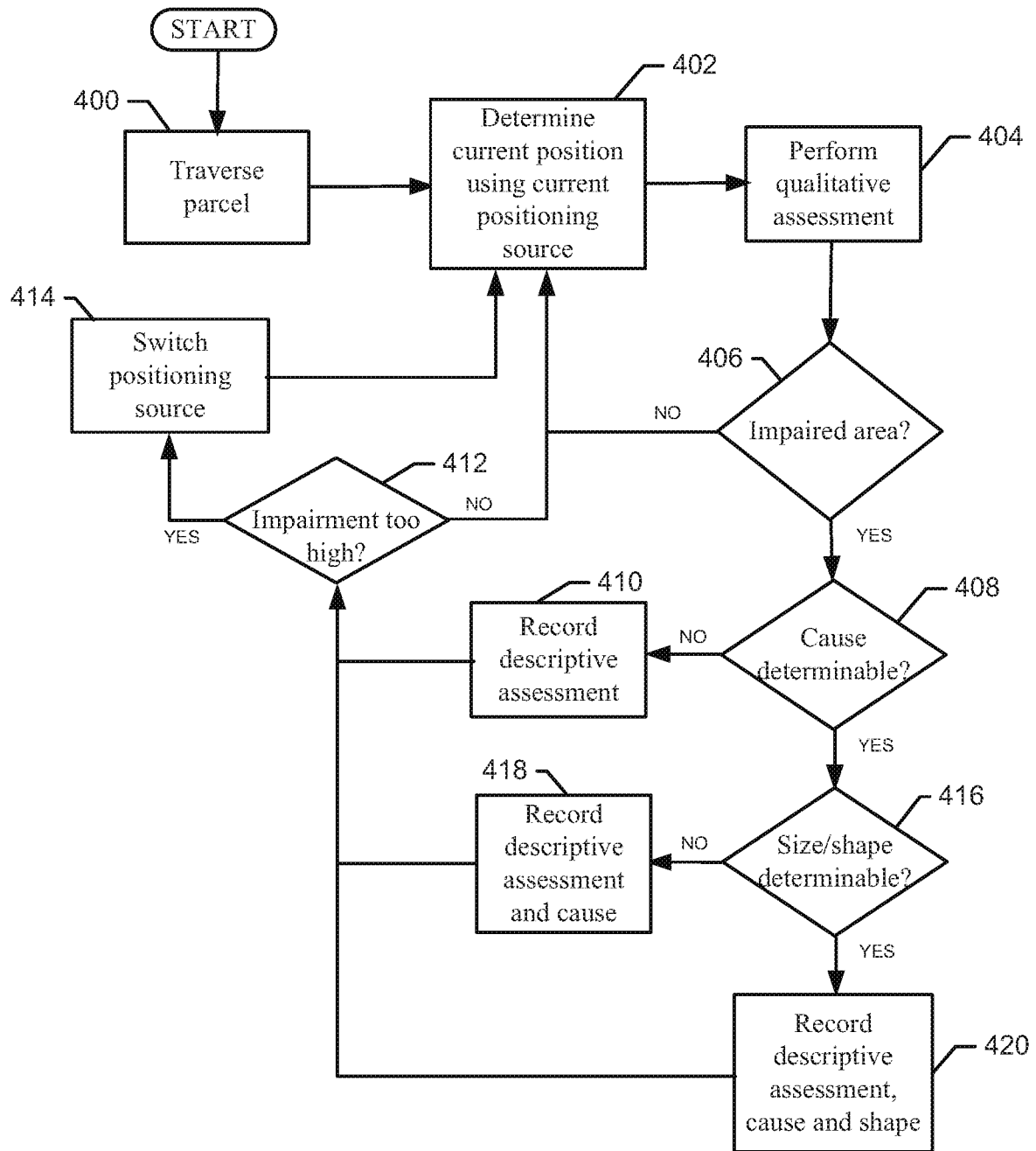


FIG. 5.

6/6

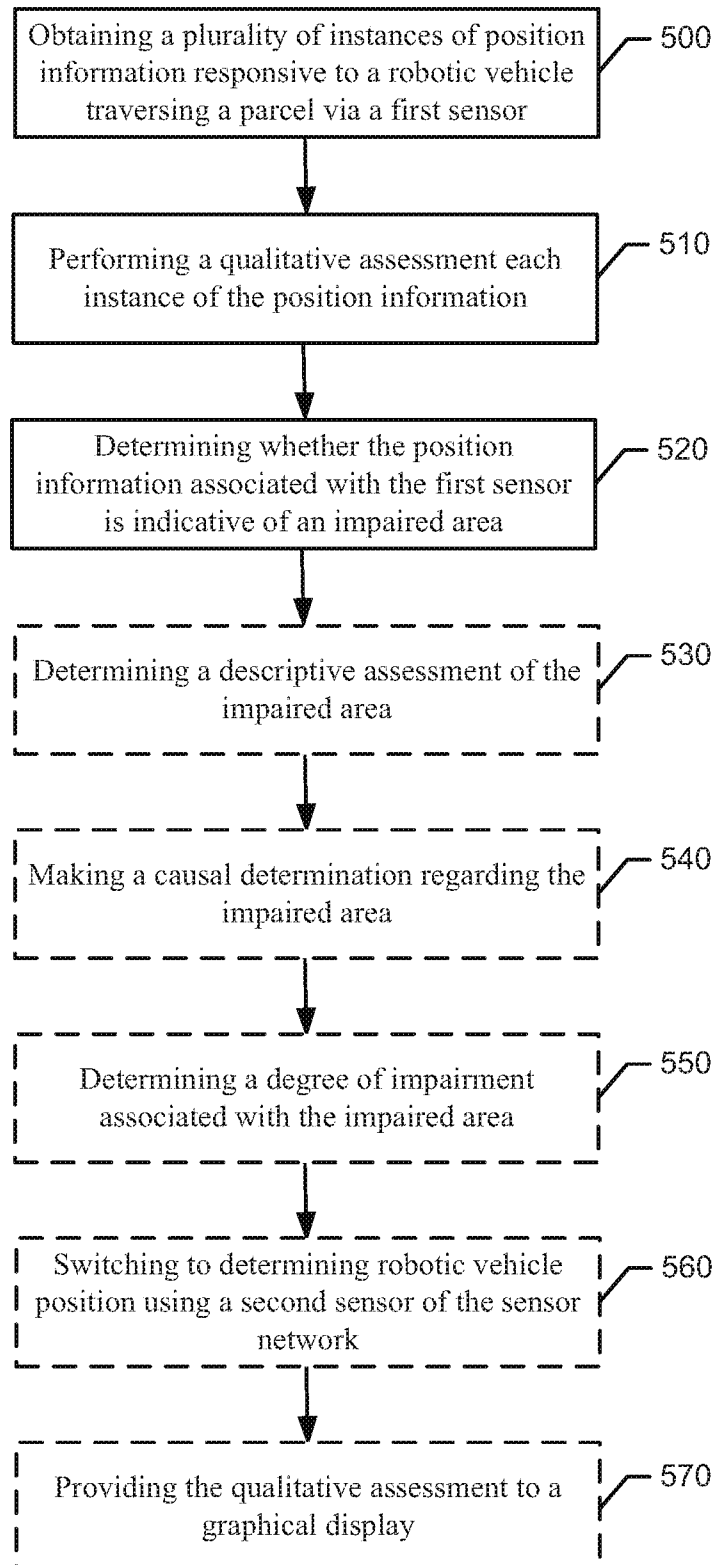


FIG. 6.

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/058251

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01S19/14 G01S19/48 A01D34/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01S A01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	WO 2015/072897 A1 (HUSQVARNA AB [SE]) 21 May 2015 (2015-05-21) page 4, line 12 - page 10, line 27; figures 1-3 -----	1-3,5,8, 9,11-14, 16,19, 20,22
X	CH 705 178 A2 (SCHMALZ DIPL-ING HELMUT [DE]) 31 December 2012 (2012-12-31)	1-5, 8-10, 12-16, 19-21
Y	paragraph [0010] - paragraph [0033]; claims 3,6,7; figures 1,2 ----- -/--	10,11, 21,22



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

22 January 2016

Date of mailing of the international search report

04/02/2016

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INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2015/058251

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2015/058251

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