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(54) **Title**: EXPERIENCE-BASED ROADMAP FOR A ROBOTIC CLEANING DEVICE

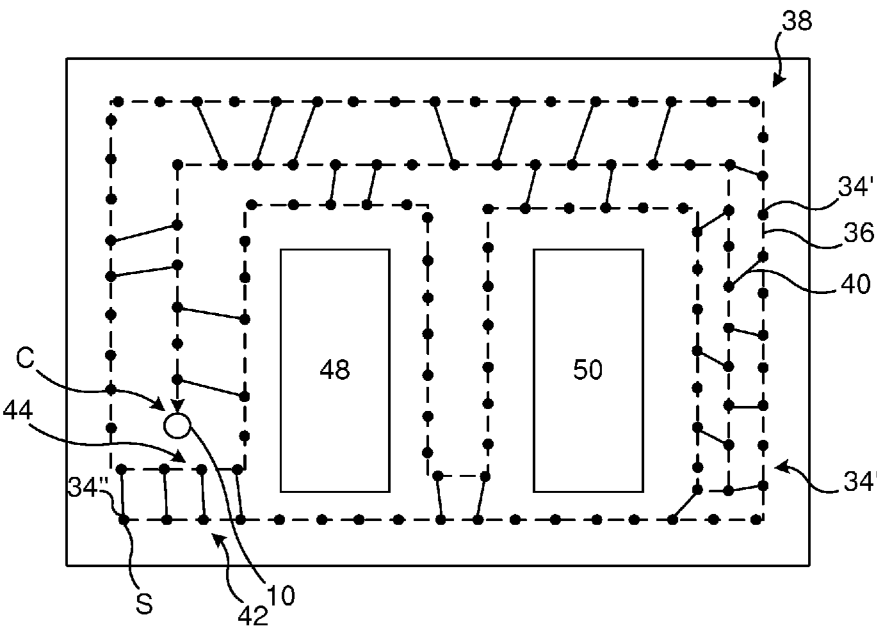

Fig. 6

(57) **Abstract**: The invention relates to a method of operating a robotic cleaning device (10) over a surface to be cleaned comprising the steps of: registering (S01) roadmap nodes (34a, 34b, 34', 34'', 34''', 34'''', 34''''') at intervals on the surface during cleaning, said roadmap nodes comprising positional information; linking (S02) the roadmap nodes to form roadmap links (36) in a roadmap graph (38, 38'), if the robotic cleaning device is driving directly from a previously registered roadmap node (34') to a currently registered roadmap node (34); wherein the roadmap links (36) in the roadmap graph facilitate navigation of the robotic cleaning device.

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EXPERIENCE-BASED ROADMAP FOR A ROBOTIC CLEANING DEVICE

TECHNICAL FIELD

The invention relates to a robotic cleaning device and to a method of operating and navigating the robotic cleaning device by registering roadmap nodes when driving.

BACKGROUND

In many fields of technology, it is desirable to use robots with an autonomous behaviour such that they can freely move around a space without colliding with possible obstacles.

Robotic vacuum cleaners or robotic floor mops, further referred to as robotic cleaning devices, are known in the art and usually equipped with drive means in the form of one or more motors for moving the cleaner across a surface to be cleaned. The robotic cleaning devices may further be equipped with intelligence in the form of microprocessor(s) and navigation means for causing an autonomous behaviour such that the robotic vacuum cleaners can freely move around and clean a space in the form of e.g. a room. Thus, these prior art robotic cleaning devices have the capability of more or less autonomously vacuum clean or mop a room, in which furniture such as tables, chairs and other obstacles such as walls and stairs are located.

There are basically two categories of robotic cleaning devices known in the prior art;- the ones which clean a surface by random motion and the ones which navigate using various sensor data.

The robotic cleaning devices, which use a random motion also look randomly for the charger. These robotic cleaning devices navigate and clean by principle of contingency. Such robotic cleaning devices may comprise a collision sensor to avoid collisions when cleaning. Typically they have means to detect and locate the charger when they happen to pass it or when the charger comes into the field of view. This is obviously not a very efficient way of cleaning and navigating and may in particular not work very well for large surfaces or for complicated layouts.

The other type of prior art robotic cleaning devices, which navigate using sensor data deduced from the sensor data where they can safely drive without collisions with obstacles. As they make assumptions about their environment based on the sensor data, which is in most cases not complete, they run a high risk of getting stuck or lost. In addition, extracting data and thus making assumptions from the sensor data additionally requires expensive electronic components.

In some cases prior art robotic cleaning devices use a stroke method to clean, which means they drive back and forth stroke by stroke in order to clean a surface. When navigating such a prior robotic cleaning device from one room to another or back to the charger, the robotic cleaning device uses sensor data to navigate. The risk of colliding with obstacles is then comparably high, since such robotic cleaning devices are also forced to make assumptions based on the sensor data. This may slow down the robotic cleaning device and thus reduce the efficiency of the cleaning.

In other cases the robotic cleaning device may even get stuck without any battery power left because the distances it has to drive are too far and not properly planned.

SUMMARY

An object of the present invention is to provide a method of operating a robotic cleaning device that is robust and efficient.

It is advantageous to provide a robotic cleaning device comprising a processing unit or the like that is configured to perform the method in order to operate the robotic cleaning device accordingly.

The inventors have realized that it is possible to take advantage of the fact that a robotic cleaning device is moving eventually across an entire surface to be cleaned. Because the robotic cleaning device is eventually covering the entire surface and this many times during its operating life, it is possible to provide a robust and surprisingly efficient method to enhance the safety and efficiency of the navigation and cleaning performed by the robotic cleaning device.

Disclosed herein is a method of operating a robotic cleaning device over a surface to be cleaned comprising the steps of:

registering roadmap nodes at intervals on the surface during cleaning, said roadmap nodes comprising positional information;

linking the roadmap nodes to form roadmap links in a roadmap graph, if the robotic cleaning device is driving directly from a previously registered roadmap node to a currently registered roadmap node, whereby the roadmap links in the roadmap graph may facilitate navigation of the robotic cleaning device.

The roadmap links may form a sequence, whereby this sequence may be continuous or not. Such a sequence forms a path, which the robotic cleaning device can reuse and follow at a later stage, for example to transport itself from one point to another or for navigating from an arbitrary position back to the charger.

The above described method takes advantages of the fact that the robotic cleaning device is navigating over the entire surface to be cleaned. Eventually the surface is virtually covered with roadmap nodes that are linked together. The robotic cleaning device thus knows exactly where it can safely drive without colliding with an obstacle. In other words, because the robotic cleaning device continuously registers roadmap nodes there will always be a possibility for the robotic cleaning device to find an obstacle-free path or sequence from its current position to any position where it has been before.

The roadmap nodes may be virtual roadmap nodes, registered in the memory of the robotic cleaning device.

In the above, the term driving directly form a previously registered roadmap node to a currently registered roadmap node means that the robotic cleaning device is driving without colliding or detecting an obstacle in between the previously registered roadmap node and the currently registered roadmap node.

In case an obstacle is detected in between two roadmap nodes the robotic cleaning device will navigate around it and continue to register roadmap nodes while doing that.

According to a preferred embodiment the method may comprise the step of adding a shortcut link between a previously registered roadmap node of a first sequence, and a currently registered roadmap node of a second sequence of registered roadmap nodes, if the two roadmap nodes are found to be close enough so that it can be safely assumed that the robotic cleaning device can drive in between them without risking any collision.

The safe assumption may for example be considered, if no obstacle is detected in between the previously registered roadmap node of the first sequence and the currently registered roadmap node of the second sequence, said second sequence being arranged at an offset from the first sequence.

The shortcut links increase the robustness of the navigation. The robotic cleaning device is capable of driving and navigating between sequence sections by using the shortcut links. The shortcut links may shorten transportation paths quite substantially, as disclosed later herein.

The criterion for adding a shortcut in between the previously registered roadmap node of the first sequence and the currently registered roadmap node of the second sequence may be that the offset is smaller than a width of the robotic cleaning device.

Generally the offset may be chosen to be less than one of the dimensions of the robotic cleaning device, for example the width or length of the robotic cleaning device.

This may help the robotic cleaning device to ensure that there is no obstacle in between the registered roadmap node of the first sequence section and the currently registered roadmap node of the second sequence section.

The first sequence section and the second sequence section may each comprise at least two roadmap nodes linked by a roadmap link.

In an embodiment the method may further comprise the step of determining a shortest distance between a first position, preferably within the roadmap graph, and a second position, preferably within the roadmap graph, by identifying the registered roadmap node in proximity to the first position and the registered roadmap node in proximity to the second position and then calculating a transportation sequence, which comprises the smallest amount of linked registered roadmap nodes that lead from the first position to the second position.

Alternatively to the above the robotic cleaning device may be configured to measure the geometrical length of each link, thus roadmap link and shortcut link, and choose a path or sequence that has the shortest total distance, said total distance being the sum of the geometrical lengths of all links involved in the path or sequence. This may provide even shorter sequences.

The transportation sequence may comprise roadmap links and shortcut links.

The smallest amount of linked roadmap nodes points generally to the shortest distance from the first position to the second position. The transportation sequence uses the roadmap links and shortcut links that are established and thus avoids a collision with an obstacle.

In an embodiment the intervals may be time intervals.

The time intervals may be in the range of 1 to 30 seconds, preferably 3 to 20 seconds and more preferably from 5 to 15 seconds.

The robotic cleaning device may be configured to only register roadmap nodes while moving on the surface to be cleaned.

In another embodiment the intervals, between registered roadmap nodes, may be distance intervals.

The distance intervals may be in the range of 1 to 20cm, preferably 5 to 15cm and more preferably in the range of 7 to 13cm.

Alternatively the distance intervals may be in the range of 1% to 100% of the largest dimension of the robotic cleaning device, more preferably 20% to 50% of the largest dimension of the robotic cleaning device.

The distance intervals may be measured by a location-sensor connected to a processing unit.

Advantageously the intervals may be shortened if it is detected that the robotic cleaning device is changing its direction of movement more than a predefined upper threshold value.

This may increase accuracy when the robotic cleaning device is navigating in complex areas, said areas having for example many obstacles or a complicated layout.

The upper threshold value may for example be measured as amount of direction changes of the robotic cleaning device per time or amount of direction changes of the robotic cleaning device per distance.

In another embodiment the intervals may be extended if it is detected that the robotic cleaning device is changing its direction of movement less than a predefined lower threshold value.

This may reduce the amount of roadmap nodes and thus data that is produced.

The lower threshold value may for example also be measured as amount of direction changes of the robotic cleaning device per time or amount of direction changes of the robotic cleaning device per distance.

In another embodiment the method may further comprise a step of adding straight shortcut links between straightly linked roadmap nodes by connecting a first roadmap node and a last roadmap node of a straight sequence segment.

The straight shortcut links may simplify the roadmap graph.

It may be advantageous not to delete the originally registered roadmap nodes arranged in between the first roadmap node and the last roadmap node of the straightly linked roadmap nodes since the roadmap nodes arranged in between may be needed for the shortcut links between a first sequence section and a second sequence section.

The straight shortcut links may be advantageous when the robotic cleaning device navigates through long narrow corridors or the like.

In another embodiment the roadmap nodes may comprise additional information about the status of the robotic cleaning device at the time of registering the roadmap node and/or the roadmap link.

The additional information may be used to select, among multiple possible roadmap nodes, an arbitrary sequence of roadmap nodes that reduces the risk for collision with an obstacle.

The additional information may for example comprise tags such as “carpet edge”, “wall”, “door sill” if such objects or obstacles are encountered, in order to improve the safety of the navigation.

Herein is also disclosed a robotic cleaning device comprising a main body, a propulsion system arranged to move the robotic cleaning device, a contact detecting portion connected to the main body and arranged to detect if the robotic cleaning device is in contact with an object and a dead reckoning sensor operatively connected to the propulsion system. The robotic cleaning device may further comprise a processing unit arranged to control the propulsion system, whereby the processing unit may be connected to the dead reckoning sensor and configured to perform the method comprising any of the previously described steps and/or features.

Disclosed herein is further a computer program comprising computer-executable instructions for causing a robotic cleaning device to perform the method comprising any of the previously described steps and/or features, when the computer-executable instructions are executed on a processing unit included in the robotic cleaning device.

Disclosed is further a computer program product comprising a computer readable storage medium, the computer readable storage medium having the computer program according to the above embodied therein.

Generally, all terms used in the claims are to be interpreted according to their ordinary meaning in the technical field, unless explicitly defined otherwise herein. All references to "a/an/the element, apparatus, component, means, device, step, etc." are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, device, step, etc., unless explicitly stated otherwise. The steps of any method disclosed herein do not have to be performed in the exact order disclosed, unless explicitly stated.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is now described, by way of example, with reference to the accompanying drawings, in which:

Fig 1 schematically illustrates a top down view onto an embodiment of a robotic cleaning device according to the invention;

Fig 2 schematically illustrates a front view onto a robotic cleaning device according to an embodiment of the invention;

Fig 3 schematically illustrates the steps of registering roadmap nodes and forming roadmap links according to a method of the invention;

Fig 4 schematically illustrates the step of adding shortcuts in between roadmap nodes;

Fig 5 schematically illustrates the step of adding straight shortcuts in between straightly connected roadmap nodes;

Fig 6 schematically illustrates a roadmap graph of cleaning environment after the completion of a cleaning by the robotic cleaning device;

Fig 7 schematically illustrates the step of determining and calculating a shortest distance between a first position and a second position in the roadmap graph of figure 6; and

Fig 8 schematically illustrates the steps of the method according to the invention.

DETAILED DESCRIPTION

The invention will now be described more fully hereinafter with reference to the accompanying drawings, in which certain embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided by way of example so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout the description.

The invention relates to robotic cleaning devices, or in other words, to automatic, self-propelled machines for cleaning a surface, e.g. a robotic vacuum cleaner, a robotic sweeper or a robotic floor washer. The robotic cleaning device 10 according to the invention can be mains-operated and have a cord, be battery-operated or use any other kind of suitable energy source, for example solar energy.

Figure 1 shows a robotic cleaning device 10 according to an embodiment of the present invention in a bottom view, i.e. the bottom side of the robotic cleaning device 10 is shown. The arrow indicates the forward direction of the robotic cleaning device. The robotic cleaning device 10 comprises a main body 11 housing components such as a propulsion system comprising driving means in the form of two electric wheel motors 15a, 15b for enabling movement of the driving wheels 12, 13, such that the robotic cleaning device 10 can be moved over a surface to be cleaned. Each wheel motor 15a, 15b is capable of controlling the respective driving wheel 12, 13 to rotate independently of each other in order to move the robotic cleaning device 10 across a surface to be cleaned. A number of different driving wheel arrangements, as well as various wheel motor arrangements, may be envisaged. It should be noted that the robotic cleaning device 10 may have any appropriate shape, such circular-shaped main body 11 as illustrated, or a triangular-shaped main body.

As an alternative to the above described propulsion system, a track propulsion system may be used or even a hovercraft propulsion system.

The propulsion system is further connected to two dead reckoning sensors 30, 30', one assigned to each driving wheel 12, 13, as illustrated in figure 1. The dead reckoning sensors 30, 30' are configured to independently measure distances travelled by the robotic cleaning device 10 by observing the movement and turns, respectively, of the driving wheels 12, 13, in order to help to position the robotic cleaning device 10, for example within a room.

The embodiment of the robotic cleaning device 10 as illustrated in figure 1 comprises two dead reckoning sensors 30, 30', it is however possible to envisage robotic cleaning devices comprising only one dead reckoning sensor 30, 30'.

A controller such as processing unit 16 controls the wheel motors 15a, 15b to rotate the driving wheels 12, 13 as required in view of information received from an obstacle detecting device (shown in figure 2) for detecting obstacles in the form of walls, floor lamps, table legs, around which the robotic cleaning device must navigate. The dead reckoning sensors 30, 30' are connected to the processing unit 16, for example via the electric wheel motors 15a, 15b, as illustrated in figure 1.

The obstacle detecting device may be embodied in the form of infrared (IR) sensors and/or sonar sensors, a microwave radar, a 3D sensor system registering its surroundings, implemented by means of e.g. a 3D camera, a camera in combination with lasers, a laser scanner, etc. for detecting obstacles and communicating information about any detected obstacle to the processing unit 16. The processing unit 16 communicates with the wheel motors 15a, 15b to control movement of the wheels 12, 13 in accordance with information provided by the obstacle detecting device.

In figure 1 the width W of the robotic cleaning device 10 is further illustrated. As the main body 11 has a round shape, the width W corresponds to a diameter of the main body. In general terms the width W may be defined as the widest part or largest dimension of the robotic cleaning device 10 as measured in a forward direction M.

The main body 11 may optionally be provided with a cleaning member 17 for removing debris and dust from the surface to be cleaned in the form of a rotatable brush roll arranged in an opening 18 at the bottom of the robotic cleaner 10. Thus, the rotatable brush roll 17 is arranged along a horizontal axis in the opening 18 to enhance the dust and debris collecting properties of the cleaning device 10. In order to rotate the brush roll 17, a brush roll motor 19 is operatively coupled to the brush roll to control its rotation in line with instructions received from the processing unit 16.

Moreover, the main body 11 of the robotic cleaner 10 comprises a suction fan 20 creating an air flow for transporting debris to a dust bag or cyclone arrangement (not shown) housed in the main body via the opening 18 in the bottom side of the main body 11. The suction fan 20 is driven by a fan motor 21 connected to the processing unit 16 from which the fan motor 21 receives instructions for controlling the suction fan 20. It should be noted that a robotic cleaning device 10 having either one of the rotatable brush roll 17 and the suction fan 20 for transporting debris to the dust bag may be envisaged. A combination of the two will however enhance the debris-removing capabilities of the robotic cleaning device 10.

Alternatively, the robotic cleaning device 10 may comprise a mop (not shown) and/or a rotating floor brush (not shown).

With further reference to Figure 1, the processing unit 16 may be embodied in the form of one or more microprocessors arranged to execute a computer program 25 downloaded to a suitable storage medium 26 associated with the microprocessor, such as a Random Access Memory (RAM), a Flash memory or a hard disk drive. The processing unit 16 is arranged to carry out a method according to embodiments of the present invention when the appropriate computer program 25 comprising computer-executable instructions is downloaded to the storage medium 26 and executed by the processing unit 16. The storage medium 26 may also be a computer program product comprising the computer program 25. Alternatively, the computer program 25 may be transferred to the storage medium 26 by means of a suitable computer program product, such as a digital versatile disc (DVD), compact disc (CD) or a memory stick. As a further alternative, the computer program 25 may be downloaded to the storage medium 26 over a network. The processing unit 16 may alternatively be embodied in the form of a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), a complex programmable logic device (CPLD), etc.

In figure 1 is further a contact detecting portion 32 illustrated. The contact detecting portion 32 is arranged at a front end of the robotic cleaning device 10 as seen in a direction of movement. The contact detecting portion 32 may extend over the whole front part of the robotic cleaning device 10, similar to a park distance sensor of a modern car. Alternatively, the contact detecting portion 32 may only extend over the front extremity of the robotic cleaning device 10, as illustrated in figure 1. The contact detecting portion 32 is arranged in order to detect whether or not the robotic cleaning device 10 is in contact with an object or landmark. This may be useful when a collision with obstacles has to be avoided.

Figure 2 shows a front view of the robotic cleaning device 10 according to an embodiment illustrating the previously mentioned obstacle detecting device in the form of a 3D camera system 22 comprising at least a camera 23 and a first and a second structured light source 27, 28, which may be horizontally or vertically oriented line lasers. Further illustrated is the processing unit 16, the main body 11, the driving wheels 12, 13, and the rotatable brush roll 17 previously discussed with reference to Figure 1. The processing unit 16 is operatively coupled to the camera 23 for recording images of a vicinity of the robotic cleaning device 10. The first and second structured light sources 27, 28 may preferably be vertical line lasers and are arranged lateral of the camera 23 configured to illuminate a height and a width that is greater than the height and width of the robotic cleaning device 10. The camera 23 is controlled by the processing unit 16 to capture and record a plurality of images per second. Data from the images is extracted by the processing unit 16 and the data is typically saved in the storage medium 26 along with the computer program 25.

The first and second structured light sources 27, 28 are configured to scan, preferably in a vertical orientation, the vicinity of the robotic cleaning device 10, normally in the direction of movement of the robotic cleaning device 10. The first and second structured light sources 27, 28 are configured to send out laser beams, which illuminate furniture, walls and other obstacles of a home or room. The camera 23 is controlled by the processing unit 16 to capture and record images from which the processing unit 16 creates a representation or layout of the surroundings that the robotic cleaning device 10 is operating in, by extracting features from the images and by measuring the distance covered by the robotic cleaning device 10, while the robotic cleaning device 10 is moving across the surface to be cleaned. Thus, the processing unit 16 may derive positional data of the robotic cleaning device 10 with respect to the surface to be cleaned from the recorded images, to generate a 3D representation of the surroundings in particular the obstacles.

The 3D representation generated from the images recorded by the 3D camera system 22 thus facilitates detection of obstacles in the form of walls, floor lamps, table legs, etc. around which the robotic cleaning device 10 must navigate as well as rugs, carpets, doorsteps, etc., that the robotic cleaning device 10 must traverse.

With respect to Figure 2, for illustrational purposes, the 3D camera system 22 is separated from the main body 11 of the robotic cleaning device 10. However, in a practical implementation, the 3D camera system 22 is likely to be integrated with the main body 11 of the robotic cleaning device 10 to minimize the height of the robotic cleaning device 10, thereby allowing it to pass under obstacles, such as e.g. a sofa.

The robotic cleaning device 10 has now been described comprising an obstacle detecting device having a 3D camera 23 and first and second structured light sources 27, 28, as this provides for an efficient and rather quick navigation of the robotic cleaning device. However, in its simplest form the robotic cleaning device 10 may only comprise the contact detecting portion 32, since this contact detecting portion 32 enables the robotic cleaning device 10 to navigate around detected obstacles. For the method as illustrated herein, it is sufficient that the robotic cleaning device 10 comprises the contact detecting portion 32, the obstacle detecting device is not essential to perform the method described herein.

Figures 3 to 5 illustrate steps of the method according to the present invention. In the following the terms roadmap node 34, roadmap link 36 and roadmap graph 38 (c.f. figures 6 and 7) relate to the following:

Roadmap node 34: a position of the robotic cleaning device 10 at a specific point in time whereby the roadmap node is a virtual point, for example stored on the storage medium 26, said virtual point eventually building a roadmap graph;

Roadmap link 36: a record, which also may be stored on the storage medium 26, that connects two or more roadmap nodes 34, 34', 34" in between which the robotic cleaning device could drive directly without colliding with any obstacles;

Roadmap graph 38: a virtual map, for example stored on the storage medium 26, of the surface to be cleaned comprising at least some of the roadmap nodes 34 and the roadmap links 36.

The roadmap graph 38 may comprise additional features as will be described later herein.

Figure 3 illustrates how the robotic cleaning device 10 moves in a direction M while registering S01 roadmap nodes 34, 34' at intervals. When it is detected that the robotic cleaning device 10 could directly drive or move from a previously registered roadmap node 34' to a currently registered roadmap node 34 the two roadmap nodes 34', 34 are linked S02 by a roadmap link 36. As illustrated in figure 3, the robotic cleaning device 10 has been driving straight for a sequence of five roadmap nodes 34, 34' without colliding with any obstacle and thus these roadmap nodes 34', 34 are all linked together by roadmap links 36. This indicates to the robotic cleaning device 10 that it is safe to drive along these roadmap links 36 and that his may be done again if necessary for example for transportation (c.f. figure 7).

The linked roadmap nodes 34, 34' may form a sequence 54. This sequence 54 is continuously extended as the robotic cleaning device 10 is driving and cleaning, as for example illustrated in figures 6 and 7. It should however be noted that the sequence 54 does not have to be continuous it may be interrupted.

The intervals between the registered roadmap nodes 34, 34' may be time intervals or distance intervals. Thus the roadmap nodes 34, 34' may be dropped or registered at time intervals of for example 1 to 30 seconds, preferably 3 to 20 seconds and more preferably from 5 to 15 seconds or at distance intervals of for example 1 to 20cm, preferably 5 to 15cm and more preferably in the range of 7 to 13cm.

Alternatively the distance intervals may be in the range of 1% to 100% of the largest dimension of the robotic cleaning device 10, more preferably 20% to 50% of the largest dimension of the robotic cleaning device 10, which is in the illustrated case the diameter or width W but may in other cases be a length or width of the robotic cleaning device.

Figure 4 illustrates additionally to the steps illustrated together with figure 3, how the robotic cleaning device 10 is adding S03 a shortcut link 40 between a registered roadmap node 34" of a first sequence section 42 or first sequence of a sequence 54 of registered roadmap nodes and a currently registered roadmap node 34 of a second sequence section 44 or second sequence of the sequence 54 of registered roadmap nodes, if no obstacle is detected in between the registered roadmap node of the first sequence section 42 and the currently registered roadmap node 34 of the second sequence section 44. As shown in figure 4, the second sequence section 44 is arranged at an offset D from the first sequence section 42.

The first sequence section 42 is illustrated as a dashed line in figure 4 for illustrative purposes in order to easier distinguish between the two sequence sections 42, 44. Additionally, the robotic cleaning device 10 is illustrated in a dashed shape to show that it drove along the second sequence section 44 while adding the illustrated shortcut links 40. The robotic cleaning device is further shown transparent in order to illustrate the registering S01 of the current roadmap node 34.

The robotic cleaning device 10 is thus configured to follow previously registered roadmap nodes 34" as soon as the processing unit 16 detects that previously registered roadmap nodes 34" are encountered, which is usually the case as for example illustrated in figures 6 and 7. In other words, the robotic cleaning device 10 is capable of noticing where it has been before, since it will detect and thus recognize these areas because of the previously registered roadmap nodes 34', 34".

The shortcut links 40 thus connect the at least approximately parallel first sequence section 42 and second sequence section 44 if no obstacle is detected. Shortcut links 40 may be added continuously whenever possible or only sequentially at defined distance or time intervals.

The offset D between the second sequence section 44 and the first sequence section 42 must be smaller than the width W (c.f. figure 1) of the robotic cleaning device 10, only then is safe to assume that no obstacle is arranged in between the currently registered roadmap node 34 of the second sequence section 44 and the previously registered roadmap node 34" of the first sequence section 42. The offset D may further be chosen to be less than a width (not illustrated in the figures) of the opening 18 of the suction fan 20. The processing unit 16 may be configured to navigate the robotic cleaning device 10 accordingly at an offset D less than the width W of the robotic cleaning device 10, when previously registered roadmap nodes 34" are encountered.

Figure 5 illustrates how straight shortcut links 46, 46', 46" may be added S04 between straightly linked roadmap nodes 34"', 34a, 34b forming a straight sequence section 43. When the processing unit 16 detects that the robotic cleaning device 10 was driving at least approximately straight for sequence of roadmap nodes 34a, 34"', 34b it may add S04 straight shortcut links 46, 46', 46" between a first roadmap node 34a and a last roadmap node 34b of a straight sequence of roadmap nodes 34a, 34b, 34"'. In order to add shortcut links 40 (c.f. figure 4) later on, thus when following (not shown in the figures) the sequence of roadmap nodes 34"', 34a, 34b illustrated in figure 5 upon encountering them, the roadmap nodes 34"' in between the first roadmap node 34a and the last roadmap node 34b are not deleted. The robotic cleaning device 10 may thus revert back to those intermediate roadmap nodes 34"' in case a shortcut link 36 needs to be added later on to a roadmap node 34 of another sequence section 42, 44, as shown and described referring to figure 4.

In case the robotic cleaning device 10 detects (not shown in the figures) an obstacle in between a currently registered roadmap node of the second sequence section and the previously registered roadmap node 34" of the first sequence section, the robotic cleaning 10 will navigate around it using the contact detecting portion 32 and optionally the obstacle detecting device, while registering S01 and linking S02 roadmap nodes until previously registered roadmap nodes 34" suitable for adding S03 shortcut links 40 are again encountered.

For the sake of simplicity the robotic cleaning device 10 is not shown in figure 5. However its current position would be at the current registered roadmap node 34.

Further, it should be mentioned that the roadmap graph 38' as schematically illustrated in figure 5 may for instance be established while the robotic cleaning device 10 was following a wall or the like.

Referring now to figure 6, which illustrates a roadmap graph 38 of a surface to be cleaned after completion of the cleaning and thus after the roadmap nodes 34 have been registered. The roadmap nodes 34, 34', 34", 34"", 34""', 34a, 34b, the roadmap links 36 and the shortcut links 40 are illustrated, said roadmap nodes 34, 34', 34", 34"", 34""', 34a, 34b, the roadmap links 36 and the shortcut links 40 forming a complete and robust roadmap graph 38. The roadmap graph 38 comprises the positional information about two obstacles 48, 50 thus teaching the robotic cleaning device 10 that it cannot drive in these areas. The starting point S of the cleaning and registering of roadmap nodes 34 and the current position C of the robotic cleaning device 10 are also visible in figure 6. Figure 6 illustrates well how the robotic cleaning device 10 and the processing unit 16, respectively, add shortcut links 40 whenever previously registered roadmap nodes 34" of a an earlier sequence section 42 are encountered.

For illustrated purposes potential straight shortcuts 46, 46', 46" as shown in figure 5, are not shown in figure 6 although they may be present.

Figure 7 illustrates schematically how the roadmap graph 38 of figure 6 may be used to determine So5 a shortest distance from a first position A to a second position B. The shortest distance from positions A to B may be determined by identifying a registered roadmap node 34”” close to the first position A and another registered roadmap node close 34””’ close to the second position and by then calculating a transportation sequence 52. The transportation sequence 52 may be chosen as the sequence comprising the smallest amount of linked registered roadmap nodes 34, 34””, 34””’ that lead from the first position A to the second position B. Linked registered roadmap nodes 34, 34””, 34””’ is herewith to be understood as registered roadmap nodes 34, 34””, 34””’ being linked by roadmap links 36, shortcut links 40 and/or straight shortcut links 46 (not shown in figure 7).

Determining S05 a shortest distance between a first position A and a second position B by identifying a registered roadmap node 34”” in proximity to the first position A and another registered roadmap node 34””’ in proximity to the second position B and then calculating a transportation sequence 52 may alternatively involve the calculation of a transportation sequence (not shown), which comprises the shortest total distance, when summarizing the geometrical length of all roadmap links 36 and shortcut links 40 involved in the transportation sequence. In some cases, for example when many roadmap nodes are involved, this may lead to a shorter transportation sequence 52 than the calculation of the smallest amount of linked roadmap nodes 34, 34””, 34””’ that lead from the first position A to the second position B.

Figures 6 and 7 further illustrate another sequence 54’ of roadmap nodes 34, 34’, 34””, 34””’ linked by roadmap links 36. This sequence 54’ is illustrated as being continuous this is however not necessarily the case, as previously mentioned.

The sequence 54’ further comprises a plurality of sequence sections 42, 43, 44 as previously described.

The robotic cleaning device 10 is thus capable to navigate safely and with a small risk of getting lost. Additionally, even if a new obstacle is added to the cleaning environment in between a first cleaning session of a room or surface and a second cleaning session of the same room or surface, the robotic cleaning device 10 will be able to navigate safely since the registered roadmap nodes 34a, 34b, 34', 34", 34"', 34"", 34""', the roadmap links 36, the shortcut links 40 and the straight shortcut links 46, 46', 46" are deleted after each completed cleaning session. The roadmap graph 38 is thus always up to date and experience based leaving the robotic cleaning device 10 with a reliable and robust method for navigation.

The roadmap nodes 34a, 34b, 34', 34", 34"', 34"", 34""' may comprise positional information and additional information about the status of the robotic cleaning device 10 at the time of registering the roadmap node 34a, 34b, 34', 34", 34"', 34"", 34""' and/ or the roadmap link 36. The additional information may for example be used to determine an arbitrary sequence of roadmap nodes that reduce the risk for collision with an obstacle.

In other words if the robotic cleaning device 10 for example detects that is regularly cross an edge of a carpet, the processing unit 16 may be configured to plan the cleaning and in particular a potential transportation sequence 52 accordingly to avoid that the carpet edge needs to be crossed if possible. Thus the registered roadmap nodes 34a, 34b, 34', 34", 34"', 34"", 34""' may provide the robotic cleaning device 10 and the processing unit 16, respectively, with additional information about the surface to be cleaned.

Further the additional information may comprise a tag such as "bumpy" which means that a certain area of the surface was bumpy or difficult to drive on, which will teach the robotic cleaning device 10 and the processing unit 16, respectively, to avoid this area when planning a sequence in order to make this sequence safer and more robust.

The time or distance intervals as previously described may not be regular or continuous they may vary depending on the amount of direction changes of the robotic cleaning device 10 during a specific time period. These direction changes may be easily detected by the dead reckoning sensor 30, 30'.

Figure 8 illustrates the steps according to the present invention. If an obstacle is detected (not shown), for instance when trying to add shortcut links 40, the robotic cleaning device 10 will not add a shortcut link 40 and go back to the first step and registering S01 and linking S02 roadmap nodes 34 while following the edge of the obstacle until previously registered roadmap nodes of a previous sequence section are again encountered.

The invention has mainly been described above with reference to a few embodiments. However, as is readily appreciated by a person skilled in the art, other embodiments than the ones disclosed above are equally possible within the scope of the invention, as defined by the appended patent claims.

CLAIMS

1. A method of operating a robotic cleaning device (10) over a surface to be cleaned comprising the steps of:

registering (S01) roadmap nodes (34a, 34b, 34’, 34”, 34’”, 34””, 34”””) at intervals on the surface during cleaning, said roadmap nodes comprising positional information;

linking (S02) the roadmap nodes to form roadmap links (36), if the robotic cleaning device is driving directly from a previously registered roadmap node (34’) to a currently registered roadmap node (34);

wherein the roadmap links (36) facilitate navigation of the robotic cleaning device.

2. The method according to claim 1, comprising the step of adding (S03) a shortcut link (40) between a registered roadmap node (34”) of a first sequence section (42) of registered roadmap nodes (34”) and a currently registered roadmap node (34) of a second sequence section (44) of registered roadmap nodes 34, 34’), if no obstacle is detected in between the registered roadmap node of the first sequence section and the currently registered roadmap node of the second sequence section, said second sequence section being arranged at an offset (D) from the first sequence section.

3. The method according to claim 2, wherein the offset (D) is smaller than one of the dimensions of the robotic cleaning device (10), preferably the larger dimension of length and width of the robotic cleaning device.

4. The method according to any of claims 2 or 3, wherein the first sequence section (42) and the second sequence section (44) each comprise at least two roadmap nodes (34, 34’, 34”) linked by a roadmap link (36).

5. The method according to any of claims 1 to 4, comprising the step of determining (S05) a shortest distance between a first position (A) and a second position (B) by identifying a registered roadmap node (34””) in

proximity to the first position (A) and another registered roadmap node (34”””) in proximity to the second position (B) and then calculating a transportation sequence (52), which comprises the smallest amount of linked registered roadmap nodes (34, 34””, 34”””) that lead from the first position (A) to the second position (B).

6. The method according to any of claims 1 to 4, comprising the step of determining (S05) a shortest distance between a first position (A) and a second position (B) by identifying a registered roadmap node (34””) in proximity to the first position (A) and another registered roadmap node (34”””) in proximity to the second position (B) and then calculating a transportation sequence, which comprises the shortest total distance, when summarizing the geometrical length of all roadmap links (36) and shortcut links (40) involved in the transportation sequence.

7. The method according to any of the previous claims, wherein the intervals, between the registering or roadmap nodes (34a, 34b, 34’, 34”, 34’”, 34””, 34”””), are time intervals.

8. The method according to any of previous claims 1 to 6, wherein the intervals, between the registering or roadmap nodes (34a, 34b, 34’, 34”, 34’”, 34””, 34”””), are distance intervals.

9. The method according to any of the previous claims, wherein the intervals, between the registering or roadmap nodes (34a, 34b, 34’, 34”, 34’”, 34””, 34”””), are shortened if it is detected that the robotic cleaning device (10) is changing its direction of movement more than a predefined upper threshold value.

10. The method according to any of the previous claims, wherein the intervals, between the registering or roadmap nodes (34a, 34b, 34’, 34”, 34’”, 34””, 34”””), are extended if it is detected that the robotic cleaning device (10) is changing its direction of movement less than a predefined lower threshold value.

11. The method according to any of the previous claims, comprising the step of adding (S04) straight shortcut links (46, 46’, 46”) between straightly linked roadmap nodes (34a, 34b, 34’”) by connecting a first roadmap node (34a) and a last roadmap node (34b) of a straight sequence segment (43).

12. Method according to any of the previous claims, wherein the roadmap nodes (34a, 34b, 34, 34’, 34”, 34’”, 34””, 34’””) comprise additional information about the status of the robotic cleaning device at the time of registering the roadmap node and/ or the roadmap link.

13. Method according to claim 11, wherein the additional information is used to select among multiple possible sequences of roadmap nodes between the registering or roadmap nodes, an arbitrary sequence of roadmap nodes that reduce the risk for collision with an obstacle.

14. Robotic cleaning device (10) comprising:

a main body (11);

a propulsion system (12, 13, 15a, 15b) arranged to move the robotic cleaning device;

a contact detecting portion (32) connected to the main body (11) and arranged to detect if the robotic cleaning device is in contact with an object;

a dead reckoning sensor (30, 30’) operatively connected to the propulsion system;

a processing unit (16) arranged to control the propulsion system;

wherein the processing unit (16) is connected to the dead reckoning sensor and configured to perform the method according to any of claims 1 to 13.

15. A computer program (25) comprising computer-executable instructions for causing a robotic cleaning device (10) to perform the steps recited in any one of claims 1-13, when the computer-executable instructions are executed on a processing unit (16) included in the robotic cleaning device (10).

16. A computer program product comprising a computer readable storage medium (26), the computer readable storage medium (26) having the computer program (25) according to claim 15 embodied therein.

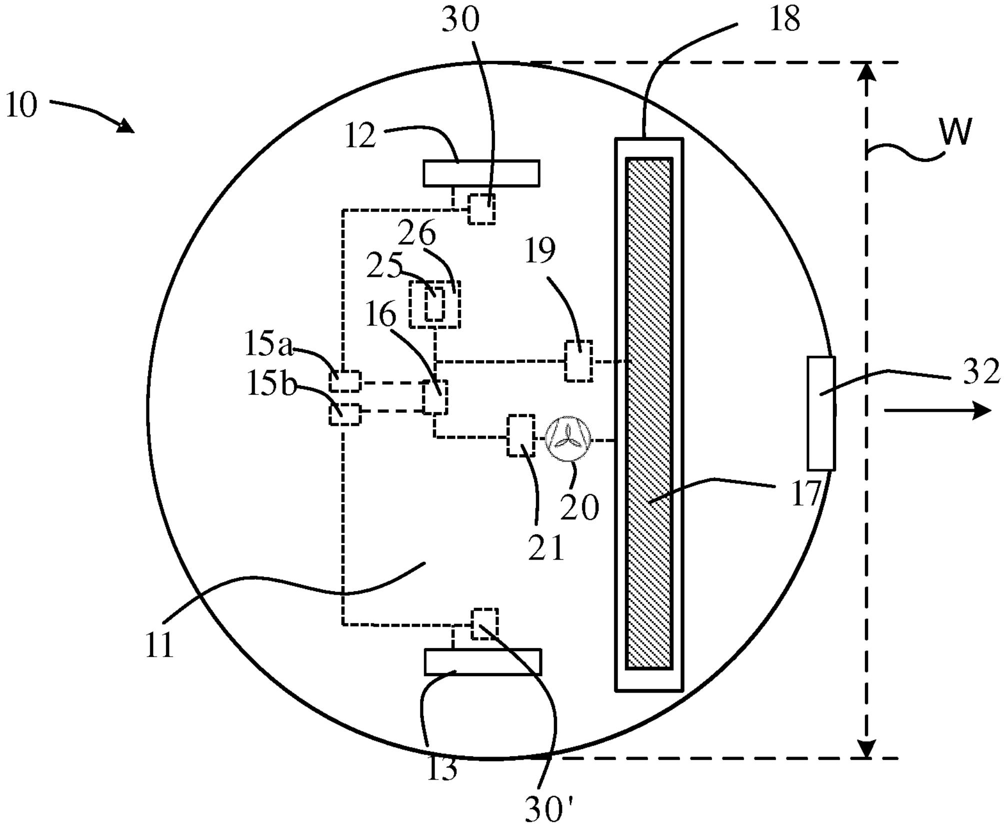

Fig. 1

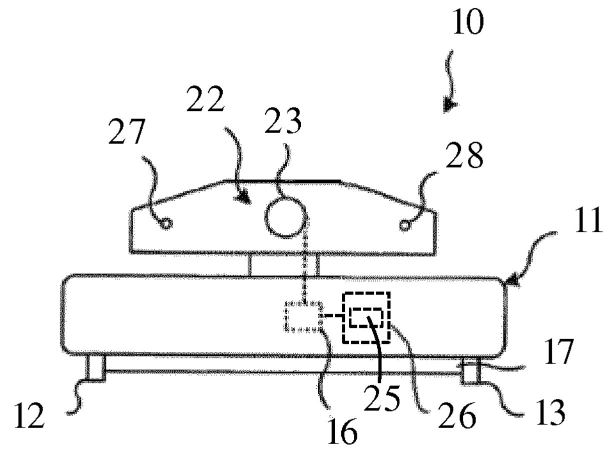

Fig. 2

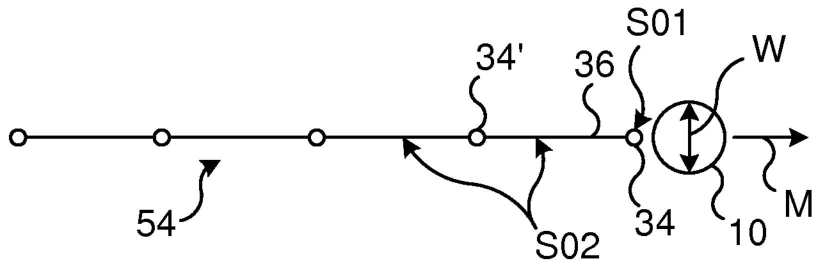

Fig. 3

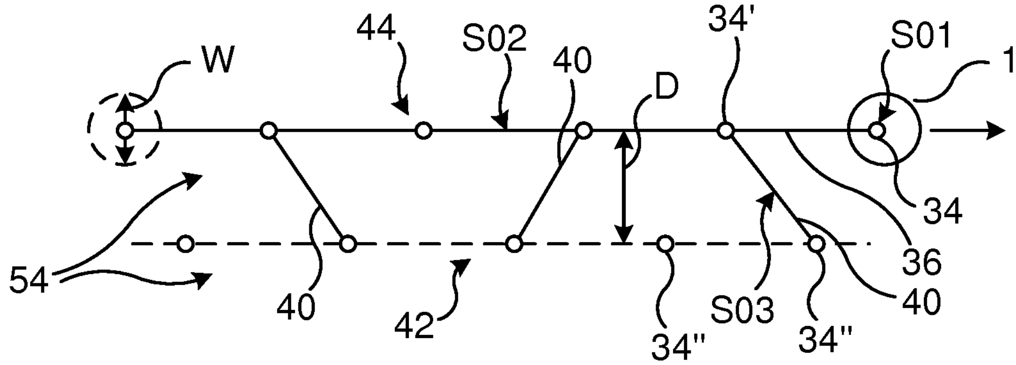

Fig. 4

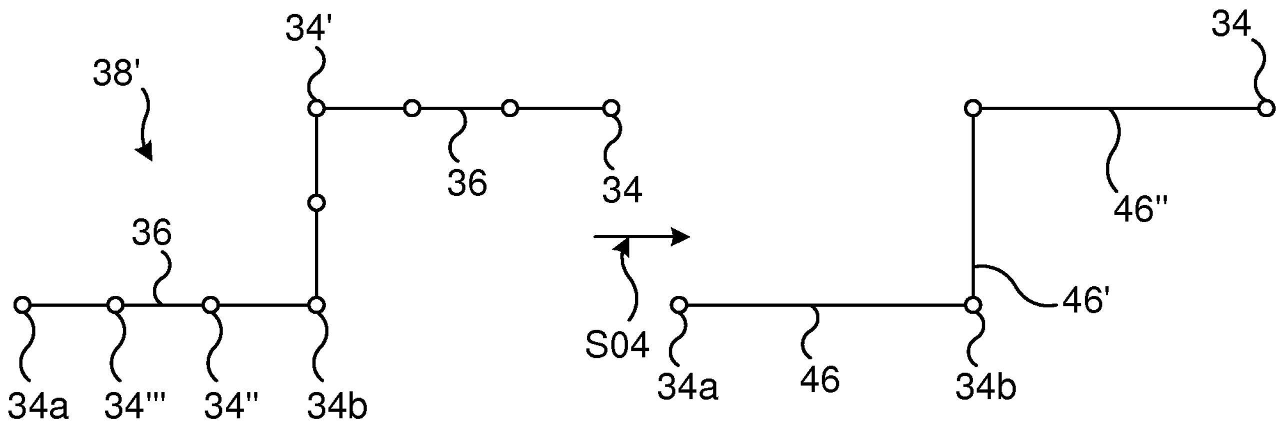

Fig. 5

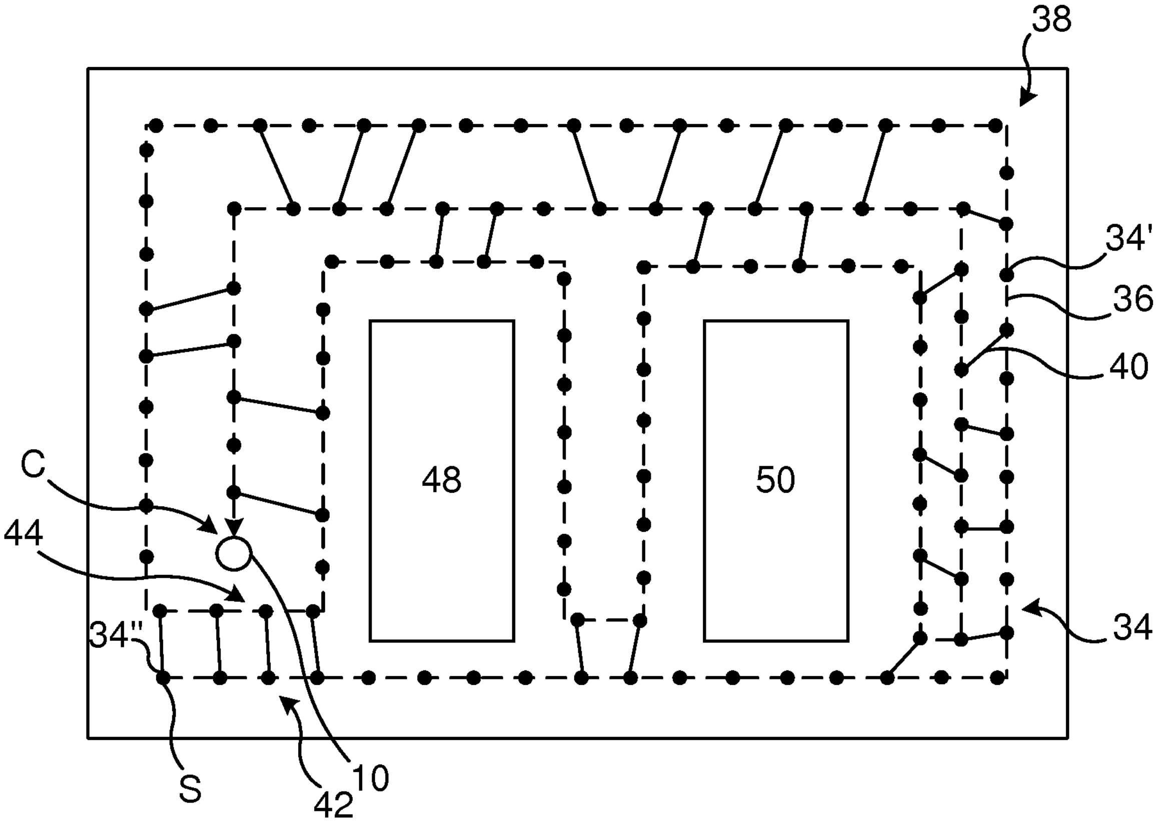
38
34'
36
40
C
48
50
44
34''
34'
S
42
10

Fig. 6

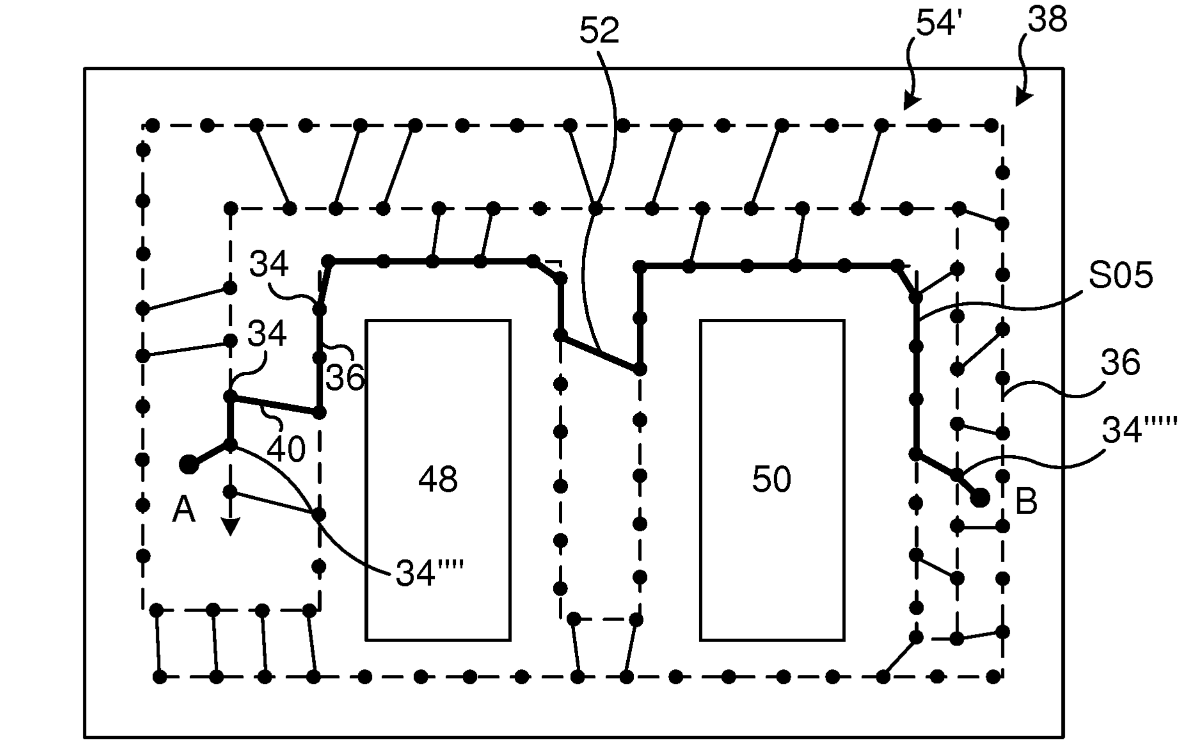
52
54'
38
34
S05
34
36
36
34
40
48
50
34'''''
A
B
34''''

Fig. 7

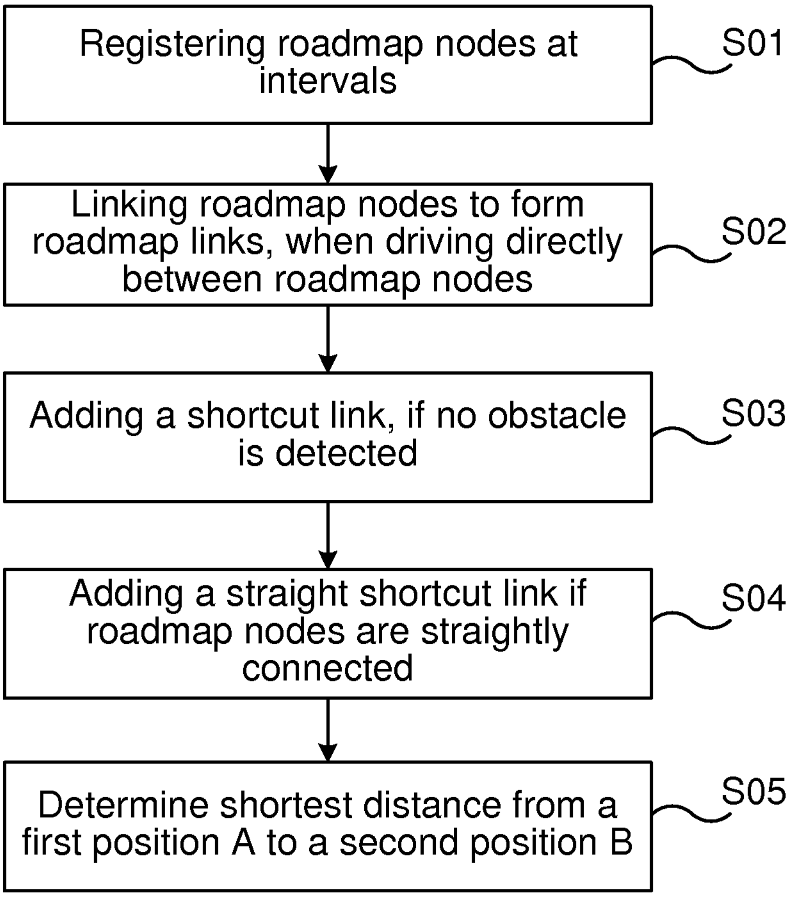
Registering roadmap nodes at intervals
S01
Linking roadmap nodes to form roadmap links, when driving directly between roadmap nodes
S02
Adding a shortcut link, if no obstacle is detected
S03
Adding a straight shortcut link if roadmap nodes are straightly connected
S04
Determine shortest distance from a first position A to a second position B
S05

Fig. 8