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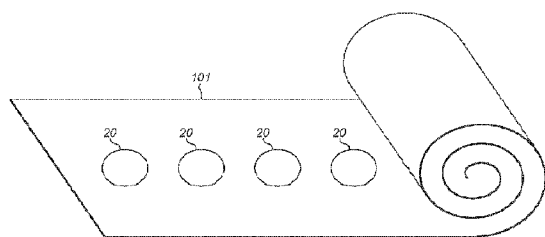


FIG. 3a

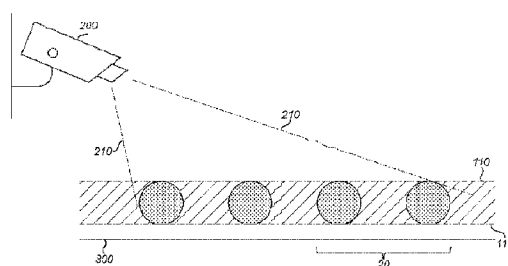


FIG. 3b

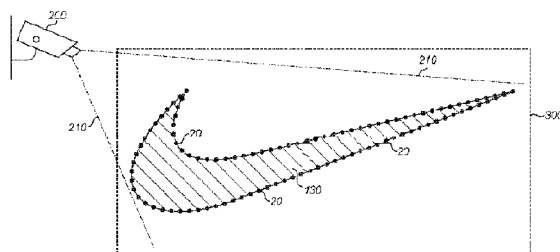


FIG. 3c

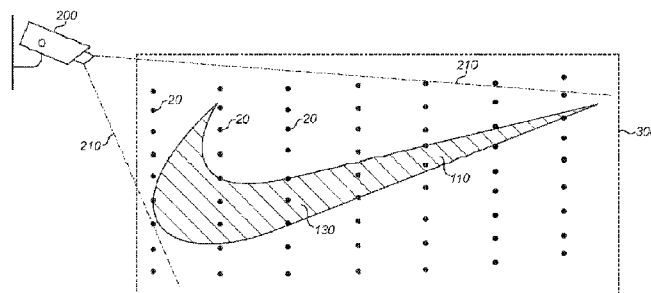


FIG. 3d

(57) Abstract: A navigation guide for use with an autonomous mobile robot (AMR), wherein the AMR comprises a sensor detection system to detect the navigation guide and in operation, is equipped to move over a ground surface, the navigation guide comprising a guideline, the navigation guide further comprising one or more guide markers, and wherein in operation, the guideline and the one or more guide markers are visible on the ground surface. The use of a pre-placed navigation guide means that advantageously, no extra electronic navigational aids such as beacons and/or GPS systems are required to make positional adjustment in either the way or forward navigation. Thus, lowering the cost of the AMR and simplifying its use operationally, whilst maintaining high accuracy movement.

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5 **AN IMPROVED NAVIGATION SYSTEM FOR AN AUTONOMOUS MOBILE ROBOT (AMR)**

The present invention relates to an improved navigation system for use with an Autonomous Mobile Robot (AMR). Specifically, but not exclusively an AMR of a type equipped to deposit materials such as an ink and paint, but may equally deposit sand, seed, fertiliser, or other
10 ground treatments onto a ground surface.

BACKGROUND

Ground marking is typically carried out manually. It requires significant pre-planning, the manufacture of pre-ordered plastic stencils, and large teams of workers to decipher
15 instructions, prepare, lay out, and complete a site for marking. Where marking is required such as for logos, safety or hazard signs, the complex make-up of these images mean that difficulties persist to print any image, any size, any colour, directly onto any ground surface without significant cost of time, expense and compromise in image attributes, such as resolution.

20 One approach to automating ground marking is found in US 2005/0055142 A1 in which a turf image marker comprises a ground maintenance vehicle adapted to both mow and store grass as well as carry a marking device that includes a delivery system for applying a marking material to the ground. Dispensing devices for putting down marking materials are provided
25 in the form of boxes requiring mechanisms that require to be driven such as a motor, electric, air or other fluid motor.

One approach to scalable autonomous ground marking is found in the Applicant's co pending patent "Ground Printing Machine", Micropply Limited, PCT/GB2021/052671, which discloses
30 an AMR capable of ground printing and which uses the tiling of segments to cover an image print area and wherein navigation is performed using locally positioned beacons.

Another approach is found in Pixelrunner's application US2019381529, which disclose using a camera and computer vision to compensate for a degree of adjustment *between* sequential
35 print segments. Initial navigation and set up is performed using a global navigation system.

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Autonomous Vehicles may be completely autonomous (i.e. free from human operation and/or supervision) or may require at least partial human operation and/or supervision depending on the application. Autonomous vehicle systems, as known in the art, are able to follow a pre-determined path, path follow another AMR, or follow a virtual path (eg SLAM).

10 They use many methods of navigation including sensors, beacons, and/or GPS.

Further some applications require high accuracy navigation, needed in order to satisfy a need in large image prints of an accuracy of tiling alignment should be $\pm 2\text{mm}$ and scalable to 50m^2 image/print activations. Thus, there is the need to control the tiling error to within $\pm 2\text{mm}$.

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However, in order to make ground marking or depositing materials on the ground as efficient as printing or marking on paper a novel approach is needed in order to seek high resolution of marking combined with development of the AMR carrying the marking material towards a reduction in size and increase in portability, whilst trying to keep AMR cost and complexity to a minimum.

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SUMMARY OF INVENTION

According to a first aspect of the present invention, there is provided a navigation guide for use with an autonomous mobile robot (AMR), wherein the AMR comprises a sensor detection system to detect the navigation guide and in operation, is equipped to move over a ground surface, the navigation guide comprising a guideline, the navigation guide further comprising one or more guide markers, and wherein in operation, the guideline and the one or more guide markers are visible on the ground surface.

30

The one or more guide markers may be comprised of a repeating pattern.

The repeating pattern may be comprised of a series of dots and spaces. The repeating pattern may be comprised of an array of dots and spaces. The one or more guide markers may be a

- 5 QR code. The repeating pattern may be seen in its entirety within the field of view of the sensor system of the AMR.

The guideline may be an elongated guideline. The elongated guideline may be formed from an elongated strip of material. The elongated guideline may be formed from a flexible
10 material.

The navigation guide may be formed of a light which is displayed on the ground surface by a light source. The guideline may comprise the edge of an image of a logo or design.

- 15 The one or more guide markers may be comprised in the guideline.

The navigation guide may be a colour which is a contrasting colour to the ground surface upon which it is placed or displayed. The guideline may be red in colour. The one or more guide markers may be a colour which is a contrasting colour to the colour of the guideline. The guide
20 marker may be black.

According to a second aspect of the present invention, there is provided an autonomous mobile robot (AMR), the AMR comprising: a locomotion arrangement; a sensor system, the sensor system operable in use to provide sensor data about the location of a pre-placed
25 navigation guide, the pre-placed navigation guide in accordance with any preceding claim; and a control unit, the control unit operable to receive sensor data; and in operation, control the locomotion arrangement to navigate based on the sensor data.

The sensor system may comprise a computer vision system. The computer vision system may
30 comprise a camera. The sensor system may be mounted externally to the AMR.

The AMR may comprise a support arm operable to support the sensor system. The support arm may be at a first end, fixed to the chassis of the AMR, and the sensor system is fixed at a second end, and may be arrangeable in use to form a distance (d) between the AMR and the
35 pre-placed navigation guide. The support arm may be fixed in length. The support arm may

5 be adjustable in length between a minimum and maximum length, such that distance (d) may be adjustable accordingly. The AMR may comprise a second support arm. One end of the second support arm may be fixed to the AMR and the other end may be fixed to the support arm.

10 The AMR may comprise dynamically determining an offset with regard to the navigation guide and operating one or more locomotion arrangements to minimize said offset. The AMR may comprise dynamically determining an angular offset of the rotation angle (b) between the navigation guide and the apparatus and the control unit controlling one or more locomotion arrangements to minimize said angular offset.

15

The locomotion arrangement may be a ground wheel arrangement. The AMR may comprise a deposition arrangement, and at least one reservoir capable of holding at least one deposition material, the deposition arrangement in use being operable to deposit the deposition material on a ground surface.

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The AMR may comprise an onboard control system configured to transmit data to a remote resource, such as a cloud server, or an edge device, optionally a tablet or smartphone.

25 According to a third aspect of the present invention, there is provided an method of navigation using the pre-placed navigation guide of the first aspect and the AMR of the second aspect, the method comprising: using a sensor system operable to detect the pre-placed navigation guide placed at a distance (d) from the AMR; and the AMR navigating whilst maintaining said distance (d) between the AMR and the pre-placed navigation guide.

30 The method may comprise using a path following algorithm to maintain said distance (d) between the AMR and the pre-placed navigation guide for at least a first section of the deposition.

35 The method may comprise dynamically determining an offset with regards to the pre-placed navigation guide and operating one or more locomotion arrangements to minimize said

- 5 offset. The method may comprise dynamically determining an angular offset of the rotation angle (b) between the pre-placed guide and the apparatus and the control unit controlling one or more locomotion arrangements to minimize said angular offset.

According to a fourth aspect of the present invention, there is provided a method of
10 depositing material using apparatus of the second aspect, and the pre-placed guide of the first aspect, the method comprising the steps of: receiving deposition instructions from a user; and using a sensor system operable to detect a pre-placed guide at a distance (d) from the AMR; and the AMR then depositing material according to the deposition instructions, whilst maintaining said distance (d) between the AMR and the pre-placed guide for at least a
15 first section of the deposition.

The method may comprise using a different navigational method for a subsequent section of the deposition.

- 20 The deposition instructions may be a command to print an image in a certain size and the control unit calculates the required sections of the print. The user may send deposition instructions to the AMR via a cloud server or device, or an edge server or device.

In accordance with all relevant aspects of the present invention, the material for deposition
25 may be a herbicide, pesticide, insecticide, plant growth aid, water or marking material. The marking material may be a paint, ink, coloured material, powder.

Thus, the computer vision system locates the AMR's real position after the execution of each action, such as for example the next row of a print and/or material deposition, based on the
30 dots and other navigational information about its expected position. Thus the use of the guideline and the repeating dots pattern means the guideline can be followed using line following algorithms and help the AMR to make any positional or navigational adjustments in the yaw movement of the AMR. The series of dots (and/or or other pattern applied to the guide tape) are then used to finer navigate, using relative position algorithms as explained in,

- 5 for any adjustment for the speed of movement of the AMR as it travels in a forward and/or backward motion.

Further, the use of a pre-placed guide means that advantageously, no external electronic navigational aids such as beacons and/or GPS systems are necessarily required. Thus, lowering the cost of the AMR and simplifying its use operationally. Should electronic navigation systems be used, then the use of the guide may improve the accuracy of the navigation. Thus advantageously, an accuracy of tiling alignment of $\pm 2\text{mm}$ and scalable to 50m^2 activations can be achieved.

- 15 Advantageously the code may be a QR code and/or a repeating pattern, and/or a repeating pattern of dots and spaces. Preferably, the pattern and/or code can be seen in its entirety within the field of view of the computer vision system.

Advantageously, an adjustable support arm providing the ability to print at different distances (d) from a fixed position guide, such as a touch line. Further preferably where the field of view of the camera is wide enough that can be mounted flush to the AMR and still detect the guide tape. Further preferably wherein a coupling cable is provided between the sensor system and the apparatus, such that data and electrical power can be transmitted between the sensor system and the apparatus.

25

Thus, advantageously allowing for multi-section or large-scale tiled prints and/or wherein the material for deposition is a herbicide, pesticide, insecticide, plant growth aid, water or marking material, optionally wherein the marking material is a paint, ink, coloured material, powder.

30

Preferably, the AMR is connected to a cloud system. Connection to a cloud system allows the user to achieve functionality anywhere, for example over the air fault diagnostics, real-time print management, vast secure storage and the means to operate robots anywhere in the operator's network. Use of a cloud system allows the collection of data which can aid in AMR learning functionality, improve robot diagnostics, data aggregation and secure

35

5 communication links between the edge, the cloud and all data processing devices as required. Use of a cloud-based system is built around the user to achieve functionality anywhere, over the air fault diagnostics, real-time print management, vast secure storage and the means to operate AMR printers anywhere in the operator's network.

10 Accordingly, there is provided a ground marking AMR that in addition to high accuracy and throughput marking provides for robot diagnostics, data aggregation and secure communication links between the edge, the cloud and all data processing devices as required.

LIST OF FIGURES

15 Embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Figures 1a and 1b are schematic diagrams of an autonomous mobile robot (AMR), in this example suitable for ground printing, according to one embodiment of the present invention;

Figure 2 is a diagram illustrating a smart communications module 22, as used in the AMR of **Figure 1**;

25 **Figure 3a**, is an illustration of a first example of a dotted guide, according to one embodiment of the present invention;

Figure 3b is an illustration of a second example of a dotted guide, according to a second embodiment of the present invention;

30 **Figure 3c** is an illustration of a third example of a dotted guide, according to the second embodiment of the present invention;

Figure 3d is an illustration of a fourth example of a dotted guide according to the second embodiment of the present invention;

5

Figure 4, is a diagram of a sequence of dots with a specific pattern and an example camera view of an AMR, according to one embodiment of the present invention;

10

Figure 5 is a process flow diagram of an example guideline following solution, according to one embodiment of the present invention;

Figure 6 is a process flow diagram illustrating an example line detection sub-routine, as can be used in the process flow of **Figure 5**; and

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Figure 7 is a process flow diagram illustrating a dot following solution, as can be used in the process flow of **Figure 5**.

20

The present techniques will be described more fully hereinafter with reference to the accompanying drawings. Like numbers refer to like elements throughout. Parts of the autonomous ground printer are not necessarily to scale and may just be representative of components of the ground print AMRs, or other described entities.

DETAILED DESCRIPTION

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Figures 1a and 1b are schematic diagrams of a side view and a top view of an autonomous mobile robot (AMR) 10, suitable for ground printing, comprising an outer case 12 and a ground wheel arrangement 24, comprising wheels 24a, b, c, d. Also shown is a smart communications module 22 described more fully in **Figure 2**, which may also serve as or be connected to an on-board control system (as shown in **Figure 1a** only). The smart communications module 22 comprises a transceiver 22a for communication with remote resources, as shall herein be further described.

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There is also shown a digital camera 100 supported by an elongated support arm 95, which is fixed to the frame of the AMR 10. The elongated support arm 95 may be extendible and/or retractable between a position where the camera 100 is seated flush against the outer case 12 of the AMR 10 and a maximum usable distance (m). A second sub-support arm 90 may also

5 be used to provide extra support, in which case the elongated support arm 95 may only be extendible between the end of the second sub-support arm 90 and a maximum usable distance (m). The max useable distance (m) being dependent on the strength of the support arm 95, the size of the AMR 10, the materials used for the construction of the support arm 95 and the weight of the camera 100 and/or sensor unit used.

10 It should be clear to someone skilled in the art how to calculate the maximum length of the support arm 95 and whether a second support 90 is required. Any known telescopic and/or retractable means can be used to form an adjustable length support arm 95. It should also be clear to a person skilled in the art that if needed a coupling cable (not shown) is needed
15 between the camera 100 and the AMR 10, such that data and electrical power can be transmitted between the sensor system and the AMR. Alternatively, a wireless connection such as a Bluetooth or BLE connection can be used, as known the art.

The camera 100 must be capable of following a guide tape comprising guide dots (see **Figure**
20 **3a**) placed down, for example, placed on a ground surface, such as grass, at a calculated distance (d) from where the AMR is to navigate itself. Alternatively, the camera 100 must be capable of following a series of guide dots or lines (see **Figures 3b, 3c & 3d**) displayed using a light source, for example, on a ground surface, such as grass, from which pattern the AMR can navigate itself.

25 If the camera 100 and/or sensor system used to follow the pre-placed guide (example of which are shown in **Figures 3a & 3b**) is seated flush to the side of the AMR 10, then the field of view of the camera 100 must be wide enough to give a good distance (d) between the side of the AMR 10 and the guide tape. If the camera or sensor system used has a limited field of
30 view, then the elongated support arm 95 can then be adjusted to enable a suitable distance (d).

If the camera is seated flush to the side of the AMR 10 and has a good field of view, then in a further embodiment (not shown), a user can input a distance (d) between the side of the AMR
35 10 and the pre-placed guide. The distance (d) corresponding to the distance required between

5 the pre-placed guide and the start of the navigation. The pre-placed guide (see **Figure 3**) placed on the grass, or ground, is then used as a 'guidance line' for the first section of the print, as is described in the Applicant's co-pending applications. Other means as used in the art also as described in the Applicant's co-pending application can then be used for the following sections of the print run if a multi-section large scale print is required. The colours and/or materials to be deposited, as well as the number of sections required, being under the control of a 'print file' that can be loaded into the on-board control system, such as may be contained communications module 22.

15 Alternatively, if a fixed length elongated support arm 95 is used, then the distance (d) between the guidance line and the start of the print must be measured out by a user or operator to match the length of the elongated support arm 95. Then the AMR 10 moved into position to start the print at a distance (d) from the pre-placed guide (of **Figure 3**), as shall be described in further detail with reference to **Figures 5-7** following.

20 Referring to **Figure 1a** in particular, there is shown an example of the AMR 10 in communication with the cloud 110, and/or a remote resource 102, which may be a tablet 108, or smartphone 106, when the present techniques are applied. The tablet 108, or smartphone 106 may be controlled by a user.

25 In the present example, it will be appreciated that the cloud 110 may comprise any suitable data processing device or embedded system which can be accessed from another platform such as a remote computer, content aggregator or cloud platform which receives data posted by the AMR 10. Use of a cloud 110 means that the onboard memory 82 of the AMR 10 does not need to store everything, data e.g. AMR learning libraries, navigation instructions and operation instructions, history data can be stored in the cloud 110.

In the present example, the AMR 10 is configured to connect with the cloud 110 to push data to the tablet 108, or the smartphone 106, whereby, for the example, the AMR 10 may be provided with the connectivity data (e.g. a location identifier (e.g. an address URL)) and

5 credential data (e.g. a cryptographic key, certificate, a site secret) of the cloud 110 or the tablet 108, or smartphone 106.

In alternative embodiments, a user may specify to which remote resource the AMR 10 should push data. For example, the user may connect the AMR 10 directly to a portable device e.g. via universal serial bus (USB), and install code capable of executing on the AMR 10, whereby
10 the code may comprise connectivity data and/or credential data relating to the remote resource with which the user wants the AMR 10 to communicate. The connectivity data and/or credential data may be provided to the AMR 10 using any suitable method e.g. via USB/BLE. The credential data may also comprise credential data relating to a network to
15 which the AMR 10 may be required to connect e.g. WPA2 key for pairing with nodes in a Wi-Fi network.

The wheel arrangement 24 a, b, c, d may have independent drives to manage torque for optimised positioning accuracy on any surface. The independent drives may be connected to
20 the smart communications module 22 to feedback into drive control. The AMR 10 may be able to respond in real time to changing terrain needs. The AMR 10 may include an autonomous traction management capability, to safeguard the terrain the robot is interacting with and to reduce skidding and turf damage.

25 It should be clear to a person skilled in the art, that any suitable sensor or camera system may be used, however generally better camera enables successful function at a further distance, due to higher resolution, successful function in more dynamic light conditions due to better response times to light changes and function at a higher frequency due to better processing power and connectivity which provides data to the navigation controller more regularly.

30

Turning to **Figure 2**, there is shown a diagram illustrating a smart communications module 22, as used in the AMR of **Figure 1**, which includes processing circuitry 80 coupled to memory circuitry 82 e.g. volatile memory (V)/non-volatile memory (NV), such as such as flash and ROM. The memory circuitry 82 may store programs executed by the processing circuitry 80,
35 as well as data such as user interface resources, time-series data, credentials (e.g.

5 cryptographic keys) and/or identifiers for the remote resource (which may for convenience be referred to as the cloud 110 or the remote resource 102(s) (e.g. URL, IP address). The memory circuitry 80 may also comprise access to machine learning algorithms stored in libraries to provide for an artificial intelligence equipped AMR 10.

10 The smart communications module 22 may also comprise communication circuitry 84 including, for example, near field communicating (NFC), Bluetooth Low Energy (BLE), Wi-Fi, ZigBee or cellular circuitry (e.g. 3G/4G/5G) for communicating with the remote resource(s)/device(s) e.g. over a wired or wireless communication link (not shown). For example, the smart communications module 22 may connect to remote resource(s)/device(s)
15 within a local mesh network over BLE, which in turn may be connected to the internet via an ISP router.

The smart communications module 22 may also comprise input/output (I/O) circuitry 88 such as sensing circuitry to sense inputs (e.g. via sensors (not shown)) from the surrounding
20 environment and/or to provide an output to a user e.g. using a buzzer or light emitting diode(s) (not shown).

The processing circuitry 80 may control various processing operations performed by the smart communications module 22 e.g. encryption of data, communication, processing of
25 applications stored in the memory circuitry 82.

Alternatively, the smart communications module 22 may, for example, comprise an embedded temperature sensor, which generates operational data based on the temperature of the surrounding environment, and may, for example be generated as a time series and fed,
30 as best seen in **Figure 1a**, to a remote resource such as the cloud 110, the remote resource 102 such as a tablet used to control the AMR 10. The cloud 110 or the remote resource 102 may by return send instructions back to the AMR 10 for the real-time adjustment of ground marking properties based on the data. In the present example, the cloud 110 and remote resource 102 may also communicate with each other. This could be to update the

5 instructions, send new instructions, initiate or prevent the operation of the robot. The edge 202 may be between the communication between the AMR 10 and the cloud 102.

In **Figure 3a**, there is shown an illustration of dotted guide tape, according to one embodiment of the present invention. There is shown a foldable guide tape 101, marked with a series of
10 black dots (20). Any suitable material such as ribbon or tape, can be used. Any colour of line or tape can be used as a pre-placed guide 101. Any suitable sensor system may be used on an AMR to detect the presence of the pre-placed guide 101.

The guide tape 101 and dots 20 maybe formed of any suitable colour combination, however
15 a red fabric tape is the most contrasted, easy to supply colour, to a common background of green grass, for example. As such, this enables better contrast (known in the art as 'segmentation') for the camera sensor system used in this embodiment. Using a black colour for the dots 20 is then an easy colour to segment, as black dots show up against red in many different intensities of lighting. In future applications on other surfaces such as concrete or
20 asphalt, other more suitable colour combinations may be used, such as white and black for tarmac.

The combination of red and black colours against a green background enables the segmentation and dot following in this embodiment (see **Figures 5-7**) to work well in a
25 broader set of lighting conditions than most.

The use of the guideline 101 and the dots 20 means the guideline 101 can be followed using line following algorithms as explained in **Figures 5 & 6** and help the AMR to make any positional or navigational adjustments in the yaw movement of the AMR. The series of dots
30 20 (or other pattern applied to the guide tape) are then used to finer navigate, using relative position algorithms as explained in **Figure 5 & 7**, for any adjustment for the speed of movement of the AMR as it travels in a forward and/or backward motion.

In **Figure 3b**, there is shown an illustration of dotted guide, according to a second embodiment of the present invention. There is shown a light source, such as a projector, 200, which is
35

5 shining light 210, comprising a pattern, in this case a series of dots 20, and if needed a line 110, on a ground surface 300. The camera and/or sensor system of the AMR (not shown) is able to then detect the light projected pattern of dots 20 and/or line 110 on the ground surface, as described following with reference to **Figures 5-7**. A laser line or projected laser pattern, such as a series of dashes, can also be used by an AMR of the present invention to
10 assist in its navigation while performing its functions, in this example the ground printing of a surface, but which can be many different functions.

In **Figure 3c**, there is shown a second example illustration of dotted guide, according to a second embodiment of the present invention. There is shown a light source, such as a
15 projector, 200, which is shining light 210, comprising an image 130 of a logo or design to be printed, which further comprises a pattern along the edge of the image 130, in this case a series of dots 20, on a ground surface 300. The camera and/or sensor system of the AMR (not shown) is able to then detect the light projected pattern of dots 20 and/or the edge of the image 130 on the ground surface, as described following with reference to **Figures 5-7**. A laser
20 line or projected laser pattern, such as a series of dashes, can also be used by an AMR of the present invention to assist in its navigation while performing its functions, in this example the ground printing of a surface, but which can be many different functions.

In **Figure 3d**, there is shown a third example illustration of dotted guide, according to a second
25 embodiment of the present invention. There is shown a light source, such as a projector, 200, which is shining light 210, comprising a pattern, in this case a series of dots 20, and an image 130 which is the image to be printed, on a ground surface 300. The camera and/or sensor system of the AMR (not shown) is able to then detect the light projected pattern of dots 20 and/or the edge of the image 130 on the ground surface, as described following with
30 reference to **Figures 5-7**. A laser line or projected laser pattern, such as a series of dashes, can also be used by an AMR of the present invention to assist in its navigation while performing its functions, in this example the ground printing of a surface, but which can be many different functions.

5 In **Figure 4**, there is shown a diagram of a sequence of dots with a specific pattern and an example camera view, according to one embodiment of the present invention. There is shown a plan view of an AMR 10, with a computer vision system, wherein the field of view 13 of the computer vision system is shown as covering a certain number of dots and gaps, in this example a specific pattern 20 comprising 4 dots and a gap is shown. This specific pattern is used so the whole pattern can be seen within the field of view 13 of the camera, such that the AMR always knows whether it is in the middle, the start or end of the pattern.

The dots and/or pattern is pre-placed on a ground surface by many methods as is herein described, one example of which may be by rolling out a guideline, such as a tape or ribbon, with the dots marked in a contrast colour, another example maybe by shining dots and/or a line or other such pattern on the ground surface.

Wherein the computer vision system calculates the AMR position *within* a current print row, based on the dots printed from a previous section in a specific pattern 20 on the floor, comparing with the camera position (shown as a field of view 13) to determine how much should the AMR moving forward. Thus, using the specific pattern 20, the computer vision system locates the AMR's real position, based on the dots and other navigational information about its expected position. As shall be described in further detail in relation to **Figure 5, 6 & 7** following.

25 It should also be clear to someone skilled in the art that and dots or dashes or other code or pattern can be used to allow the AMR to follow the guide path in an accurate way. Numbers or letters could be used, other shapes such as squares, rectangles or stars. The size of the dots could also get larger and then smaller again. Any code or pattern can be used in order to discern the AMR's 'true position' in relation to the path it has already taken, such that an accurate navigation can be performed.

Figure 5 is a process flow diagram of an example guideline following solution, according to one embodiment of the present invention. The process starts once the following actions have taken place: the system has been positioned at desired activity start; the encoded line has been placed along a travel path in view of sensor; and the AMR's navigation and camera

5 sensor systems have been turned on. Then as shown in **Figure 5**, the following process steps occur in order to use the guideline to navigate:

START

10 **S1: Get line detection sensor data.** Get the data from the sensor being used in the detection system for the detection of the guideline.

S2: Crop sensor data to desired region, if required. For example, if the Field of View (FOV) of the camera or sensor is greater than the width of the guideline, then crop the data.

S3: Segment line in sensor data (see **Figure 6**)

S4: Segment dots in line sensor data (see **Figure 7**)

15 **S5: Calculate vector to line (x,y,heading).** Use the outputs from step S3 and Step S4 to determine any offsets from the last position.

S6: Feedback line location data to system navigation and apply navigation algorithm to follow line. Move forward by the required amount and in the required orientation. Making any adjustments to the print head height accordingly. If the control system still needs to run
20 the line detection sensor system, go to step S1. If not, end the process.

End

Thus, the use of the guideline 101 and the dots 20 means the guideline 101 can be followed using line following algorithms as explained in **Figures 6 & 7** and help the AMR to make any
25 positional or navigational adjustments in the yaw movement of the AMR. The series of dots 20 (or other pattern applied to the guide tape) are then used to finer navigate, using relative position algorithms as explained in **Figure 6 & 8**, for any adjustment for the speed of movement of the AMR as it travels in a forward and/or backward motion.

30 **Figure 6** is a process flow diagram illustrating an example line and dot detection sub-routine, as can be used in the process of **Figure 5**. The following steps of the process relate to Step S3 of **Figure 5**.

START

5 **S1: Receive Sensor Data.** Receive the sensor data generated by the sensor system. As the AMR moves long the ground, the camera 13 of **Figures 3-5** is able to take an image of the ground. Each frame of the camera image is captured and processed by an on-board computer in step 2.

S2: Process the image. Each frame of the camera image that is captured in Step 1 is processed
10 by the on-board computer, as described in the following steps.

S3: Apply Contour detection to threshold image and find centre of the line. Apply a contour detection algorithm, as known in the art, to process the captured image and find the centre point of the line.

S4: Detect regions in the contours - This is so subsequent calculations are centralised to the
15 centre of the dot and are not offset by the size of the dots themselves.

S5: Segment detected regions with contours as dots calculate centroid of each region. The dot sizes and centurms are then used to find out if any adjustment is needed in the nozzle print height, for example. The gap positions are used to determine the overall place in the pattern is at the beginning, middle or end.

20 **S6: Output segmented image and centroid data.** Output the resulting data back to the main process of **Figure 5** (step S3), as well as the dot following process described in **Figure 7** following.

FINISH PROCESS

25 **Figure 7** is a process flow diagram of a dot pattern following solution, as used in the process of **Figure 5**. The following steps of the process relate to Step S4 of **Figure 5**.

START

S1: Initialize pattern following algorithm. Initialize the dot and/or pattern following
30 algorithm.

S2: Receive dot centroid data. Receive the current dot centroid data from the output of the process of **Figure 5**.

S3: Store origin centroid position. Store the current dot centroid data in local memory.

S4: Send command to move to desired position. Move to next position, for example the
35 next row of a print and/or material deposition.

- 5 **S5: Wait for motion to complete.** Wait for the AMR to stop moving.
- S6: Receive new centroid data.** Receive the new dot centroid data from the output of the process of **Figure 5**.
- S7: Calculate actual motion delta to desired motion.** Calculate whether the move forward was by the correct amount and make any adjustment to movement/positions are needed
- 10 **S8: Reached target motion/position?** Has the AMR reached where it is supposed to be in a forward direction? If YES, then go to Step S4. If no, go to Step S9.
- S9: Calculate actual motion delta to desired motion.** Calculate any minor positional adjustments necessary.
- 15 **S10: Send command to move to motion delta.** Make any minor positional adjustments necessary.
- End Process**

Thus, the computer vision system locates the AMR's real position after the execution of each

20 action, such as for example the next row of a print and/or material deposition, based on the dots and other navigational information about its expected position. Thus the use of the guideline 101 and the repeating dots pattern 20 means the guideline 101 can be followed using line following algorithms as explained in **Figures 5 & 6** and help the AMR to make any positional or navigational adjustments in the yaw movement of the AMR. The series of dots

25 20 (and/or or other pattern applied to the guide tape) are then used to finer navigate, using relative position algorithms as explained in **Figure 5 & 7**, for any adjustment for the speed of movement of the AMR as it travels in a forward and/or backward motion.

In the present example, on powering on for the first time, the AMR 10 undertakes a

30 registration process with the cloud 110 and the remote resource 102 and pushes identification data and is on standby to receive printing or ground marking data in return.

It will be clear to one skilled in the art that many improvements and modifications can be made to the foregoing example embodiments without departing from the scope of the

35 present technique.

5

The robots, systems, and methods described herein can be adapted for use with different types of surface of substrate, depending on the purpose and surface for it to be used with. For example, the robots, systems, and methods described herein can be used to deposit material on multiple different substrates, surfaces, or the ground. For example, these could

10 be, grass, turf, AstroTurf, artificial turf, synthetic turf, plastic turf, concrete, polished concrete, tarmac or tarmacadam ground surfaces, dirt, gravel, wood chip, carpeting, rubber, roads, asphalt, brick, sand, beaches, mud, clay wood, decking, tiling, stone, rock and rock formations of varying types of rock or stone, snow, ice, ice rinks, artificial snow, polymer surfaces such as polyurethane, plastic, glass and leather.

15

The robots, systems, and methods described herein can be adapted for use with different surfaces, such as sports (e.g. football, cricket, racing, rugby, hockey, ice hockey, skiing, shooting) pitches, ski slopes, dry ski slopes, race courses, gymnasiums, indoor sports venues and running tracks.

20

In some embodiments, the robots, systems, and methods described herein may be used for printing or painting on a substrate or on the ground. This can be to print or paint, with inks or paint, logos, information, advertising, or messages on the ground. When large images are printed, they are printed with adjacent dots or pixels so that when viewed from above or a

25 suitable distance from afar (e.g. from the stand in a stadium or from a television view) the images are easily determined. Print instructions can be determined so that when an image, e.g. a logo is printed, they can be visible from stadium stand or by a viewer watching an event at home on television. The robots, systems, and methods described herein offer an improvement to printing methods for advertising purposes. Brand logos, slogans, pictures etc.

30 can be printed to advertise a brand, logo or message. These can be printed more efficiently, quickly and with a higher degree of accuracy than the methods and printers of the prior art.

The robot is therefore in some embodiments configured to print an image or logo on a surface, the robot housing two, three, four or more flexible bags containing a material for

35 deposition, the material for deposition contained within each flexible bag being an ink or paint

5 selected from a cyan, magenta, yellow, black, white, green, blue or red colour, the image or
logo optionally being an advertising logo, design or safety warning. The method may include
ground marking using an autonomous robot housing a flexible bag containing a material for
deposition therein, the flexible bag provided with an airtight valve outlet sealed to the flexible
bag; the method including opening the valve outlet and depositing the ground marking
10 material.

In examples, the material for deposition is a herbicide, pesticide, insecticide, plant growth aid,
water or marking material, optionally wherein the marking material is a paint, ink, coloured
material, powder.

15

In examples, a method of depositing material using a robot includes i) a user sending
deposition instructions to the autonomous robot; and ii) the autonomous robot depositing
material according to the deposition instructions. In such an example, the user may send
deposition instructions to the autonomous robot via a cloud server or device, or an edge
20 server or device. Preferably, the material to be deposited is marking material, paint or ink,
and the deposition instructions are printing instructions and the autonomous robot is
configured to print an advertising logo, design or safety warning. The method may also
include gathering performance diagnostics of the autonomous robot.

5 CLAIMS:

1. A navigation guide for use with an autonomous mobile robot (AMR), wherein the AMR comprises a sensor detection system to detect the navigation guide and in operation, is equipped to move over a ground surface, the navigation guide comprising a guideline, the navigation guide further comprising one or more guide markers, and
10 wherein in operation, the guideline and the one or more guide markers are visible on the ground surface.
2. The navigation guide according to claim 1, wherein the one or more guide markers is comprised of a repeating pattern.
- 15 3. The navigation guide according to claim 2, wherein the repeating pattern is comprised of a series of dots and spaces.
4. The navigation guide according to claim 2, wherein the repeating pattern is comprised
20 of an array of dots and spaces.
5. The navigation guide according to claim 2, wherein the one or more guide markers is a QR code.
- 25 6. The navigation guide according to any of claims 2 to 5, wherein the repeating pattern can be seen in its entirety within the field of view of the sensor system of the AMR.
7. The navigation guide according to any preceding claim wherein the guideline is an elongated guideline.
- 30 8. The navigation guide according to claim 7, wherein the elongated guideline is formed from an elongated strip of material.
9. The navigation guide according to claim 7 or claim 8, wherein the elongated guideline
35 is formed from a flexible material.

5

10. The navigation guide according to any of claims 1 to 7, wherein the navigation guide is formed of a light which is displayed on the ground surface by a light source.

10

11. The navigation guide according to claim 10, wherein the guideline comprises the edge of an image of a logo or design.

12. The navigation guide according to any preceding claim, wherein the one or more guide markers are comprised in the guideline.

15

13. A navigation guide according to any preceding claim wherein the navigation guide is a colour which is a contrasting colour to the ground surface upon which it is placed or displayed.

20

14. A navigation guide according to claim 13 where in the guideline is red in colour.

15. A navigation guide according to any preceding claim where in the one or more guide markers is a colour which is a contrasting colour to the colour of the guideline.

25

16. A navigation guide according to any preceding claim wherein the guide marker is black.

17. An autonomous mobile robot (AMR), the AMR comprising:

30

- a. a locomotion arrangement;
- b. a sensor system, the sensor system operable in use to provide sensor data about the location of a pre-placed navigation guide, the pre-placed navigation guide in accordance with any preceding claim; and
- c. a control unit, the control unit operable to receive sensor data; and in operation, control the locomotion arrangement to navigate based on the sensor data.

35

5 18. An AMR according to claim 17, wherein the sensor system comprises a computer vision system.

19. An AMR according to claim 18, wherein the computer vision system comprises a camera.

10 20. An AMR according to any of claims 17 to 19, wherein the sensor system is mounted externally to the AMR.

15 21. An AMR according to any of claims 17 to 20, further comprising a support arm operable to support the sensor system.

22. An AMR according to claim 21, wherein the support arm is at a first end, fixed to the chassis of the AMR, and the sensor system is fixed at a second end, and is arrangeable in use to form a distance (d) between the AMR and the pre-placed navigation guide.

20 23. An AMR according to claim 21 or 22, wherein the support arm is fixed in length.

24. An AMR according to either claim 21 or 22, wherein the support arm is adjustable in length between a minimum and maximum length, such that distance (d) is adjustable accordingly.

25 25. An AMR according to any of claims 21 to 24, further comprising a second support arm, one end of the second support arm is fixed to the AMR and the other end is fixed to the support arm.

30 26. An AMR according to any of claims 17 to 25, comprising dynamically determining an offset with regard to the navigation guide and operating one or more locomotion arrangements to minimize said offset.

35 27. An AMR according to claim 26, further comprising dynamically determining an angular offset of the rotation angle (b) between the navigation guide and the apparatus and

5 the control unit controlling one or more locomotion arrangements to minimize said angular offset.

28. An AMR as claimed in any of claims 17 to 27, wherein the locomotion arrangement is a ground wheel arrangement.

10

29. An AMR as claimed in any of claims 17 to 28 further comprising a deposition arrangement, and at least one reservoir capable of holding at least one deposition material, the deposition arrangement in use being operable to deposit the deposition material on a ground surface.

15

30. An AMR as claimed in any of claims 17 to 29, comprising an onboard control system configured to transmit data to a remote resource, such as a cloud server, or an edge device, optionally a tablet or smartphone.

20

31. A method of navigation using the pre-placed guide of any of claim 1 to 16 and the AMR of any one of claims 17 to 30, comprising

- a. using a sensor system operable to detect the pre-placed navigation guide placed at a distance (d) from the AMR; and
- b. the AMR navigating whilst maintaining said distance (d) between the AMR and the pre-placed navigation guide.

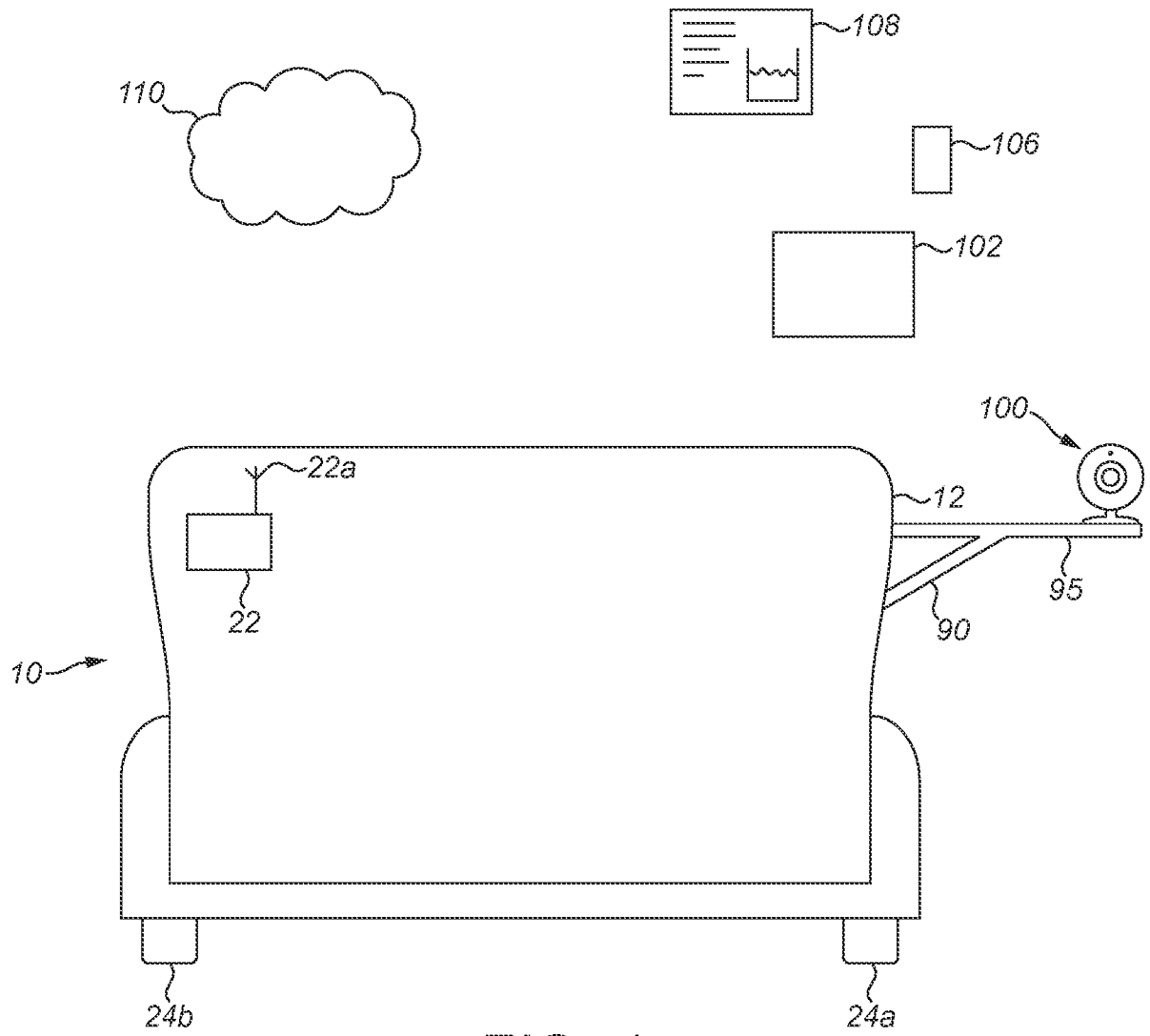
25

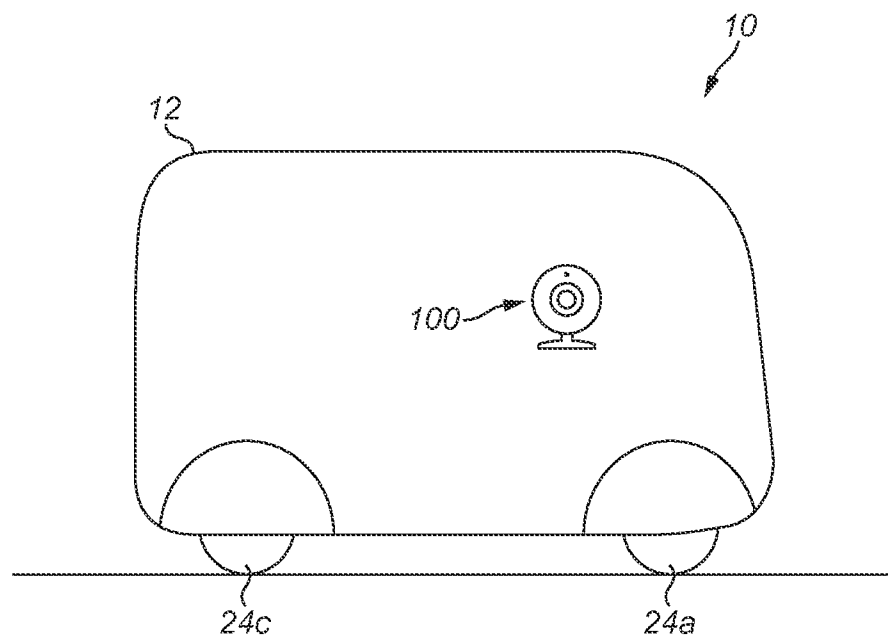
32. A method according to claim 31, comprising using a path following algorithm to maintain said distance (d) between the AMR and the pre-placed navigation guide for at least a first section of the deposition.

30

33. A method according to claim 31 or 32, further comprising dynamically determining an offset with regards to the pre-placed navigation guide and operating one or more locomotion arrangements to minimize said offset.

- 5 34. A method according to any of claims 31 to 33, further comprising dynamically determining an angular offset of the rotation angle (b) between the pre-placed guide and the apparatus and the control unit controlling one or more locomotion arrangements to minimize said angular offset
- 10 35. A method of depositing material using the apparatus of any one of claims 17 to 30, and using the pre-placed guide of any of claim 1 to 16, the method comprising the steps of:
- 15 a. receiving deposition instructions from a user;
- b. using a sensor system operable to detect the pre-placed navigation guide at a distance (d) from the AMR; and
- c. the AMR then depositing material according to the deposition instructions, whilst maintaining said distance (d) between the AMR and the pre-placed navigation guide for at least a first section of the deposition.
- 20 36. A method according to claim 35, further comprising using a different navigational method for a subsequent section of the deposition.
37. A method according to claim 35 or claim 36, wherein the deposition instructions are a command to print an image in a certain size and the control unit calculates the required sections of the print.
- 25 38. A method according to any of claims 35 to 37, wherein the user sends deposition instructions to the AMR via a cloud server or device, or an edge server or device.
- 30 39. An apparatus or method as claimed in any preceding claim, wherein the material for deposition is a herbicide, pesticide, insecticide, plant growth aid, water or marking material, optionally wherein the marking material is a paint, ink, coloured material, powder.



*FIG. 1b*

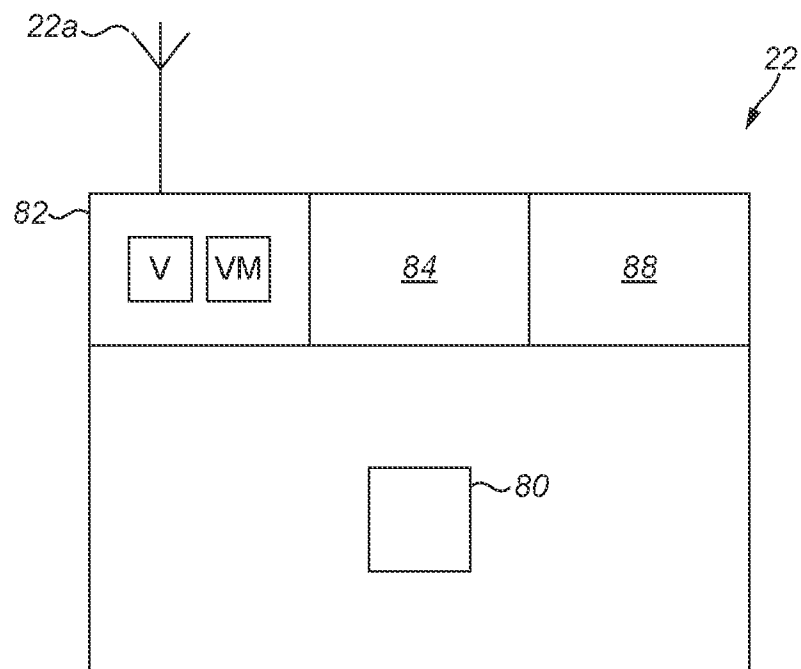


FIG. 2

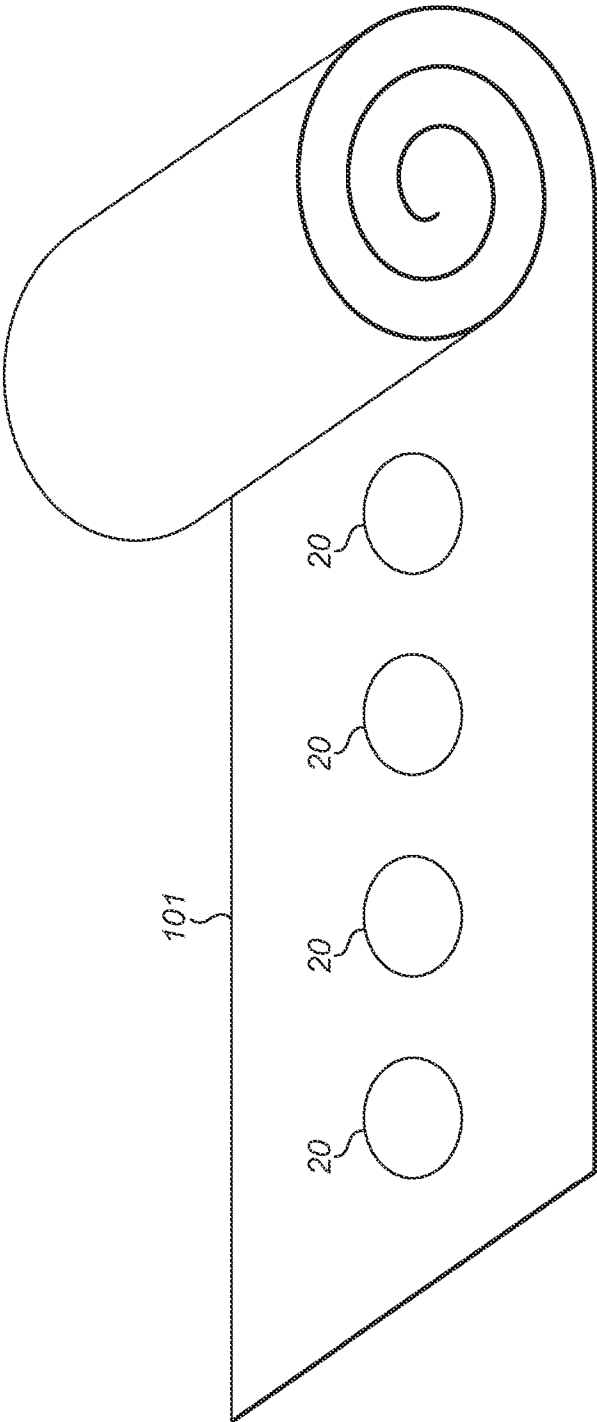


FIG. 3a

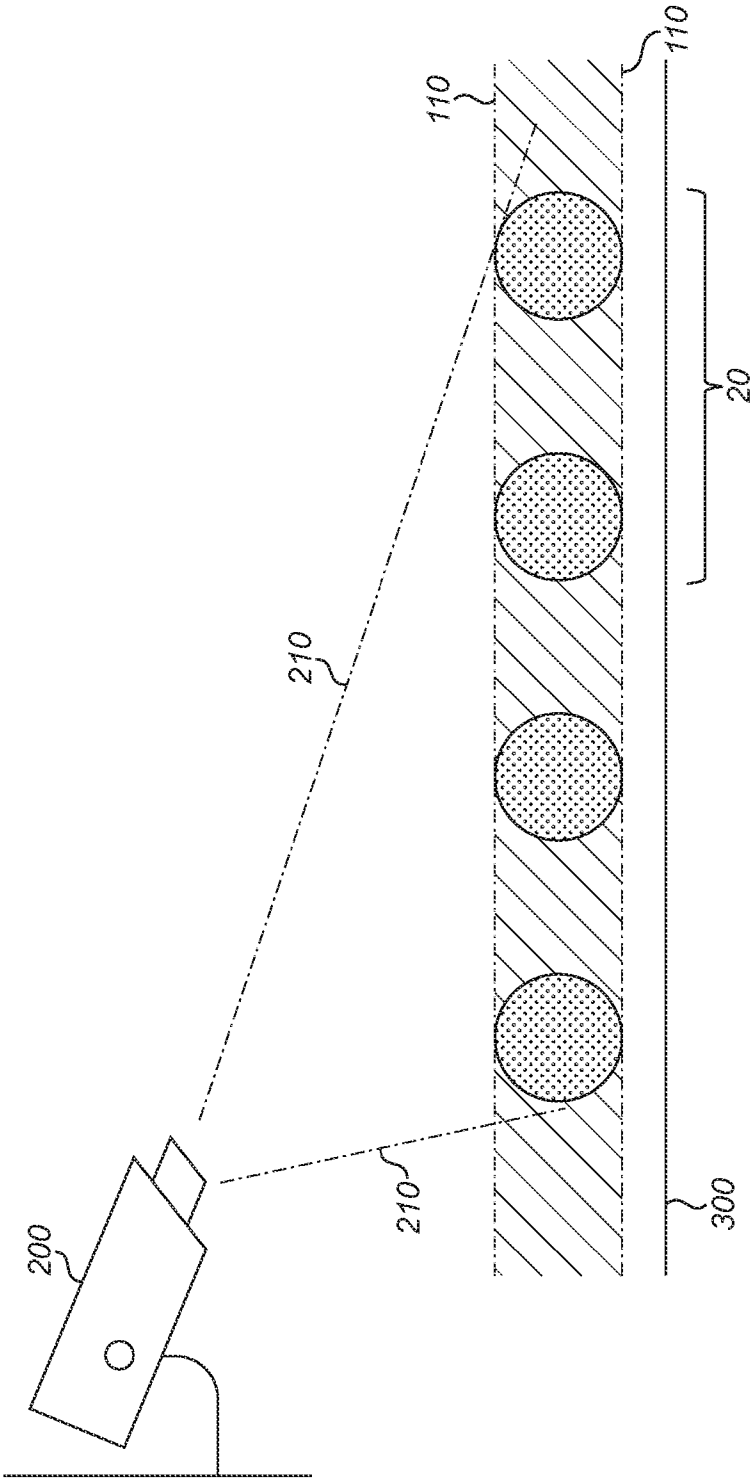


FIG. 3b

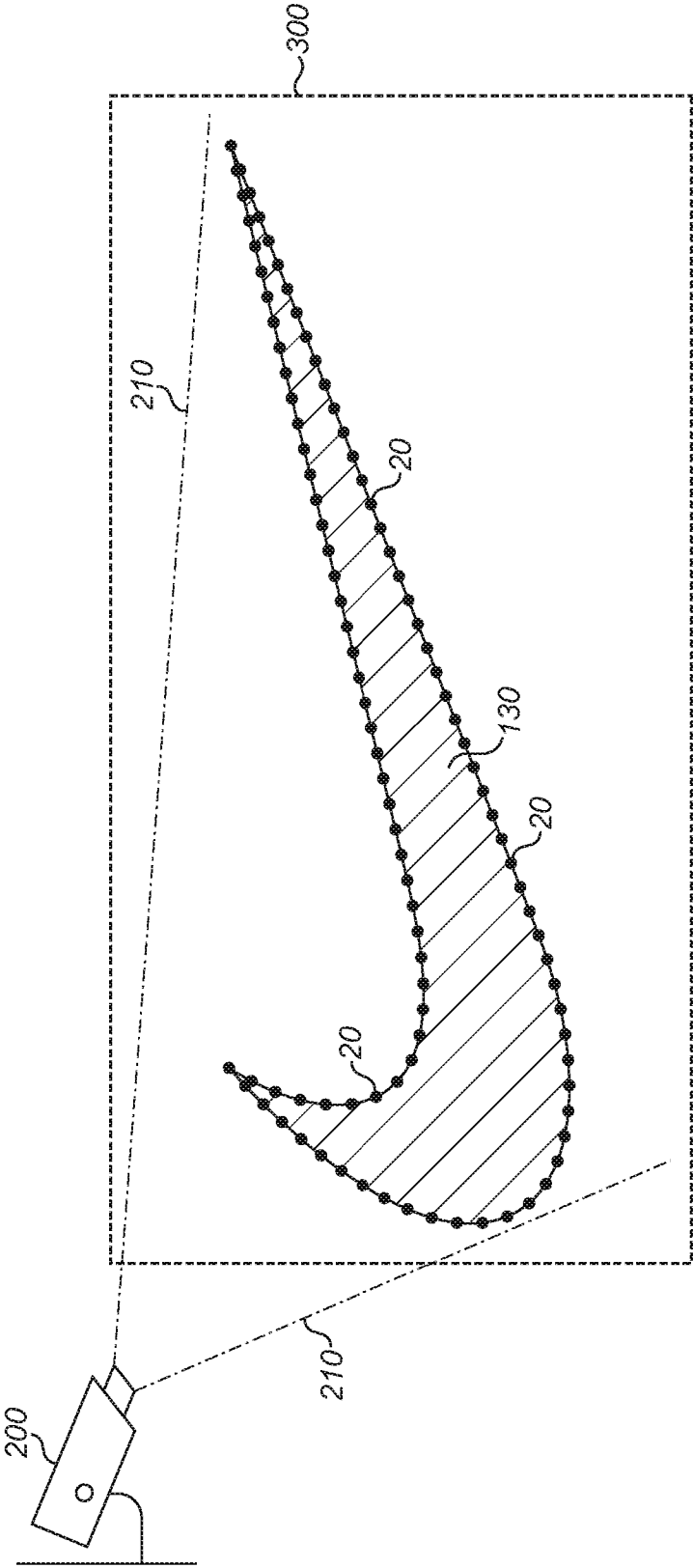


FIG. 3C

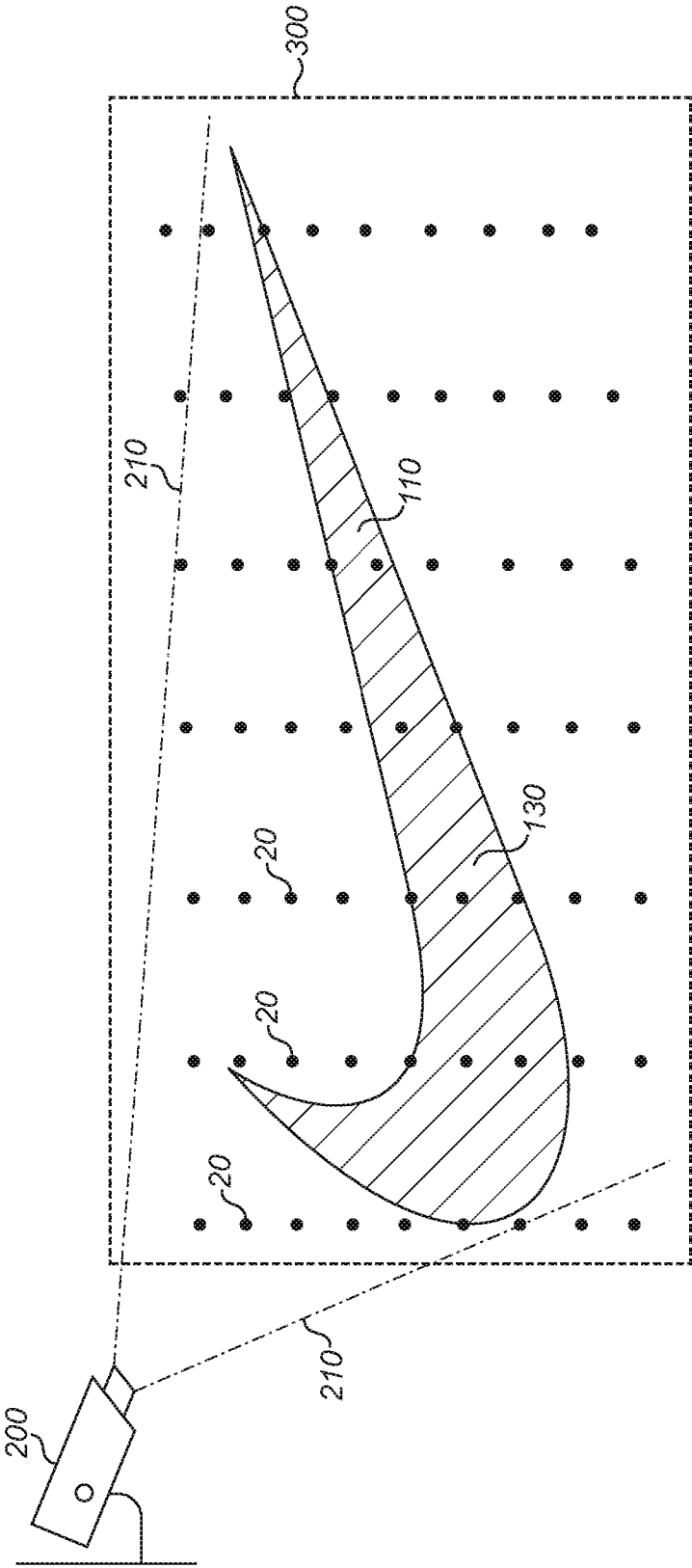


FIG. 3d

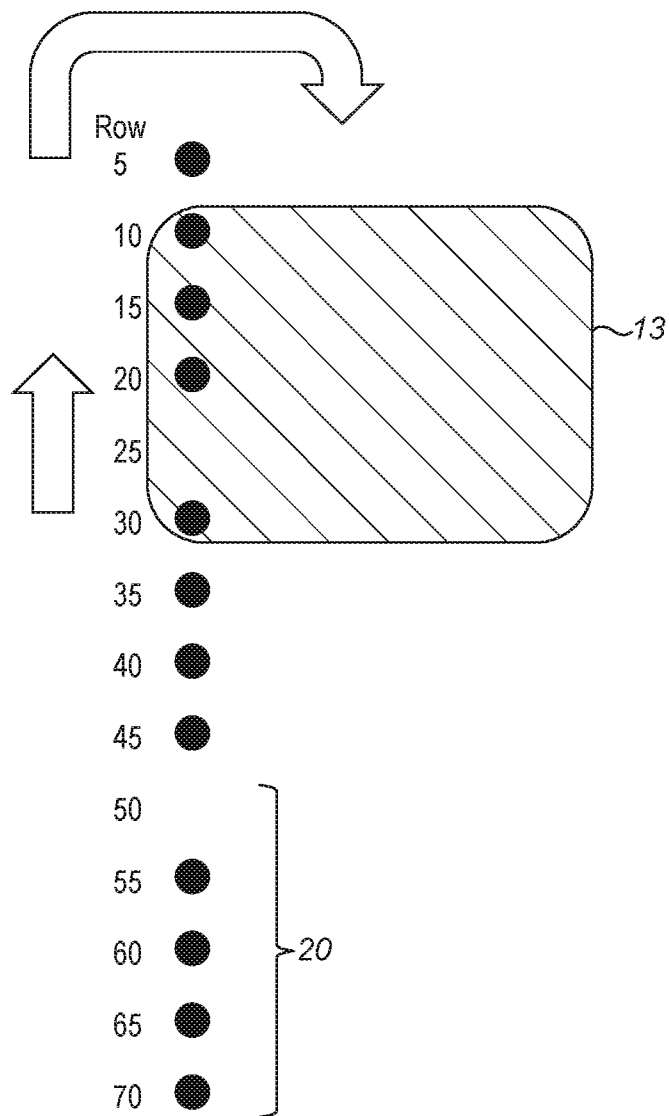
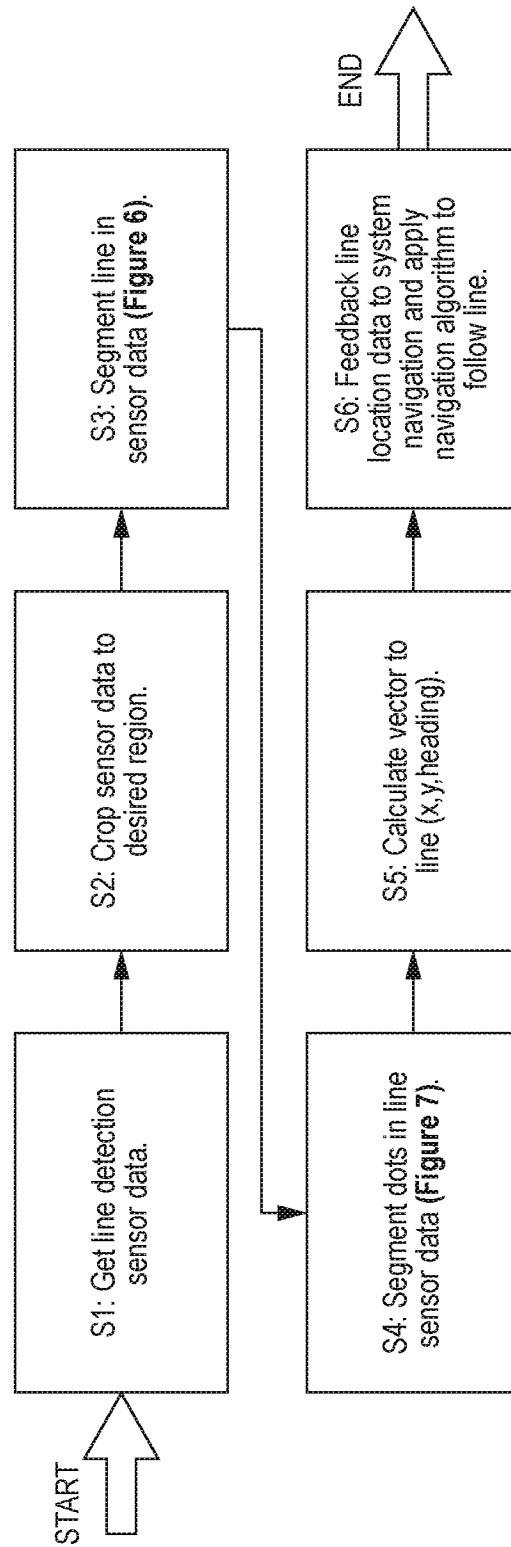


FIG. 4

**FIG. 5**

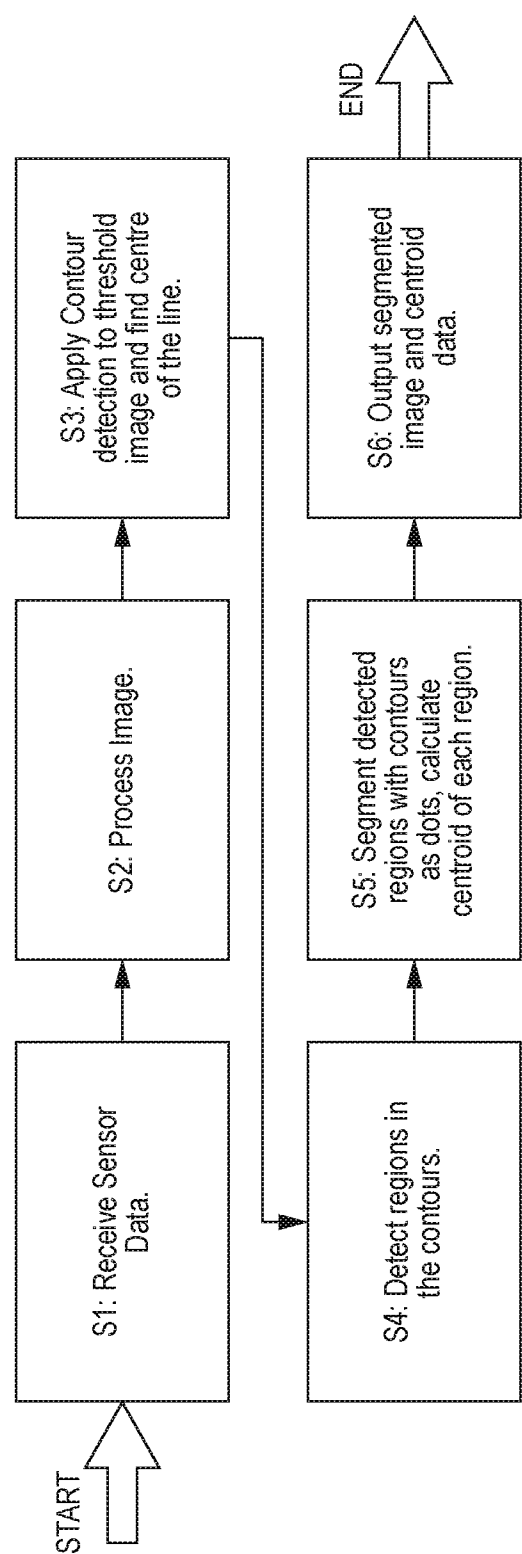
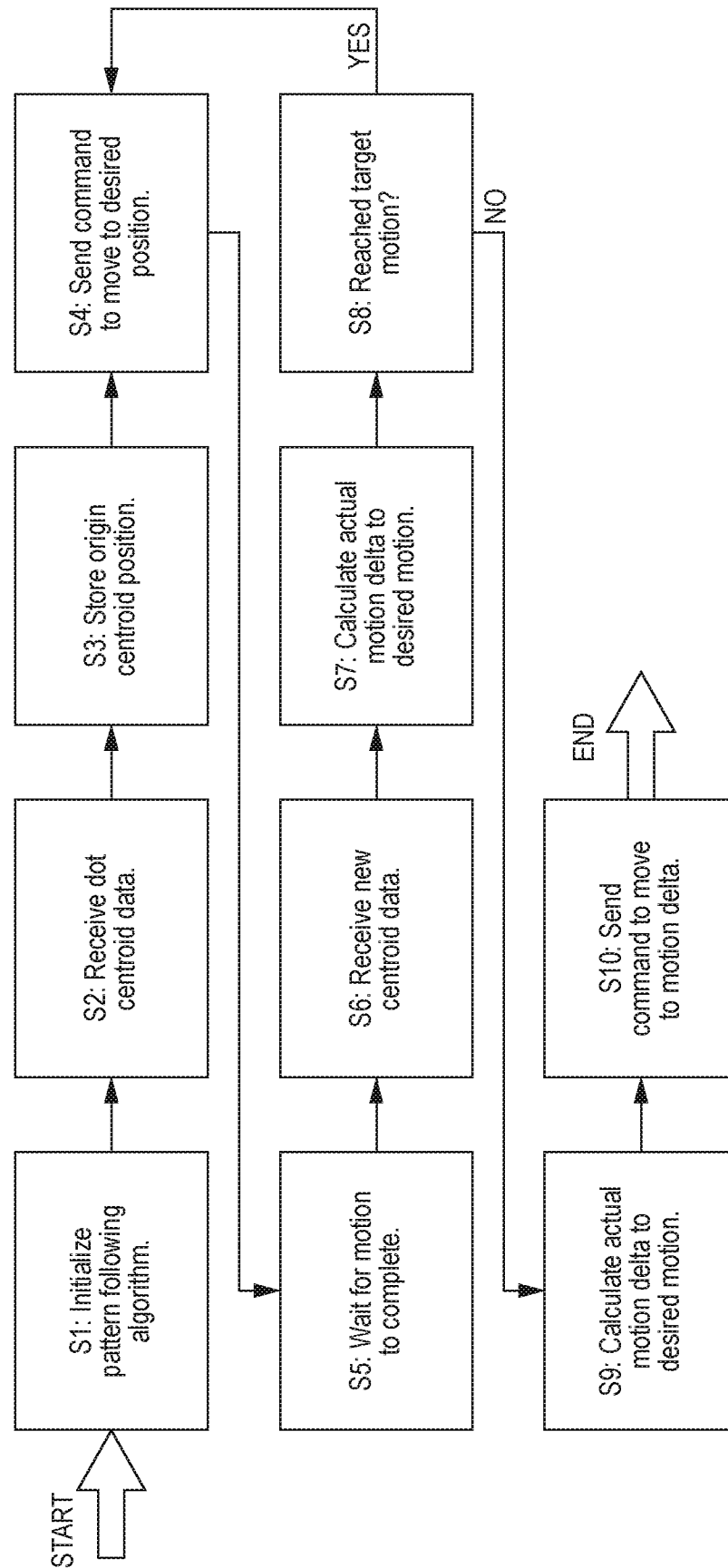


FIG. 6

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*FIG. 7*