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(54) ROBOTIC VEHICLE FOR BOUNDARIES DETERMINATION

(57) The present disclosure relates to a robotic vehicle (101, 200, 401) for performing a movable operation in a workable area (104, 404, 724) in accordance with a planned path. The movable operation comprises a soil cultivation. The vehicle (101, 200, 401) comprises a memory (209) and a processor (207). The memory (207) comprises instructions, wherein execution of the instructions by the processor (209) causes the vehicle (101, 200, 401) to: detect, in a current position of the vehicle (101, 200, 401), a change (417) in at least part (412) of current boundaries of the workable area (104, 404, 724); update the workable area (104, 404, 724) by changing boundaries of the workable area (104, 404, 724), the changed boundaries (422) becoming the current boundaries, wherein the update is performed such that the change does not exceed a predefined change threshold (501); and perform the movable operation using the planned path or a re-planned path based on the detected change (417).

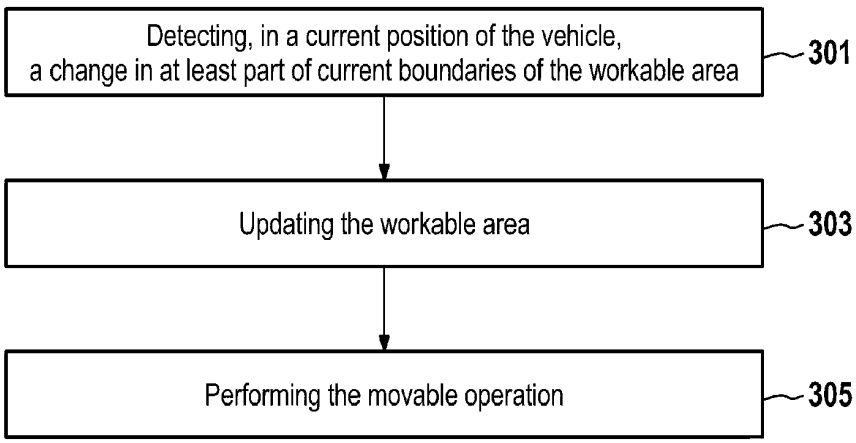

Fig. 3

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Description

BACKGROUND

[0001] The invention relates to a robotic vehicle for soil cultivation, a method for operating a robotic vehicle and a computer program product.

[0002] A robotic lawn mower is an autonomous robot used to maintain lawn grass. A typical robotic lawn mower requires the user to continuously set up a border wire around the lawn that defines the area to be mowed. The robot uses this wire to locate the boundary of the area to be trimmed. However, this border definition requires multiple user interventions.

SUMMARY

[0003] It is an objective to provide for an improved robotic vehicle for soil cultivation, an improved method for operating a robotic vehicle and a computer program product.

[0004] Example embodiments provide a robotic vehicle for performing a movable operation in a workable area in accordance with a planned path. The movable operation comprises a soil cultivation. The robotic vehicle comprises a memory and a processor. The memory comprises instructions, wherein execution of the instructions by the processor causes the robotic vehicle to: detect, in a current position of the vehicle, a change in at least part of current boundaries of the workable area; update (or change) the workable area by changing (or shifting or adjusting) boundaries of the workable area, the changed boundaries becoming the current boundaries, wherein the update is performed such that the change does not exceed a predefined change threshold; and perform the movable operation using the planned path or a re-planned path based on the detected change.

[0005] A robotic vehicle may be a self-propelled vehicle that autonomously moves within the workable area. For example, the robotic vehicle may be battery-powered and may make use of a vehicle base in order to recharge batteries of the robotic vehicle at the base. The robotic vehicle may be configured to automatically travel to the base in order to recharge the batteries at the base.

[0006] The workable area may be a subarea of a larger work area. The work area may comprise non-workable regions or subareas (e.g. non-mowable regions) that may not be suitable for performing the movable operation. For example, the non-workable areas may comprise obstacles and/or areas that a user defined as non-workable areas. The obstacles may define boundaries that delimit the workable area. The workable area may be the work area excluding or without the non-workable areas. A configuration of the work area may, for example, describe or indicate at least part of these different areas of the work area. The configuration may change over time. However, the changes may be non-controllable changes such as natural changes caused by whether conditions etc. This may require a lot of user interventions in order to adapt the workable area in accordance with configuration changes. The configuration may be provided as position data in the robotic vehicle.

[0007] For example, the robotic vehicle may be configured to access position data indicative of the boundaries and/or of the workable area. For example, the robotic vehicle may store the position data. In another example, the position data may be stored in a remote database system, wherein the robotic vehicle is configured to access e.g. query, the position data in the database system via a network connection such as internet. The position data may, for example, comprise boundary position data indicating positions of the boundaries of the workable area. The position data may further comprise workable are position data indicating positions of the boundaries of the workable area. The position data may, for example, be used for planning a path that is to be followed by the vehicle robot in order to perform the movable operation. The robotic vehicle may be configured to use the position data for planning a path. The boundary position data may be used by the robotic vehicle in order to keep the robotic vehicle movement within the workable area. For example, by comparting its current position with the boundary position data, the robotic vehicle may avoid performing the movable operation beyond the workable area. The updating of the workable area may comprise updating the position data. For example, changing the current boundaries may comprise replacing by the robotic vehicle at least part of the current boundary position data by new position data that reflects the changed boundaries. The position data may, for example, be provided in different formats. In one example, the position data may be provided as a grid of points or of cells (e.g. a grid point may represent a respective grid cell) in association with cell information. The cells of the gird may have a square form or other form such as a triangle. The size of the cells may be defined or controlled e.g. depending on user needs or on the level of details needed for path planning.

[0008] The robotic vehicle may be configured to perform one or more predefined localization methods for enabling the movable operation along the planed path. The localization method may enable the robotic vehicle to determine its position while moving in the workable area. The robotic vehicle may be configured to process the vehicle positions (e.g. determined by a localization method) such that the vehicle positions can be compared with the position data. For example, using a RF triangulation, the robotic vehicle may determine where it is located. By matching its location to the position data, the robotic vehicle may perform the movable operation in an accurate manner. This may improve the robotic vehicle's efficiency compared to performing the movable operation in a random pattern.

[0009] The robotic vehicle may be configured to perform the movable operation using the planned path. The planned path may be determined using a predefined planning algorithm e.g. a planning algorithm that uses

the position data. Alternatively, the robotic vehicle may be configured to perform the movable operation using a re-planned path based on the detected change. For example, using the updated position data, the robotic vehicle may determine the re-planned path using the predefined planning algorithm. The planned path m ay be a random path. The re-planned path may be a random path.

[0010] The robotic vehicle may be configured to change the current boundaries in accordance with the detected change. For example, by comparing new detected positions with the boundary position data, the robotic vehicle may determine whether a change occurred or not. For example, by determining that a new detected position is not present in the boundary position data, the robotic vehicle may detect or determine that the boundaries changed.

[0011] For example, the change threshold may dynamically be determined depending on a position of the boundary to be changed. For example, a polygon area may be provided such that the boundaries may be shifted within the polygon area. Thus depending on where the position of the boundary to be changed is located with respect to the polygon area a corresponding change threshold may be used.

[0012] The soil cultivation may comprise mowing of a lawn, core aerification (recommended practice for many lawns reducing soil compaction and thatch, improve surface drainage etc.), watering of soil areas etc. For example, the robotic vehicle is a robotic lawn mower.

[0013] The present subject matter may increase or improve the autonomy of robotic vehicles with little user interactions. The robotic vehicle may be a safe vehicle as it may operate in accordance with up-to-date boundaries e.g. avoiding scratches. The present subject matter may seamlessly be integrated in existing vehicles with fewer burdens.

[0014] According to one embodiment, the execution of the instructions by the processor further causes the robotic vehicle to automatically adapt the change threshold depending on conditions of an environment of the workable area. The change threshold may be time dependent. The robotic vehicle may automatically change the change threshold in predefined time points. For example, depending on the seasons, trees forming boundaries of the workable area may change in size and form e.g. the trees may grow up or the trees may be cut etc. This may imply an inward or outward shifting of boundaries. Depending on the type of the change (which is time dependent) the change threshold may be set accordingly e.g. outward shifting may need to be more limited than inward shifting. This embodiment may enable an optimal control of the movable area and thus may increase the movable operation efficiencies. This may further have the advantage of reducing or eliminating user interventions and thus providing more autonomy for the present robotic vehicle. This may also reduce the risk of damaging the robotic vehicle e.g. in case the change is not controlled over time (e.g. using a single threshold or not using a threshold at all) the movable area may cover in some cases non movable areas.

[0015] According to one embodiment, the change threshold is one of a set of different change thresholds. Each change threshold of the set of change thresholds is associated with a respective part of the work area. The update of the workable area comprises identifying the change threshold of the set of change thresholds that corresponds to a location of the detected change, wherein the predefined change threshold is the identified change threshold. Boundaries may be defined by different obstacle objects e.g. different types of trees, fences, stones etc. The change of the boundaries may thus be dependent on the type of objects and thus dependent on their location in the workable area. This embodiment may enable to control time dependent and position dependent changes in the movable. This may enable a further optimal control of the movable area and thus may increase the movable operation efficiencies. This may further have the advantage of reducing or eliminating user interventions and thus providing more autonomy for the present robotic vehicle. This may also reduce the risk of damaging the robotic vehicle e.g. in case the change is not controlled depending on the position (e.g. using a single threshold or not using a threshold) the movable area may cover in some cases non movable areas.

[0016] According to one embodiment, the set of change thresholds comprise a change threshold for inner boundaries and a change threshold for an outer boundary of the workable area. This may particularly be advantageous because the inner boundary may need to be adapted differently from the outer boundary e.g. mowing areas near inner boundaries may need to be performed more accurately than in areas near outer boundaries due to use preferences. Thus the change threshold may roughly be set of the outer boundary and may more accurately be set for the inner boundary. This embodiment may further optimize the movable operations using the present robotic vehicle.

[0017] According to one embodiment, the detection of the change comprises: detecting an object in the workable area having an object boundary; wherein the update is performed such that the changed boundaries include the object boundary. For example, if the detected object is a tree, the object boundary may be a 2D projection onto the soil of at least part of the tree crown of the tree. The object boundary may, for example, be determined by the robotic vehicle using a 2D light detection and ranging (LiDAR) scanner. This embodiment may enable an automatic and accurate definition of the workable area. This may further reduce or limit user interventions and thus increase the autonomy of the present robotic vehicle.

[0018] According to one embodiment, the execution of the instructions by the processor further causes the vehicle to provide one or more reference boundaries; wherein exceeding the predefined change threshold is

determined relative to the reference boundaries. For example, the reference boundaries are current boundaries of the workable area before the update is performed or predefined fixed boundaries. This embodiment may particularly be advantageous in case the boundary objects frequently change over time. For example, if a boundary changes N times with a same amount X, the boundary may be shifted N times, wherein for each change the current boundary is shifted e.g. this may result in that the initial boundary has been changed by N*X. However, this may result in the workable area covering obstacles. By providing a reference boundary the change may optimally be controlled regardless of the change frequencies. This may further increase the accuracy of the defined workable areas and the autonomy of the robotic vehicle. The reference boundary may, for example, be fixed by the user at once, and the robotic vehicle may store data indicative of the reference boundary. In one example, for each change threshold a respective reference boundary may be provided. This may further increase the accuracy of the defined workable areas and the autonomy of the robotic vehicle.

[0019] According to one embodiment, the execution of the instructions by the processor further causes the vehicle to repeatedly detect, update the workable area, and perform the movable operation, resulting in a set of current boundaries, wherein the reference boundaries are obtained by a combination of the set of current boundaries. This embodiment may, for example, automatically be executed by the robotic vehicle and thus may further increase the autonomy of the robotic vehicle. This embodiment may make use on a history of changes that a normal user may not accurately save or acquire.

[0020] According to one embodiment, the repetition is performed over a predefined time period. This may particularly be advantageous as changes (such as changes for trees) may be periodic changes that repeatedly occur after each time period. Thus, using a predefined time period may enable to set an accurate reference boundary.

[0021] According to one embodiment, in case the change exceeds the predefined change threshold, the execution of the instructions by the processor further causes the vehicle to provide the changed boundaries as boundaries obtained by a change equal to the change threshold. This may enable the robotic vehicle to automatically decide on the definition of the workable area without user interventions.

[0022] According to one embodiment, the detection of the change comprises: detecting an object inside the workable area; wherein the update of the workable area is performed in case the detection of the object fulfills a repetition criterion. This may enable a controlled and systematic adaptation of the workable area, and thus may further increase the autonomy of the robotic vehicle.

[0023] According to one embodiment, the repetition criterion requires that the object is detected for at least N predefined times; the object is detected with a predefined minimum frequency. For example, while moving in a garden, the robotic vehicle may detect many obstacles like a car, a bike a deckchair or other objects. The robotic vehicle may store information indicative of the detected objects in a database and after a certain amount of finding the same obstacle (e.g. having the same place and same size) the robotic vehicle may set automatically a new inner boundary. This may, for example, avoid to change the workable area in case the detected object is temporary object such a person sitting in the workable area or a missed chair in the workable area. This may further increase the autonomy of the robotic vehicle.

[0024] The robotic vehicle may be configured to navigate the work area using a grid based path planner, beacons or other techniques. Each of these techniques may provide a respective representation of the work area that may be used by the robotic vehicle. According to one embodiment, the vehicle comprises a set of discretized coordinate grid points (referred to by the grid), wherein a first set of points of the grid points have status values representing the boundaries of the workable area and a second set of points of the grid points have status values representing the workable area. A grid point may be referred to as a grid cell e.g. the vehicle comprises a grid of cells. For example, the grid and associated status values may be used by the robotic vehicle for detecting the change and the updating of the workable area. For example, boundaries may be changed by changing the status values of cells of the grid to indicate the changed boundaries. For example, a status value of 1 may indicate a boundary cell or boundary point and a status value of 0 may indicate a cell of the workable area that can be operated by the robotic vehicle. Other status values may, for example, be used e.g. to represent cells that are outside the workable area and beyond the boundaries. This embodiment may enable an efficient control of and systematic processing of the movable operation by the robotic vehicle. This may further be advantageous as the grid may be used or shared by multiple present vehicles.

[0025] The grid may further be used by the robotic vehicle to plan the movement of the robotic vehicle in the workable area. In order to improve the path planning process and the resulting movable operations, the grid may be augmented by information. According to one embodiment, each point of the gird points is associated with a quality value indicating the vehicle position determination accuracy when the vehicle is at the point, wherein the path is planed using points having a quality value higher than a predefined threshold. The quality values may, for example, be user defined e.g. the user may set different quality values for different regions of the workable area and/or for different points of time.

[0026] According to one embodiment, the update of the workable area comprises assigning points of the first set to the second set by changing the status values of the assigned points or assigning points of the second set to the first set by changing the status values of the assigned points and determining quality values of the as-

signed points.

[0027] According to one embodiment, determining of the quality value of a given assigned point assigned to the second set comprises predicting the quality value by interpolation of quality values of points of the second set neighboring the given assigned point, or using the quality value of a point of the second set that is adjacent to the given assigned point as the quality of value of the given assigned point. This may save processing resources of the robotic vehicle that would otherwise be required for computing the quality values of each assigned point using the method used for quality values determination of the other points.

[0028] According to one embodiment, the vehicle comprises a Global Navigation Satellite System, GNSS, receiver wherein execution of the instructions by the processor causes the vehicle for each point of a subset of the grid points at different first points in time performing an initialization process, the initialization process comprising: receiving at the first point in time a first set of GNSS signals from a vehicle base; receiving at the first point in time a second set of GNSS signals from the GNSS receiver; determining an accuracy of a location determination, the location determination being based on the second set of GNSS signals, the determination of the accuracy being based on a comparison of the signal qualities of the first set of GNSS signals and the second set of GNSS signals, wherein the quality value of the point is the determined accuracy.

[0029] The "vehicle base" is understood as a fixed base comprising a GNSS receiver for receiving the first set of GNSS signals. The purpose of the vehicle base may be manifold. For example, the base could serve as a shelter for the robot to protect it from the weather when the robot is not in use. The base could serve as a charging station for the robot. Or the base could serve as a reference position for the robot, in which case the exact position of the base should preferably be known. In this case a later exact position determination of the robot via differential GNSS (especially differential GPS) is possible. Differential Global Positioning Systems (DGPS) are e.g. enhancements to the Global Positioning System (GPS) which provide improved location accuracy, in the range of operations of each system. A fixed ground-based reference station may be used to broadcast the difference between the positions indicated by the GPS satellite system and its known fixed position. Receiver stations may correct their positions based on that difference.

[0030] GNSS signals may be signals originating from satellites of the GPS, GLONASS, Galileo or BeiDou system. The GNSS positioning for obtaining a receiver's position is derived through various calculation steps. In essence, a GNSS receiver measures the transmitting time of GNSS signals emitted from four or more GNSS satellites and these measurements are then used to obtain its position (i.e., spatial coordinates) and reception time.

[0031] It has to be noted that that location determination does not have to be performed in such a manner that a real spatial position is obtained from that. It may be sufficient to calculate the uncertainty that may exist in case a determination off the spatial position from the second set of GNSS signals would be performed. Typically, trilateration is used for GNSS based spatial position determination, wherein for the above described accuracy determination it may be sufficient to know "size" of the zone of uncertainty the spheres in trilateration will intersect.

[0032] In order to permit the robotic vehicle to determine at which grid point it is actually located, either the second set of GNSS signals may be used for that purpose or other means may be used that permits to determine the actual location of the vehicle. For example, any kinds of optical systems, acoustical systems and beacon guidance systems may be used for that purpose. Further, if available, a deduced reckoning navigation device of the vehicle may be used for that purpose.

[0033] This embodiment may have the advantage that the accuracy of a location determination is available at rather high accuracy. The accuracy of GNSS data may depend on many factors. One source of errors in the GNSS position accuracy originate from multipath effects. Multipath occurs when part of the signal from the satellite reaches the receiver after one or more reflections from the ground, a building, or another object. First at all, these reflected signals can interfere with the signal that reaches the receiver directly from the satellite. Second, due to the range delay in multipath due to the result of the reflection of the GNSS signal the position as determined using such a multipath signal is falsified. Another source of errors are weak signals. Signals from other high-frequency transmitters can interfere with the GNSS receiver even at low field strengths, resulting in measurement errors and interference from high-frequency signals. Potential sources of interference may, for example, include harmonics of the transmission frequencies of TV and radio transmitters, mobile telecommunication system networks and radar transmitters.

[0034] By comparing the signal qualities of the first set of GNSS signals and the second set of GNSS signals the (hypothetical) accuracy of a location determination based on the second set of GNSS signals is not solely relying on this second set of GNSS signals but also considers the first set of GNSS signals. The signal qualities like signal-to-noise ratios or signal intensities of the first and second set of GNSS signals may permit to identify and omit parts of the second set of GNSS signals that are of low quality, i.e. that may be multipath signals, signals disturbed by interference with other non-GNSS-based signals etc.

[0035] According to one embodiment, the execution of the instructions by the processor causes the vehicle to receive a user input indicating the predefined change threshold. For example, the robotic vehicle may be controlled via a control panel on a mower chassis of the robotic vehicle or wirelessly through other interactive plat-

forms such as a smart phone, PC, etc. The user input may be received via the control panel or may be received from a smart phone via a wireless connection between the smart phone and the robotic vehicle.

[0036] According to one embodiment, the detection of the change is performed based on sensor data received from at least one of: one or more ultrasonic sensors; one or more infra-red reflex sensors; and one or more laser scanners. The sensors may or may not be part of robotic vehicle. The sensors may provide an accurate characterization of detected objects.

[0037] Further example embodiments provide a method for performing a movable operation in a workable area in accordance with a planned path. The movable operation comprises a soil cultivation. The method comprises:

- detecting, in a current position of the vehicle, a change in at least part of current boundaries of the workable area;
- updating the workable area by changing boundaries of the workable area, the changed boundaries becoming the current boundaries, wherein the update is performed such that the change does not exceed a predefined change threshold; and
- performing the movable operation using the planned path or a re-planned path based on the detected change.

[0038] Further example embodiments provide a computer program product comprising computer executable instructions to perform the method as described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0039] The accompanying figures are included to provide a further understanding of examples, and are incorporated in and constitute part of this specification. In the figures:

FIG. 1 illustrates an example of a working environment for a robotic vehicle in accordance with an example of the present subject matter.

FIG. 2 illustrates a diagram describing an example structure of a robotic vehicle 200 in accordance with the present subject matter.

FIG. 3 is a flowchart of a method for performing a movable operation in a workable area by a robotic vehicle.

FIGS. 4A-4B provide a schematic drawing illustrating a process for adapting a workable area in accordance with an example of the present subject matter.

FIG. 5A provides a schematic drawing illustrating a process for changing a boundary in accordance with an example of the present subject matter.

FIG. 5B provides a schematic drawing illustrating a process for changing a boundary in accordance with an example of the present subject matter.

FIGS. 6A-6B provide a schematic drawing illustrating a process for representing the work area in accordance with an example of the present subject matter.

FIG. 7A is a flowchart of a method for mowing a workable area as shown in FIG. 7B by a robotic vehicle.

DETAILED DESCRIPTION

[0040] In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular architectures, interfaces, techniques, etc., in order to provide a thorough understanding of the examples. However, it will be apparent to those skilled in the art that the disclosed subject matter may be practiced in other illustrative examples that depart from these specific details. In some instances, detailed descriptions of well-known devices and/or methods are omitted so as not to obscure the description with unnecessary detail. Please double check the details we provided in the following examples.

FIG. 1 illustrates an example of a working environment for a robotic vehicle 101 in accordance with an example of the present subject matter. The robotic vehicle 101 may, for example, be configured to perform a movable operation. The movable operation may, for example, be a lawn care function that may be performed by the robotic vehicle 101 while moving. The lawn care function may comprise a mowing operation, watering operation or other lawn care functions. In the following, and for simplification purpose, the movable operation is described as a mowing operation e.g. the robotic vehicle 101 may be a mower.

[0041] The robotic vehicle 101 may be configured to perform a mowing operation in a work area or parcel 100 such as a garden or yard. The work area 100 has a configuration. The configuration may change over time. The configuration of the work area 100 may define a subarea of the work area 100 that is a workable area (or mowable area), boundaries that delimit the workable area and/or characteristics of objects that define the boundaries. The workable area 104 may be an area in which the robotic vehicle 101 may be able to perform the mowing operation.

[0042] The objects that define the boundaries may collectively be referred to by 105. The objects 105 may be objects 105A that define at least part of the outer boundary 107. In one example, objects 105 may further comprise objects 105B inside the workable area 104 that define one or more inner boundaries 109. The objects 105 may be temporal or permanent objects. Example of ob-

jects 105 may be tree, wall, door, stair step etc. The characteristics of an object of the boundaries 107 and 109 may, for example, comprise a size, shape and/or other information descriptive of the object. At least part of the boundaries 107 and 109 may be defined without physical objects by using boundary data that is stored in the robotic vehicle 101. Said boundary data indicates the at least part of the boundaries. Said boundary data may, for example, be user defined. Thus, the boundaries 107 and 109 may be defined by objects e.g. of same or different types and/or of the boundary data. The boundaries 107 and 109 define or delimit the workable area 104 in that the robotic vehicle 101 may use the boundaries to limit the mowing operation in the workable area 104.

[0043] The robotic mower 101 may be configured to define or plane a path for performing the mowing over at least part of the workable area 104 in order to traverse the workable area along the planned path. The traversal may be performed while operating cutting blades to cut the grass on the workable area 104. In cases of other movable operations, the robotic vehicle may be configured to control another functional or working assembly that may replace the cutting blades.

[0044] The robotic mower 101 may be battery powered via one or more rechargeable batteries, wherein the batteries may be recharged by a charge station (or vehicle base) 103. The charge station 103 may be located at a predefined position on the work area 100. The robotic mower 101 may be configured to return to the charge station 103 in order to recharge the batteries.

[0045] The robotic mower 101 may, for example, be controlled (e.g. in order to start the movable operation) via a control panel on a mower chassis of the robotic mower 101 or wirelessly through other interactive platforms such as a smart phone, PC, etc.

[0046] While FIG. 1 shows a configuration of the work area that has a specific set of boundary objects, it will be appreciated that numerous configurations that define workable areas may exist.

[0047] **FIG. 2** illustrates a diagram describing an example structure of a robotic vehicle 200 in accordance with the present subject matter. The robotic vehicle 200 comprises a control circuitry 201, drive engine 221 and a battery 231 for powering the control circuitry 201 as well as the drive engine 221. The drive engine 221 may, for example, include two digitally controlled electric motors for driving respective wheels or tracks of the robotic vehicle 200.

[0048] The control circuity 201 comprises a data processing circuitry 203. The data processing circuitry 203 may be in communication with a device interface 205. The data processing circuitry 203 may be embodied as a circuit chip (e.g., an integrated circuit chip) configured, with hardware, software or a combination of hardware and software, to perform operations described herein.

[0049] The data processing circuitry 203 may be configured by hardware or by a combination of hardware and software. The data processing circuitry 203 may, for example, comprise a processor 207 and memory 209. In one example, the processor 207 may be configured to execute instructions stored in the memory 209. In one example, the processor 207 may be embodied as an ASIC, FPGA or the like, and may thus be a specifically configured hardware for conducting the operations described herein.

[0050] The data processing circuitry 203 may be in communication with sensor means 215 to perform at least part of the present subject matter. For example, zero or more sensors of the sensor means 215 may be part of the robotic vehicle 200. The sensor means 215 may provide data or signals to the processor 207 to enable the processor 207 to perform at least part of the present subject matter. The sensor means 215 may, for example, comprise one or more position sensors 217 to determine a position of the robotic vehicle 200 based on position information provided by position sensors 217. The sensor means 215 may further comprise one or more obstacle sensors 219 to detect an obstacle or object as the robotic vehicle 200 moves through a workable area e.g. 104. The obstacle sensors 219 may enable the robotic vehicle 200 to identify the objects without physically contacting them. The obstacle sensors 219 may be configured to produce a signal upon detecting an obstacle. The robotic vehicle may be configured to process the produced data to determine characteristics of the detected obstacle. An obstacle may be an obstacle at the boundary of the workable area such as a wall or door. An obstacle may also be an object placed in the workable area. The sensor means 215 may further comprise a camera system comprising one or more cameras and GNSS receiver.

[0051] The processor 207 may provide or create guide signals for the drive engine 221 that are capable of driving the robotic vehicle 200 along a planned path. The obstacle sensors 219 may produce obstacle signals any time the robotic vehicle 200 is approaching an object e.g. 205A as the robotic vehicle 200 moves through the workable area e.g. 104. The position sensors 217 may produce position signals indicative of the robotic vehicle 200. The guide signals may, for example, be generated based on received obstacle signals and/or position signals.

[0052] The interface device 205 provides an interface between the signals produced by the obstacle sensors 219 and the processor 207 and also provides an interface between the guide signals generated by the processor 207 and the signals required to drive the electric motors the drive engine.

[0053] For the purpose of explanation, the subject matter described in following figures may be implemented in the robotic vehicle and the work area illustrated in FIG. 1 and FIG. 2, but is not limited to this implementation.

[0054] **FIG. 3** is a flowchart of a method for performing a movable operation in a workable area e.g. 104 by a robotic vehicle e.g. 101 and 200, in accordance with a planned path.

[0055] In step 301, a change in at least part of current boundaries of the workable area may be detected in a current position of the robotic vehicle. In step 303, in response to the detected change, the workable area may be updated or adjusted by changing or adjusting boundaries of the workable area. The changed boundaries become the current boundaries, wherein the update is performed such that the change does not exceed a predefined change threshold. In step 305, the movable operation may be performed (or continued if already started) using the planned path or a re-planned path based on the detected change.

[0056] **FIG. 4A** is similar to FIG. 1 showing the status or configuration of the work area 400 at a predefined initial point of time.

[0057] The work area 400 has a configuration indicated by or comprising objects (collectively referred to by 405). The objects 405 may be objects 405A that define the outer boundary 407. The area 404 may be a workable area (e.g. mowable area) in which a robotic vehicle 401 may be able to perform the mowing operation. Objects 105 may further comprise object 405B inside the workable area 404 that defines inner boundary 409. The objects 405 may be temporal or permanent objects. For example, tree 415 of the outer boundary 407 is associated with a boundary portion 412 of the outer boundary. As illustrated in FIG. 4A, the boundary portion 412 may, for example, indicate the projection of a part of the crown of the tree 415 onto the soil. The robotic vehicle 401 may, for example, store position data that indicates the boundaries 407 and 409. The stored position data may comprise tree position data indicative of positions 425 the boundary portion 412.

[0058] At a later point of time, at least part of the boundaries 407 and 409 may change. For example, as shown in **FIG. 4B**, tree 415 of the outer boundary 407 has been cut resulting in a cut tree 415 having a size smaller than its size at the initial point of time. The size reduction of the tree 415 may indicate a change 417 in at least part of the boundaries 407, 409 of the workable area 404. For example, after cutting the tree 415 the new portion 422 (referred to as changed boundary portion) indicates the projection of a part of the crown of the cut tree 415 onto the soil. Thus the workable area 404 may be updated by changing the boundary 407 in accordance with the detected change 417. For example, the update of the workable area 404 may be performed by changing the boundary 407 so that the boundary portion 412 is replaced by the changed boundary portion 422. This change may increase the workable area 404.

[0059] The change 417 may, for example, be detected, when the robotic vehicle is in a given position of the robotic vehicle 401, as follows. The cut tree 415 may be detected by robotic vehicle 401. The detection of the cut tree 415 may be performed using obstacle sensors e.g. 219 such as LIDAR sensor. For example, the robotic vehicle 401 may receive data or signals from the obstacle sensors indicating new positions of the cut tree 415 e.g. the robotic vehicle 401 may process the received data to determine the new positions. For each new position of the new positions, the robotic vehicle 401 may, for example, determine a first distance separating the given position of the robotic vehicle 401 and the new position. The robotic vehicle 401 may further determine a second distance separating the given position and a position of the tree position data that corresponds to the new position. If the first and second distances are different, this may indicate that a change occurred in the boundary 407, and the amount of that change may be the detected change 417.

[0060] In one example, the update of the workable area 404 may be performed by replacing the tree position data by the new positions to reflect the portion 422. Other examples for updating the workable area 404 are described with reference to FIGS. 5A-B

[0061] **FIG. 5A** is a schematic drawing illustrating a process for changing a boundary in accordance with an example of the present subject matter. For purpose of clarity, the example of boundary change of FIG. 4B is used herein.

[0062] As shown in FIG. 5A, the boundary portion 412 of the boundary 407 of the initial point of time has been changed by shifting it outwardly to become the changed boundary portion 422 of the boundary 407 of the later point of time, after the change is occurred.

[0063] As shown in FIG. 5A, the boundary portion 412 may be represented by positions 503.1-N which are stored as the tree position data as described with reference to FIGS. 4A-B.

[0064] The boundary portion 412 has been shifted by the detected change 417. For simplification purpose, the same change 417 is applied to different positions 503.1-N of the boundary portion 412. The shifting may be performed, in one example, by shifting by the robotic vehicle the positions 503.1-N in the stored tree position data by the detected change 417 in order to obtain new positions 505.1-N representing the changed boundary portion 422. In another example, the shifting may comprise replacing by the robotic vehicle 101 the positions 503.1-N by the new positions 505.1-N.

[0065] FIG. 5A further illustrates a change threshold 501. The change threshold 501 may, for example, be used in accordance with the present example to control the change of the boundaries 407 and 409. The change threshold 501 may, for example, be position dependent e.g. for each type of boundary objects a change threshold may be provided. For example, for the work area 100, different change thresholds may be provided for boundaries defined by trees, boundaries defined by a house, and boundaries defined by fence boundaries. This may enable to obtain accurate and optimal workable areas for performing the movable operations.

[0066] For example, for a given position e.g. 503.1 of the tree position data that has to be shifted by the change 417, the robotic vehicle may calculate a first shift of the given position 503.1 by the change threshold 501 result-

ing in position 507.1 and may calculate a second shift of the given position 503.1 by the detected change 417 resulting in position 505.1. By comparing the two positions 505.1 and 507.1, the robotic vehicle may determine based on the comparison results if the change performed for the given position 503.1 does not exceed the change threshold 501. For example, the robotic vehicle may determine if the calculated second shift results in a position that is beyond the position calculated from the first shift.

[0067] **FIG. 5B** is a schematic drawing illustrating a process for changing a boundary in accordance with an example of the present subject matter. For purpose of clarity, the example of boundary change of FIG. 4B is used herein.

[0068] As shown in FIG. 5A, the boundary portion 412 of the boundary 407 of the initial point of time has been changed by shifting it outwardly to become the changed boundary portion 422 of the boundary 407 of the later point of time, after the change is occurred. The boundary portion 412 may be represented by positions 503.1-N which are stored as the tree position data as described with reference to FIGS. 4A-B.

[0069] FIG. 5B further illustrates a change threshold 501 and a reference boundary 511. For example, the robotic vehicle may store reference position data that defines the reference boundary 511. The reference boundary 511 may, for example, be user defined. For example, if the boundaries are defined by trees, the reference boundary may be defined by the centers of the trunks of the trees e.g. the reference boundary may be the positions having a distance d0 to the center of the respective trunks of the trees e.g. if 10 trees surround the workable area, 10 positions may be defined, wherein each position is defined with regard to the center of the respective tree's trunk, and these 10 positions may be used to define the reference boundary. Providing a reference boundary may be advantageous in particular if the changes in the boundaries occur multiple times. For example, if the tree 415 is cut four times the boundary may be shifted 4 times (e.g. by the same amount), wherein each change is performed (in case the reference boundary is not used) from the current positions of the boundary. However, this may end-up with a workable area that includes obstacles.

[0070] For example, for a given position e.g. 503.1 of the tree position data that has to be shifted by the change 417, the robotic vehicle may determine an associated reference position 510.1 of the reference position data. For example, the reference positions 510.1 to 510.N are connected by the reference boundary, wherein, with respect to a reference position 510.1, one of the points 503.1..N is associated with this reference position. This is the point 503.1..N which is closest to the reference position and which connects to the reference position with a straight line perpendicular to the reference boundary at said reference position. The robotic vehicle may calculate a first shift of the reference position 510.1 by the change threshold 501 resulting in position 517.1 and may calculate a second shift of the given position 503.1 by the detected change 417 resulting in position 505.1. By comparing the two positions 505.1 and 517.1, the robotic vehicle may determine based on the comparison results if the change performed for the given position 503.1 does not exceed the change threshold 501. For example, the robotic vehicle may determine if the calculated second shift results in a position that is beyond the position calculated from the first shift.

[0071] **FIG. 6A** is a diagram illustrating a representation of the work area 100. The work area 100 may be represented by a grid of cells 600 (also referred to as grid of points, where a point may represent a cell).

[0072] Each cell of the grid of cells 600 may be associated with a status value that indicates the configuration of the work area 100 at that cell. For example, as indicated in FIG. 6B a first set of cells 601 (filled cells of FIG. 6B) may have a status value that indicates that the corresponding parts of the work area is a boundary area. FIG. 6B further shows a second set of cells 603 (non-filled cells) which are delimited by the first set of cells and may have a status value that indicates that the corresponding parts of the work area is a workable area

[0073] The robotic vehicle may, for example, store the grid of cells 600 and associated status values. The robotic vehicle may use the grid of cells and associated status values in order to perform a mowing operation following a planned path e.g. if a status value of a cell indicates that cell is a boundary cell, the vehicle robot may avoid to traverse that cell.

[0074] The grid of cells 600 may be advantageous as it may be used by the robotic vehicle to perform in an efficient manner the change of the boundaries e.g. as described with reference to FIGS. 4A to 5B. For example, a subset of cells of the first set of cells 601 may correspond to the boundary portion 412, and the tree position data may comprise status values of that subset of cells 601. Changing the boundary portion 412 as described in FIGS. 4A to 5B may be performed by identifying new cells of the grid of cells 600 that correspond to the changed boundary portion 422. The new cells may be associated with status values indicating boundary areas and status values of the subset of cells may be changed to status values that indicate that they are movable cells.

[0075] **FIG. 7A** is a flowchart of a method for mowing a workable area 724 of a work area 722 of FIG. 7B in accordance with an example of the present subject matter. In this example, the robotic vehicle may be a mower. The work area 722 may, for example, have a given configuration at a given point of time that indicates objects characteristics such as their placements in the work area 722. The given configuration may further define which area of the work area is mowable and boundaries delimiting the mowable area. The mower may have access to information indicating or representing the given configuration. Such information may be provided as a grid. The grid may comprise cells as shown in FIGS. 6A-B. For example, the mower may store the grid of cells 600 of work area 100 in association with the status values.

[0076] In addition, and in order to control the change of the boundaries, a boundary change tolerance range may be defined. For example, one or more polygons 731A-B and 733A-B may be provided for defining the boundary change tolerance range. FIG. 7B shows an example of polygons 731A-B and 733A-B, wherein polygons 731A-B are surrounding the outer boundary 727 and polygons 733A-B are surrounding the inner boundary 729. A tolerance range may be defined by the area between the boundaries 711A and 711B and another tolerance range may be defined by the area between polygons 713A and 713B. The mower may store polygon data that indicates the positions of the polygons with respect to the work area 722. The polygon data may, for example, be provided using the grid cells. For example, cells of the grid of cells may be marked or associated with information that indicates the location of the one or more polygons in the work area 722. In order to define the tolerance range, FIG. 4B shows one pair of polygons per boundary 107 or 109 for exemplification only, but other structures of polygons or other forms may be used to define the tolerance range.

[0077] A path may be determined or planned in step 701. The path may connect a starting point of the robotic vehicle to a target point in the workable area. The path may, for example, be determined using the grid of cells 600 such that the mower may follow a sequence of cells of the workable area that connects the two cells of the starting and target points.

[0078] Before or while moving along the determined path (step 702), the configuration may change in that a change may affect at least one given object defining at least part of the boundaries (outer and/or inner boundaries). For example, a user may have cut a tree or a tree may have grown or an object has been moved or removed etc. The mower may be configured to detect in step 703 the given object when it reaches a given position along the determined path. For example, the mower may use sensor data to detect the given object and to determine one or more object positions of the detected object. By comparing or matching in step 705 the object positions with the grid of cells 600, the mower may determine (inquiry step 707) if a change is occurred. The change may result in a new configuration of the work area different from the given configuration. E.g. the mower is regularly processing sensor data while moving in order to determine if a change occurred.

[0079] If (inquiry step 707) a change is occurred (e.g. a characteristic of the detected object in the new configuration of the work area 722 has changed with respect to its characteristic in the given configuration), the mower may define an adjustment in step 709 of a boundary portion of the boundaries that corresponds to the detected object in order to take into account the occurred change. For example, the adjustment may be an inward or outward shifting of the boundary portion.

[0080] The mower may determine (inquiry step 711) if the adjusted boundary that results from the adjustment is within the tolerance range or not. If there are multiple tolerance ranges, inquiry step 711 may further comprise identifying the tolerance range that corresponds to the position of the detected object. For example, if a change is occurred at position 740 of the outer boundary, the robotic vehicle may determine if the adjusted boundary is within the tolerance range using a change threshold 741 or 743 indicative of the position of the tolerance range with respect to the position 740. If the adjustment is an outward adjustment, it may be checked if the adjusted boundary does not exceed the change threshold 741. If the adjustment is an inward adjustment, it may be checked if the adjusted boundary does not exceed the change threshold 743.

[0081] If the adjusted boundary is within the tolerance range the adjusted boundary may be confirmed and maintained in step 713 by the mower; otherwise the mower may readjust the boundary such that it fits within the tolerance range in step 715.

[0082] The mower may determine (inquiry step 717) if the planned path is to be re-planned or not. The path may be re-planned if, for example, the change in the boundary results in one o more cells of the planned-path being outside the workable area. This may result in a re-planned path of step 719 or maintaining the planned path in step 721.

[0083] Steps 702-721 may be repeated, using the resulting path, until the target point is reached.

List of reference numerals

[0084]

100 work area
101 robotic vehicle
103 vehicle base
104 workable area
105 obstacles
107 outer boundary
109 inner boundary
200 robotic vehicle
201 control circuitry
203 data processing means
205 interface
207 processor
209 memory
215 sensor means
217 position sensors
219 obstacle sensors
221 drive engine
231 battery
301-305 steps
400 work area
401 robotic vehicle
404 workable area
405 obstacles
407 outer boundary
409 inner boundary

412 boundary portion
415 tree
417 change
422 changed boundary portion
425 positions
501 change threshold
503 positions
505 positions
507 position
513 reference boundary
517 position
600 grid
601 first set of cells
603 second set of cells
701-721 steps
722 work area
724 workable area
727 outer boundary
729 inner boundary
731-733 polygons
740 position
741-743 change threshold.

Claims

1. A robotic vehicle (101, 200, 401) for performing a movable operation in a workable area (104, 404, 724) in accordance with a planned path, the movable operation comprising a soil cultivation, the vehicle (101, 200, 401) comprising a memory (209) and a processor (207), the memory (209) comprising instructions, wherein execution of the instructions by the processor (207) causes the vehicle (101, 200, 401) to:

   - detect, in a current position of the vehicle, a change (417) in at least part (412) of current boundaries (107, 109, 407, 409) of the workable area (104, 404, 724);
   - update the workable area (104, 404, 724) by changing boundaries (412) of the workable area (104, 404, 724), the changed boundaries (422) becoming the current boundaries, wherein the update is performed such that the change does not exceed a predefined change threshold (501, 741, 743); and
   - perform the movable operation using the planned path or a re-planned path based on the detected change (417).

2. The robotic vehicle of claim 1, wherein the execution of the instructions by the processor (107) further causes the vehicle to automatically adapt the change threshold (501) depending on conditions of an environment of the workable area.

3. The robotic vehicle of any of the preceding claims 1-2, wherein the change threshold (501, 741, 743) is one of a set of different change thresholds, wherein each change threshold of the set of change thresholds is associated with a respective part (740) of the workable area, wherein the update of the workable area comprises identifying the change threshold of the set of change thresholds that corresponds to a location (412) of the detected change (417), wherein the predefined change threshold is the identified change threshold, the set of change thresholds preferably comprising a change threshold for inner boundaries (109) and a change threshold for an outer boundary (107) of the workable area (104).

4. The robotic vehicle of any of the preceding claims, wherein the detection of the change comprises: detecting an object (105) in the workable area having an object boundary (425); wherein the update is performed such that the changed boundaries (422) include the object boundary.

5. The robotic vehicle of any of the preceding claims, wherein the execution of the instructions by the processor (207) further causes the vehicle to provide one or more reference boundaries (513); wherein exceeding the predefined change threshold is determined relative to the reference boundaries (513), wherein optionally the reference boundaries (513) are current boundaries (412) of the workable area (404) before the update is performed or predefined fixed boundaries.

6. The robotic vehicle of claim 4, wherein the execution of the instructions by the processor (207) further causes the vehicle to repeatedly detect, update the workable area, and perform the movable operation, resulting in a set of current boundaries, wherein the reference boundaries (513) are obtained by a combination of the set of current boundaries.

7. The robotic vehicle of claim 4, wherein the repetition is performed over a predefined time period.

8. The robotic vehicle of any of the preceding claims, wherein in case the change exceeds the predefined change threshold, the execution of the instructions by the processor (207) further causes the vehicle to provide the changed boundaries as boundaries (507) obtained by a change equal to the change threshold (501).

9. The robotic vehicle of any of the preceding claims, wherein the detection of the change comprises: detecting an object (105B) inside the workable area (104); wherein the update of the workable area (104) is performed in case the detection of the object (105B) fulfills a repetition criterion, wherein optionally the repetition criterion requires that the object is

detected for at least N predefined times; the object (105B) is detected with a predefined minimum frequency.

10. The robotic vehicle of any of the preceding claims, wherein the vehicle comprises a set of discretized coordinate grid points (600), wherein a first set of points (601) of the grid points (600) have status values representing the boundaries (107, 109) of the workable area (104) and a second set of points (603) of the grid points (600) have status values representing the workable area (104), wherein optionally each point of the gird points (600) is associated with a quality value indicating the vehicle position determination accuracy when the vehicle is at the point, wherein the path is planed using points having a quality value higher than a predefined threshold.

11. The robotic vehicle of claim 10, the update of the workable area (104) comprises assigning points of the first set (601) to the second set (603) by changing the status values of the assigned points or assigning points of the second set (603) to the first set (601) by changing the status values of the assigned points and determining quality values of the assigned points, wherein optionally wherein determining of the quality value of a given assigned point assigned to the second set comprises predicting the quality value by interpolation of quality values of points of the second set neighboring the given assigned point, or using the quality value of a point of the second set that is adjacent to the given assigned point as the quality of value of the given assigned point.

12. The robotic vehicle of any of preceding claims 10 to 11, the vehicle comprising a Global Navigation Satellite System, GNSS, receiver (215) wherein execution of the instructions by the processor causes the vehicle for each point of a subset of the grid points at different first points in time performing an initialization process, the initialization process comprising: receiving at the first point in time a first set of GNSS signals from a vehicle base; receiving at the first point in time a second set of GNSS signals from the GNSS receiver; determining an accuracy of a location determination, the location determination being based on the second set of GNSS signals, the determination of the accuracy being based on a comparison of the signal qualities of the first set of GNSS signals and the second set of GNSS signals, wherein the quality value of the point is the determined accuracy.

13. The robotic vehicle of any of the preceding claims, wherein execution of the instructions by the processor (207) causes the vehicle to receive a user input indicating the predefined change threshold (501).

14. The robotic vehicle of any of the preceding claims, wherein the detection of the change (417) is performed based on sensor data received from at least one of: one or more ultrasonic sensors; one or more infra-red reflex sensors; and one or more laser scanners (219).

15. A method for performing a movable operation in a workable area in accordance with a planned path, the movable operation comprising a soil cultivation, the method comprising:

- detecting (301), in a current position of the vehicle, a change in at least part of current boundaries of the workable area;
- updating (303) the workable area by changing boundaries of the workable area, the changed boundaries becoming the current boundaries, wherein the update is performed such that the change does not exceed a predefined change threshold; and
- performing (305) the movable operation using the planned path or a re-planned path based on the detected change.

16. A computer program product comprising computer executable instructions to perform the method of claim 15.

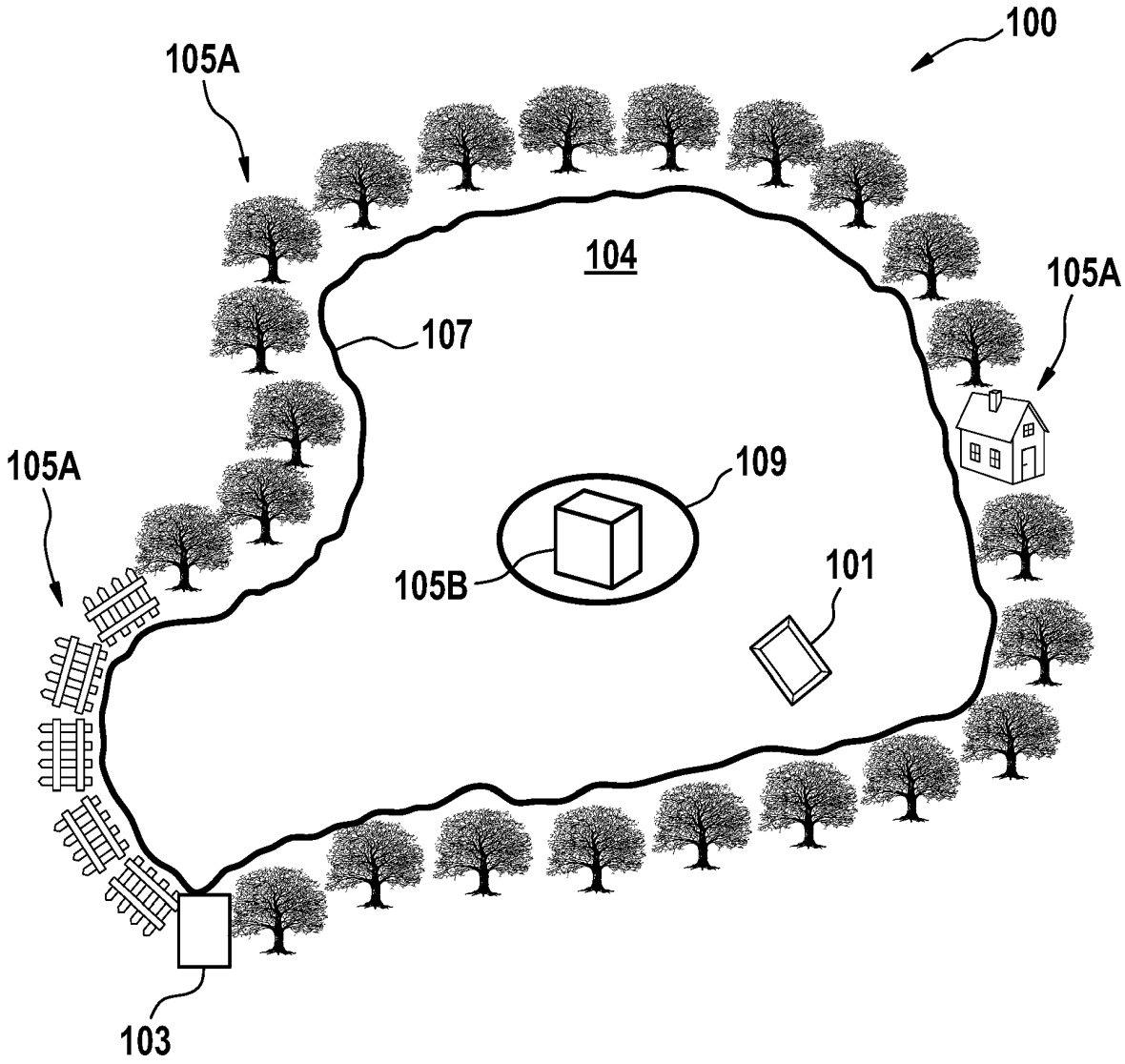


Fig. 1

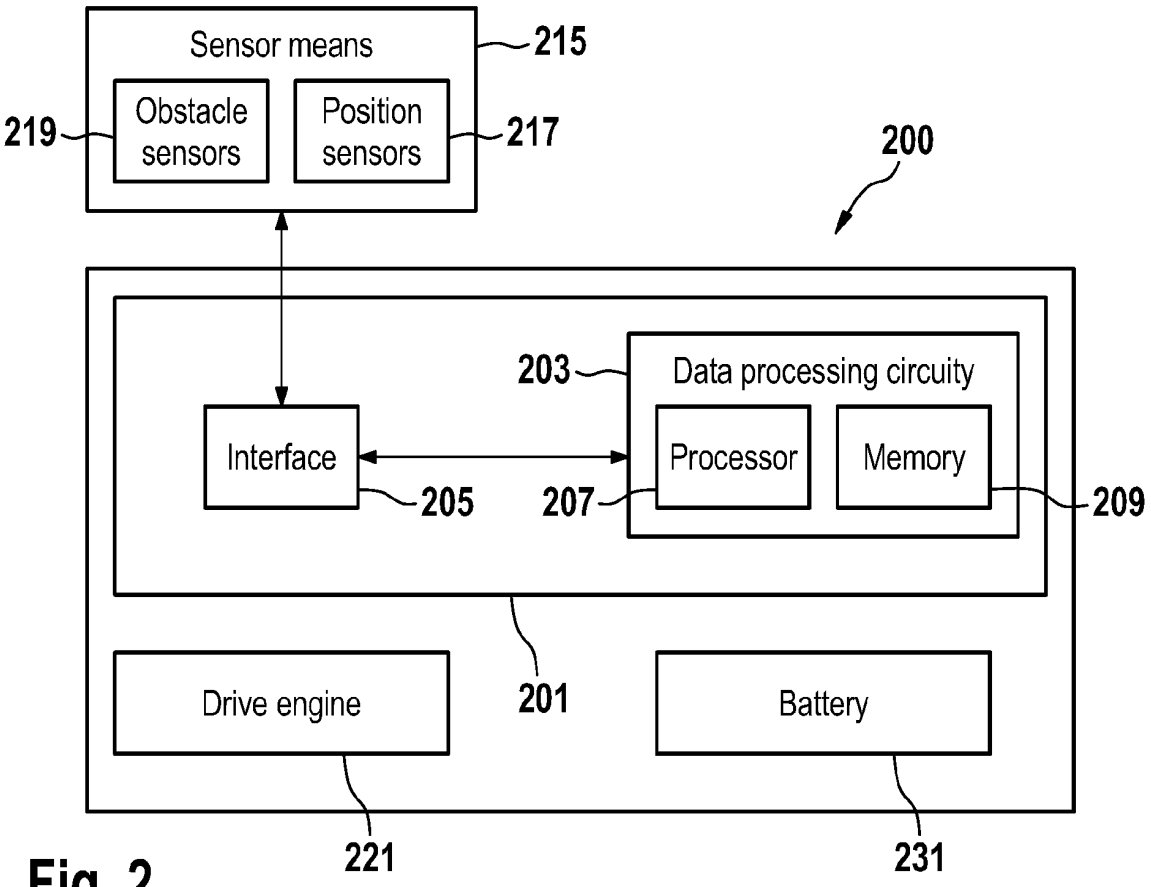

Sensor means
215
Obstacle sensors
Position sensors
219
217
200
203
Data processing circuity
Interface
Processor
Memory
205
207
209
201
Drive engine
Battery
221
231

Fig. 2

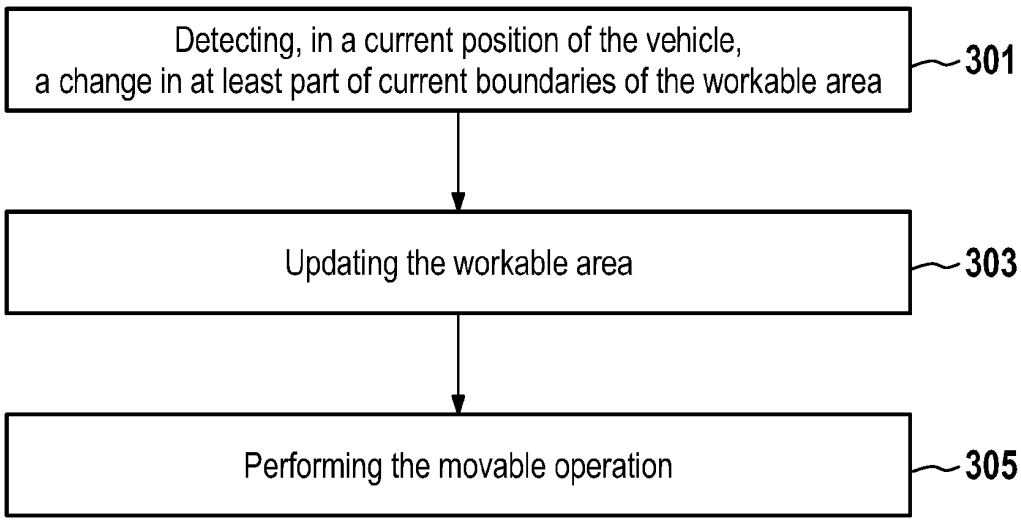
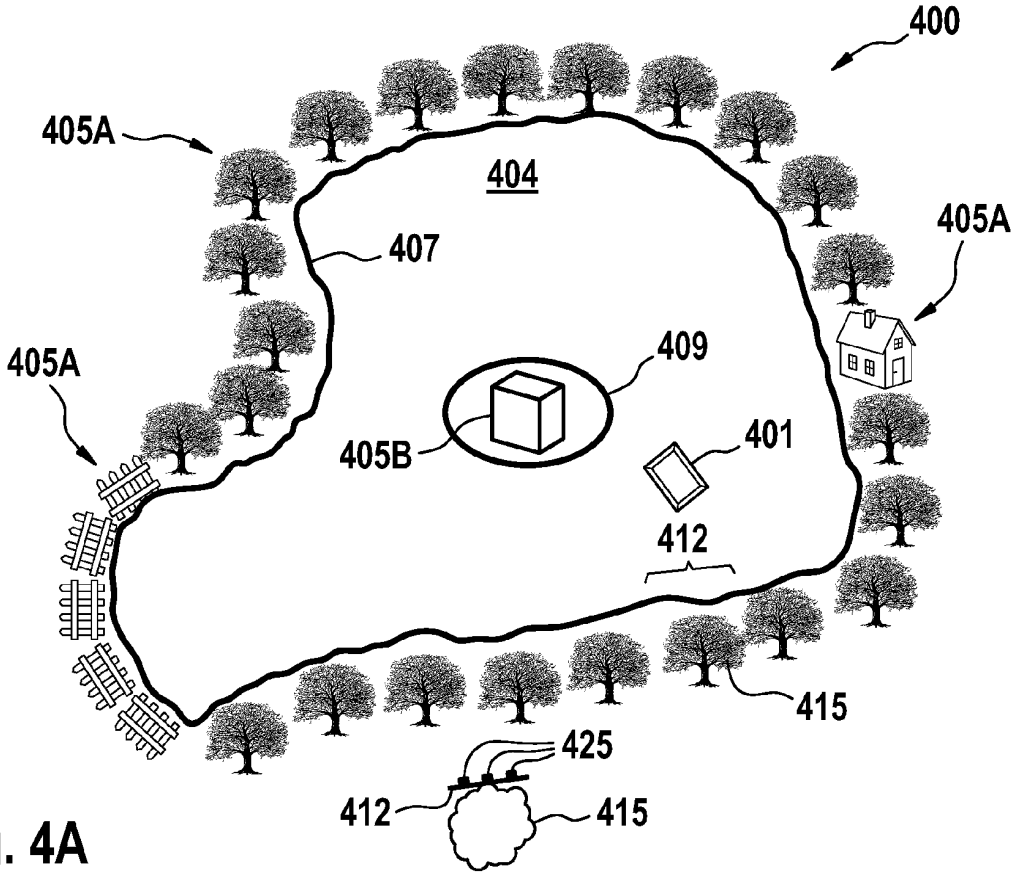

Detecting, in a current position of the vehicle, a change in at least part of current boundaries of the workable area
301
Updating the workable area
303
Performing the movable operation
305

Fig. 3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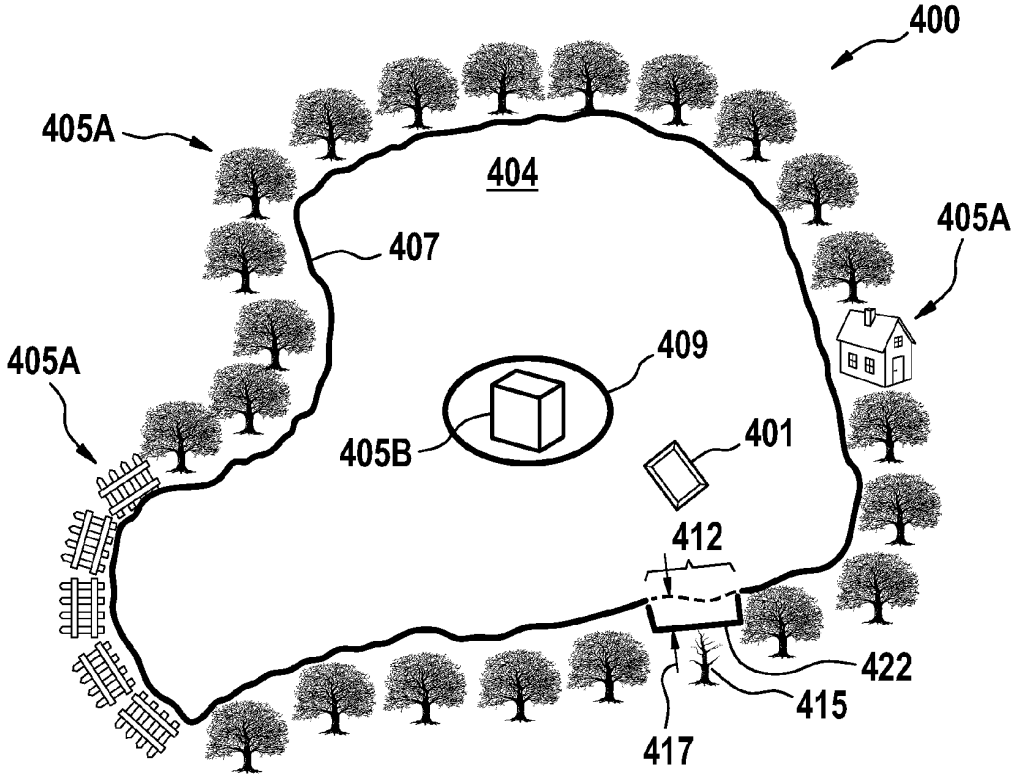
405A
404
405A
407
405A
409
405B
401
412
415
425
412
415

Fig. 4A


400
405A
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405A
407
405A
409
405B
401
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415
417

Fig. 4B

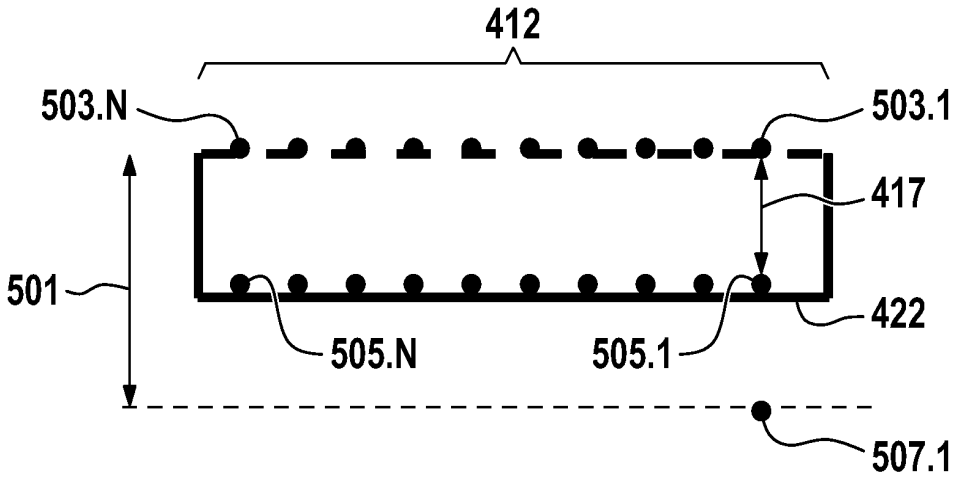
412
503.N
503.1
417
501
422
505.N
505.1
507.1

Fig. 5A

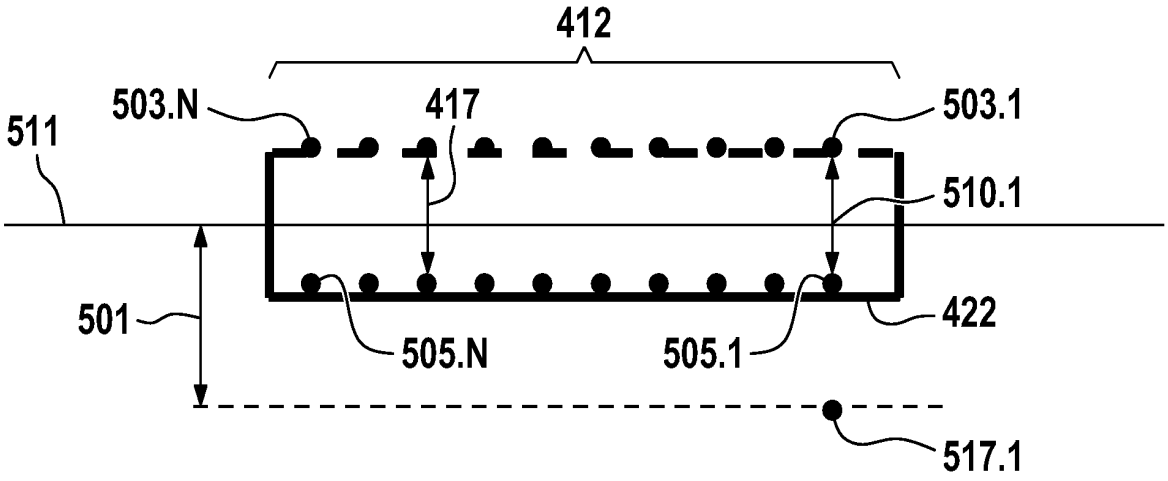
412
503.N
417
503.1
511
510.1
501
422
505.N
505.1
517.1

Fig. 5B

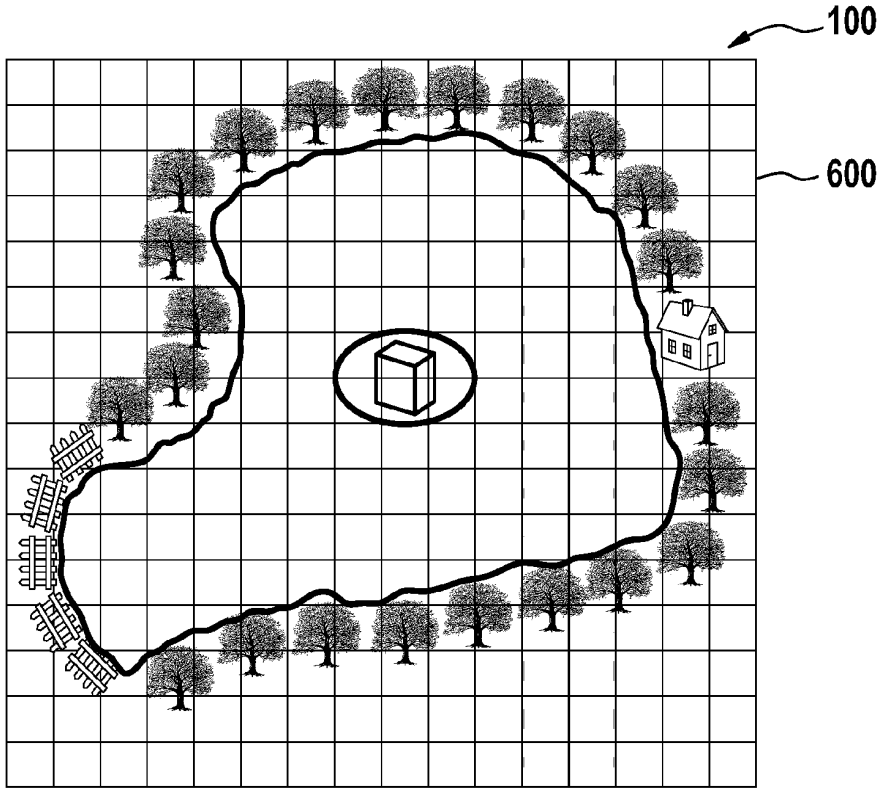

Fig. 6A

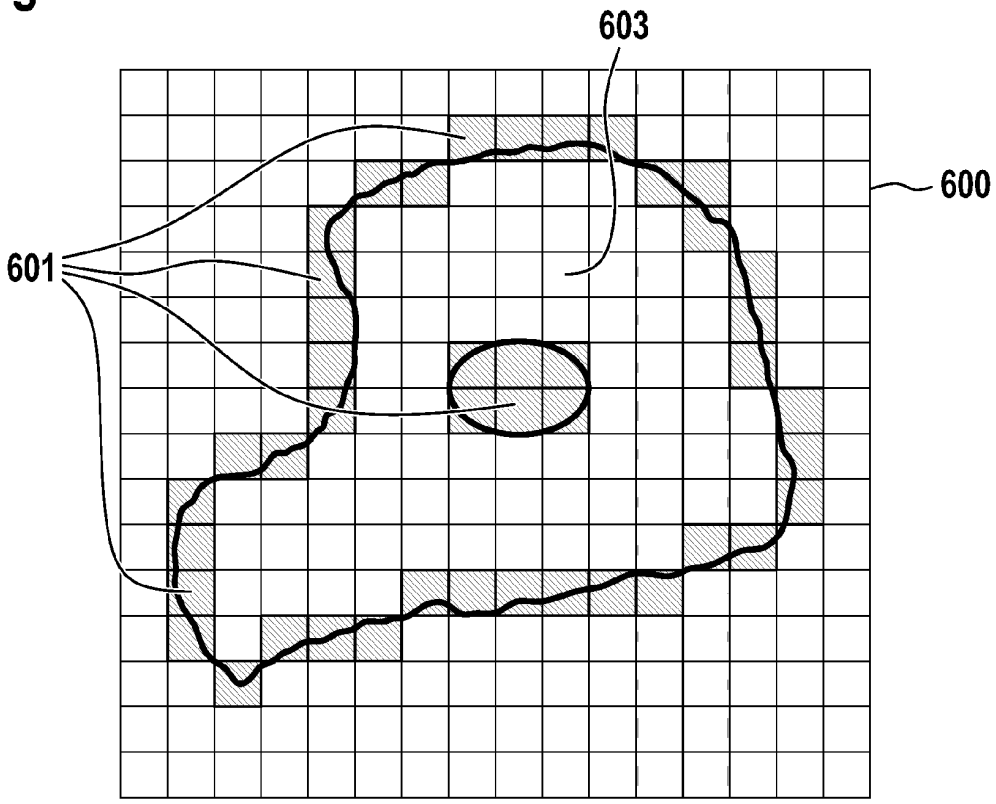

Fig. 6B

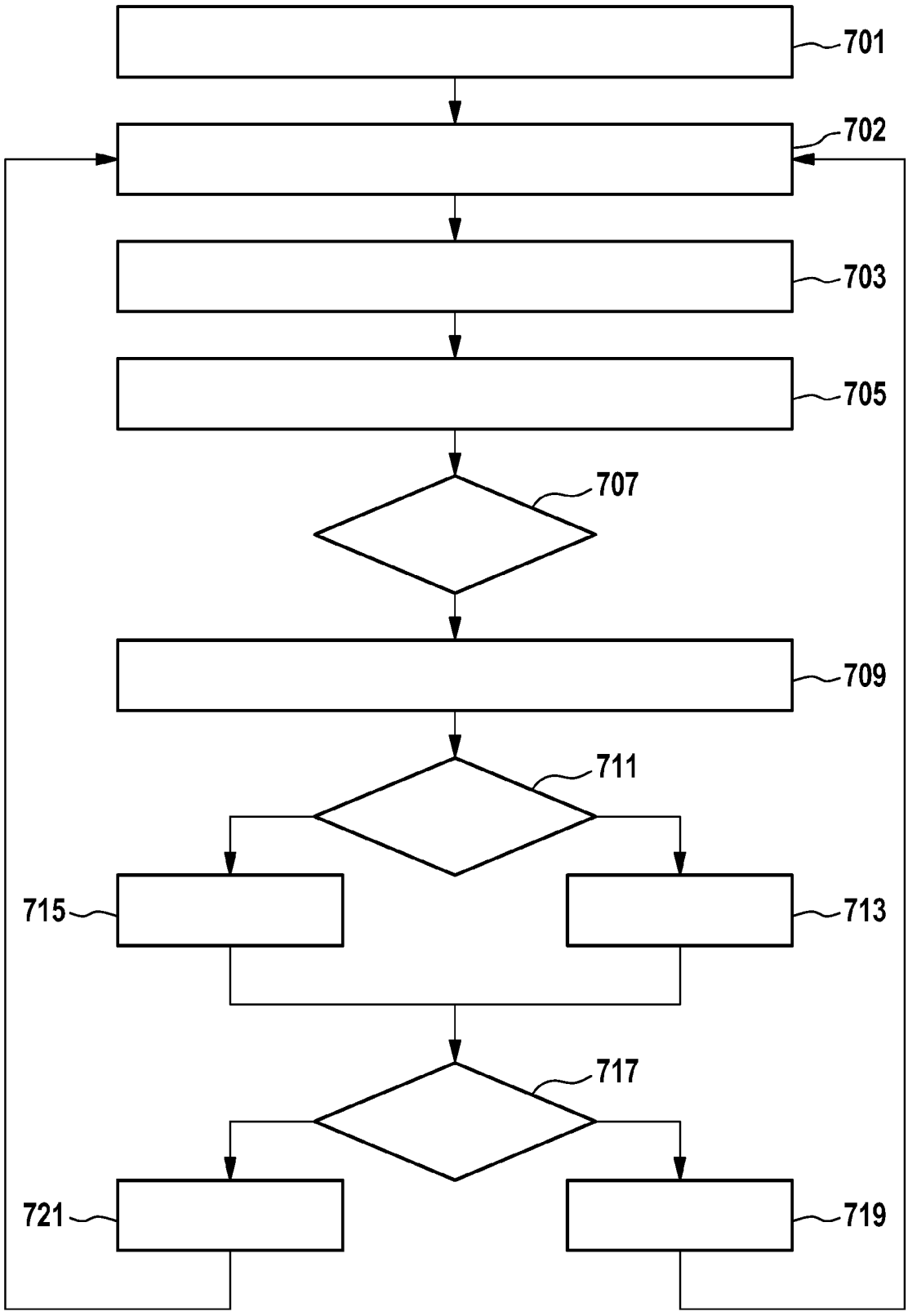

Fig. 7A

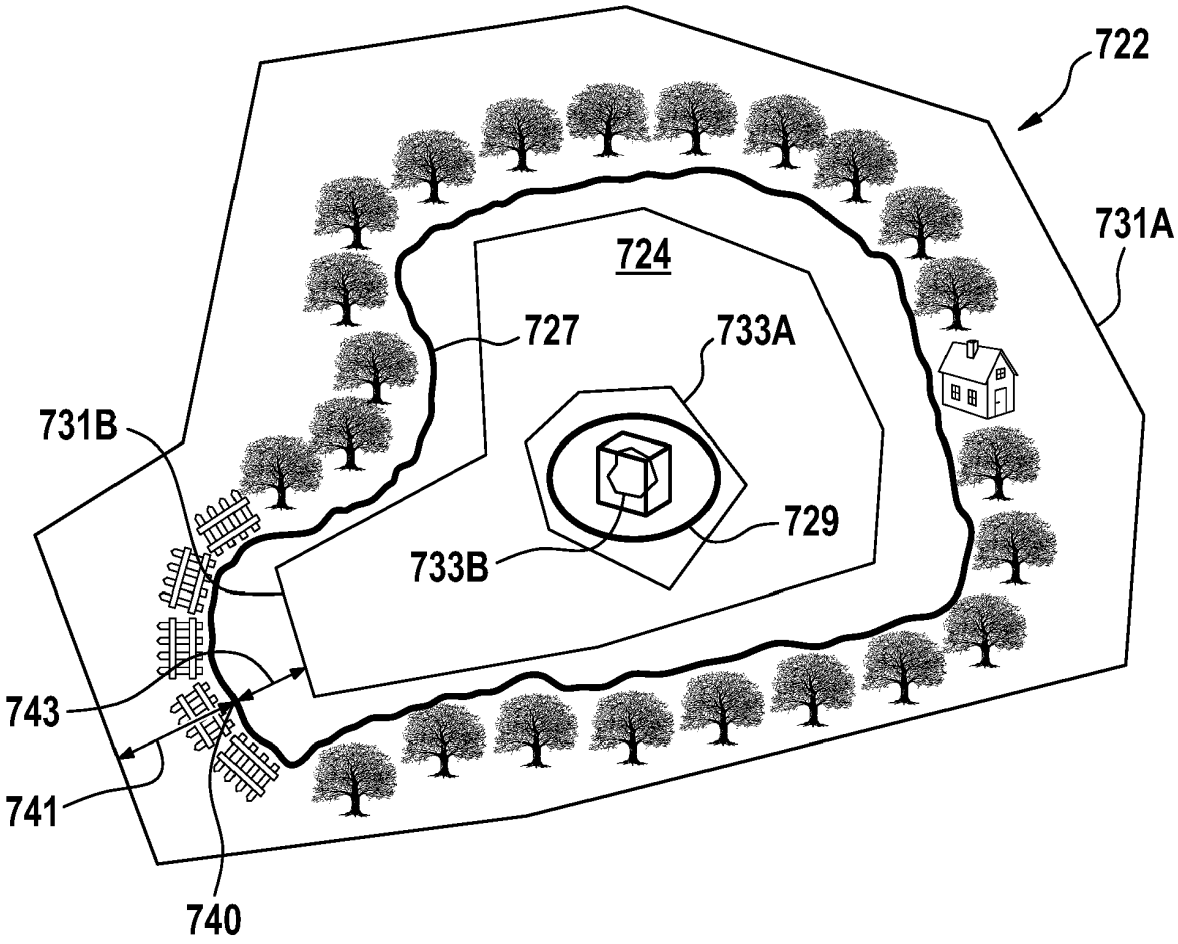

Fig. 7B

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EUROPEAN SEARCH REPORT

Application Number
EP 19 15 7247

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	WO 2016/097891 A1 (HUSQVARNA AB [SE]) 23 June 2016 (2016-06-23) * page 11, line 3 - page 12, line 19 * * page 17, line 20 - page 18, line 26 * -----	1-9,15, 16 10-14	INV. A01D34/00
X A	US 2015/271991 A1 (BALUTIS PAUL C [US]) 1 October 2015 (2015-10-01) * paragraph [0013] * * paragraph [0063] * -----	1-9,15, 16 10-14	
			TECHNICAL FIELDS SEARCHED (IPC) A01D A01F A01B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	21 August 2019	Van Woensel, Gerry

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 19 15 7247

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21-08-2019

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