

APPARATUS AND METHOD FOR PERFORMING SURFACE TRANSITION ON MAGNETIC SURFACES USING MOBILE ROBOT WITH THREE OR MORE WHEEL SETS

BACKGROUND

5 Technical Field

Embodiments of the invention relate to apparatus, e.g. vehicles, mobile robots, capable of climbing and making transitions, e.g. between angled surfaces of both internal and external walls of a confined-space structure or other structures.

Description of Related Art

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Figure 1A and 1B show a mobile robot 10 which is performing a vertical to overhead (V2O) transition. In Figure 1A, adhesive force of the rear wheel(s) 14, i.e., F_{Hreq} , has to be sufficiently strong to overcome a clockwise moment about the contact point of the front wheel 12. This clockwise moment results from the weight of the robot 10 including its chassis. Since a counter moment generated by F_{Hreq} would be proportional to a_t which refers to the minimum distance between a point of wheel contact with the source or previous surface and a nearest point on the destination surface, i.e. overhead surface 2, adhesive force F_{Hreq} has to be designed such that it is sufficient to hold the robot 10 at its weakest position, i.e. Figure 1B, where a_t is at the minimum and its value is equivalent the radius of the rear wheel 14, assuming that there is no vertical attraction force acting on the rear wheel 14 at that instance. In other words, the smaller the value of minimum a_t , the greater the F_{Hreq} is required in order to hold the robot 10 in place and carry the same payload. On the other hand, a large magnitude of F_{Hreq} would in turn have an adverse consequence on the driving force, i.e., F_d , required when the robot 10 has just completed a transition and needs to overcome adhesive force F_{Hreq} to detach the rear wheel 14 from the previous or source surface, i.e. vertical surface 1.

The driving force F_d requirement would also have to take into consideration a horizontal to vertical (H2V) transition as shown in Figure 2, wherein the mobile robot 10 is moving upwards and hence a greater driving force F_d is required to overcome the total force, i.e. $F_{Hreq} + W$ in order to detach the rear wheel 14 from the source

surface, i.e. horizontal surface. W is weight of robot. Therefore, it is imperative to consider these various factors in order to optimize the maximum payload whilst keeping within the operating driving force F_d .

There have been several proposed solutions to the aforementioned problem.

- 5 Some involves increasing the adhesive force of the rear wheel(s) while some suggests installation of an active or passive lifter mechanism. Nonetheless, they would lead to a greater required driving force during transition or a robot of a very complex design.

10 Examples of such solutions and/or existing robots are provided in US Patent No. 9,487,254 B2 "Vehicle and Method for the Independent Inspection of Hard-to-Reach Inner Spaces" and EP Patent Application Publication No. 2003044 A1 "Automotive Inspection Vehicle".

Other references of such solutions and/or existing robots include:

- 15 F. Rochat, P. Schoeneich, B. Luthi, F. Mondada, H. Blueier, "Cymag3D: a simple and miniature climbing robot with advance mobility in ferromagnetic environment", Proc. of The 13th International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines (CLAWAR), September 2010.

- 20 W. Fischer, G. Caprari, R. Siegwart, R. Moser, "Compact Magnetic Wheeled Robot for Inspecting Complex Shaped Structures in Generator Housings and Similar Environments", Proc. of the 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2009. Limitation/Difference: Passive extra wheels take up more space and robot will be less compact.

- 25 W. Fischer, G. Caprari, R. Siegwart, R. Moser, "Very Compact Climbing Robot rolling on Magnetic Hexagonal Cam-Discs, with High Mobility on Obstacles but Minimal Mechanical Complexity", ISR / ROBOTIK 2010. Limitation/Difference: Requires hexagonal wheels

W. Fischer, F. Tâche, G. Caprari, R. Siegwart, "Magnetic Wheeled Robot with High Mobility but only 2 DOF to Control", Proc. of The 11th International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines

(CLAWAR), 2008. Limitation/Difference: Requires 4 drive wheels. Requires high torque and high friction coefficient for surface transition

Wang, X. (2008). "Climbing robot with magnetic adhesion. Student project report, EPFL. Limitation/Difference: Requires an additional mechanism to flip the magnet to the next surface

In view of the above and other issues, improved robots for surface transition on ferromagnetic surfaces are highly desirable.

SUMMARY

The invention relates to a mechanical assistive apparatus and method that allow mobile robots or carriages with adhesive locomotion system to perform a successful surface transition. Transition operations, especially the horizontal to vertical surface (H2V) and vertical to overhead surface (V2O), often pose major challenges to the mobile robots, viz. the driving force F_d required as well as the maximum payload it can take. This is especially important when the mobile robot has to carry a substantial payload and it is being limited by the technical specifications of the motor and drivetrain. The invention allows a mobile robot to carry a heavy payload while ensuring that driving motors are able to generate sufficient driving force F_d to detach the robot from a previous surface such as by providing an increased a_t .

According to one aspect of the invention, a mobile robot capable of performing surface transition on ferromagnetic surfaces is provided. The robot comprises:

a chassis;

at least one driven wheel rotatably mounted to the chassis and operative to drive the chassis to transit from a first ferromagnetic surface to a second ferromagnetic surface which is non-parallel thereto; and

at least a first and a second non-driven wheel rotatably mounted to the chassis,

wherein rotation axes of the driven wheel and the first non-driven wheel are mutually spaced apart in a lengthwise direction,

wherein rotation axes of the first and the second non-driven wheel are mutually spaced apart in an elevation direction which is orthogonal to the lengthwise direction, and

wherein a distance, along the lengthwise direction, between an outer edge of the second non-driven wheel and the rotation axis of the driven wheel is greater than a distance, along the lengthwise direction, between an outer edge of the first non-driven wheel and the rotation axis of the driven wheel, such that the second non-driven wheel is arranged to be in magnetic adhesion contact with the first ferromagnetic surface when the driven wheel and the first non-driven wheel are in concurrent magnetic adhesion contact with the second ferromagnetic surface.

According to another aspect of the invention, a method of operating mobile robot capable of performing surface transition on ferromagnetic surfaces is provided. The method comprises:

performing, by a mobile robot, surface transition from a first ferromagnetic surface to a second ferromagnetic surface which is non-parallel thereto by:

rotating at least one driven wheel to move the driven wheel from the first to the second ferromagnetic surface and to actuate a first and a second non-driven wheel rotate, wherein the driven wheel, the first and the second non-driven wheel are rotatably mounted to a chassis of the mobile robot;

detaching the first non-driven wheel from the first ferromagnetic surface and landing the first non-driven wheel onto the second ferromagnetic surface;

while the driven wheel and the first non-driven wheel are in magnetic adhesion contact with the second ferromagnetic surface, disposing the second non-driven wheel in magnetic adhesion contact with a location on the first ferromagnetic surface at a location therein, wherein a minimum distance between the location and which is spaced

apart from the second ferromagnetic surface by a distance is greater than a radius of the first non-driven wheel; and
detaching the second non-driven wheel from the first ferromagnetic surface.

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BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are disclosed hereinafter with reference to the drawings, in which:

10 Figures 1A to 1B illustrate a surface transition sequence of a conventional mobile robot from a vertical surface to an overhead surface;

Figure 2 illustrates a surface transition sequence of a conventional mobile robot from a horizontal surface to a vertical surface;

15 Figure 3 illustrates a schematic side view of a mobile robot in accordance with one embodiment of the invention;

Figures 4A to 4C illustrate a surface transition sequence of a mobile robot from a vertical surface to an overhead surface in accordance with one embodiment of the invention; and

20 Figure 5 illustrate a graph of average output torque required to detach a mobile robot, according to one embodiment of the invention, from a source or previous surface during or after surface transition.

DETAILED DESCRIPTION

25 In the following description, numerous specific details are set forth in order to provide a thorough understanding of various illustrative embodiments of the invention. It will be understood, however, to one skilled in the art, that embodiments of the invention may be practiced without some or all of these specific details. In other instances, well known process operations have not been described in detail in
30 order not to unnecessarily obscure pertinent aspects of embodiments being described. In the drawings, like reference numerals refer to same or similar functionalities or features throughout the several views.

Embodiments described in the context of one of the methods or devices are analogously valid for the other methods or devices. Similarly, embodiments described in the context of a method are analogously valid for a device, and vice versa.

5 Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations
10 and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

As used herein, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

15 As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

As used herein, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

20 As used herein, the terms “operative”, “adapted to” and “configured to” are interchangeable.

As used therein, the term “coupled” and related terms are used in an operational sense and are not necessarily limited to a direct physical connection or coupling. Thus, for example, two devices may be coupled directly, or via one or more intermediary devices.

25 As used herein, the terms “front wheel”, “driven wheel” and “first wheel” may be used interchangeably; terms “rear wheel” and “first non-driven wheel” may be used interchangeably; terms “supplementary wheel” and “second non-driven wheel” may be used interchangeably.

Mobile Robot and its Components

According to embodiments of the invention, a mobile robot 20 (see Figure 3 for a schematic side view of one embodiment) comprises a chassis 21, at least one driven wheel 22, e.g. front wheel, rotatably mounted or coupled to the chassis 21 and operative to drive the chassis 21 to move along a ferromagnetic surface and/or transit from one surface to another, at least a first non-driven wheel 24 or first caster wheel, e.g. rear wheel, and at least a second non-driven wheel 26 or second caster wheel, e.g. supplemental wheel, which are rotatably mounted to the chassis 21.

The mobile robot 20 may be any motorized or automotive apparatus which is capable of moving along ferromagnetic surfaces and performing surface transition between parallel and non-parallel surfaces. The mobile robot 20 may be controlled by wired connection or wireless means. The mobile robot 20 can be employed in various operations, including but not limited to welding, blasting, inspection, installation work, etc., which are performed on magnetic surfaces. Such magnetic surfaces may be provided in a confined space structure and/or at elevated height, where accessibility is hard and/or hazardous for humans. Although the definition of a confined space varies between jurisdictions, according to guidelines published by the Workplace Safety and Health Council in Singapore, a “confined space” is any chamber, tank, manhole, vat, silo, pit, pipe, flue or any other enclosed space, in which: dangerous gases, vapours or fumes are liable to be present to such an extent as to involve risk of fire or explosion, or persons being overcome thereby; the supply of air is inadequate, or is likely to be reduced to be inadequate, for sustaining life; or there is a risk of engulfment by material. It is to be appreciated that the mobile robot 20 may be operated on magnetic surfaces provided in a non-confined space structure and/or at non-elevated height.

The chassis 21 may be a carriage or housing which supports a payload. The chassis 21 may define a lengthwise or first direction; an elevation or second direction which is orthogonal or transverse to the lengthwise direction; and a breadthwise or third direction which is orthogonal or transverse to both the lengthwise and the breadthwise direction. In the context of Figure 3, lengthwise or first direction is illustrated as a horizontal direction, elevation or second direction is illustrated as a vertical direction while a breadthwise or third direction is illustrated as a plane which

is orthogonal to both the vertical and the horizontal direction. However, it is to be appreciated that these directions may be assigned differently in other embodiments, and terms “lengthwise” and “breadthwise” do not necessarily suggest that relative dimensions or directions. In some examples, dimension of the chassis 21 in the lengthwise direction may be greater than dimension of the chassis 21 in the breadthwise direction; in some other examples, the converse may apply.

The chassis 21 may include at least a first, a second and a third rotation axis.

At least one driven wheel 22 is rotatable about the first rotation axis, and operative by motor or other actuation means to drive the chassis 21. In some examples, a mobile robot 20 comprises two driven wheels as front wheels.

At least a first non-driven wheel 24 is rotatable about the second rotation axis and operative to be driven or actuated by the driven wheel 22. In some examples, a mobile robot 20 comprises two first non-driven wheels as rear wheels.

At least a second non-driven wheel 26 is rotatable about the third rotation axis and operative to be driven or actuated by the driven wheel 22. In some examples, a mobile robot 20 comprises one or more second non-driven wheel(s) as supplemental wheel(s).

Each of the driven and non-driven wheels 22, 24, 26 includes a magnetic assembly, which may include a permanent and/or electromagnet, to allow magnetic adhesion contact with ferromagnetic surfaces while the robot 20 is moving on a ferromagnetic surface and/or stationary thereon.

The second non-driven or supplementary wheel 26 is suitably arranged to provide a protrusion relative to the first non-driven or rear wheel 24. In particular, rotation axes of the driven wheel 22 and the first non-driven wheel 24 may be mutually spaced apart, i.e. from each other, by a distance of l_1 , in the lengthwise direction. Rotation axes of the first and the second non-driven wheel 24, 26, may be mutually spaced apart, by a distance h , in an elevation direction which is orthogonal to the lengthwise direction. A distance d_2 , in the lengthwise direction, between a rim or outer edge of the second non-driven wheel and the rotation axis of the driven wheel 22 is greater or larger than a distance d_1 , in the lengthwise direction, between

a rim or outer edge of the first non-driven wheel 24 and the rotation axis of the driven wheel 22 (see Figure 3). This rim or outer edge includes reference to any location respectively on the first or the second non-driven wheel 24, 26 which is configured to contact a ferromagnetic surface during operation and is furthest from the driven wheel 22 or its rotation axis in the lengthwise direction. This arrangement of d_1 and d_2 may result in increased lengthwise dimension of the robot, at least in certain examples.

Optionally, in addition to the preceding paragraph, rotation axes of the first and the second non-driven wheel 24, 26 may be mutually spaced apart, by a distance l_2 .

The aforementioned parameters h , l_1 and l_2 may be varied in different examples according to requirements of practical application and/or user.

In one example, the values of h and l_2 may be greater than a radius of the first non-driven wheel 24.

In one example, the values of h and l_2 may be greater than a diameter of the first non-driven wheel 24.

In one example, the value of h may be greater than a radius of the first non-driven wheel 24 while the value of l_2 may be smaller than the radius of the first non-driven wheel 24. Conversely, in another example, the value of h may be smaller than a radius of the first non-driven wheel 24 while the value of l_2 may be greater than the radius of the first non-driven wheel 24.

In one example, the value of l_2 may be zero while the value of h may be greater than a radius or a diameter of the first non-driven wheel 24. In this example, a radius or diameter of the second non-driven wheel 26 is greater or larger than a radius or diameter of the first non-driven wheel 24 such that d_2 is greater than d_1 .

From at least the above and other examples according to embodiments of the invention, the second non-driven wheel 26 may be arranged to be in magnetic adhesion contact with a first ferromagnetic surface 1, i.e. source or vertical ferromagnetic surface in Figure 4C, when the driven wheel 22 and the first non-driven wheel 24 are arranged to be in concurrent magnetic adhesion contact with a

second ferromagnetic surface 2, e.g. destination surface or overhead surface in Figure 4C. In other words, the driven wheel 22 and the second non-driven wheel 26 may be arranged to allow concurrent contact with the second ferromagnetic surface 1 and the first ferromagnetic surface 1 respectively.

While the driven wheel 22 and the second non-driven wheel 26 may be arranged to allow concurrent contact with the second ferromagnetic surface 1 and the first ferromagnetic surface 1 respectively, they 22, 26 may be arranged to disallow concurrent magnetic adhesion contact with a same surface which is either the first or the second ferromagnetic surface 1, 2.

In various embodiments of the invention, by providing the second non-driven wheel 26, e.g. supplemental wheel, and by virtue of its relative position to or relative protrusion from the first non-driven wheel 24, e.g. rear wheel, the value of a_t , upon successful surface transition, is effectively increased in these embodiments each having three wheel sets, i.e. driven wheel 22 as front wheel and non-driven wheels 24, 26 as rear and supplemental wheels. The value of a_t refers to the minimum distance between a point or location of wheel contact with the source or previous surface and a nearest point on the destination surface. In various embodiments, the value of minimum a_t does not depend on the non-driven rear wheel 24 but depends on the position or elevation of the supplemental wheel 26 relative to the rear wheel 24. Furthermore, the value of minimum a_t is increased due to the relative position of the supplemental wheel 26 with respect to the rear wheel 24. This is contrasted with a conventional robot having two wheel sets, i.e. driven and non-driven wheels as front and rear wheels respectively, wherein the value of minimum a_t depends on the rear wheel and is therefore reduced or lower than that provided by embodiments of the invention.

Operation

Figures 4A to 4C illustrate a vertical to overhead (V2O) surface transition sequence of a mobile robot 20, according to one embodiment of the invention, from a vertical ferromagnetic surface to an overhead ferromagnetic surface. During the illustrated transition, relative magnetic forces acting on the surfaces vary and are represented by various labeled arrows.

At a first or source ferromagnetic surface 1 on which the mobile robot 20 is disposed, the driven or front wheel 22 is actuated, by motor(s) of the mobile robot 20, to move along the first ferromagnetic surface 1. The first non-driven or rear wheel 24 is actuated by the rotation of the driven wheel 22 to also rotate and move along the first ferromagnetic surface 1. At this time, the driven wheel 22 and the first non-driven wheel 24 are in magnetic adhesion contact with the first ferromagnetic surface 1; the second non-driven or supplemental wheel 26 is free of contact with any ferromagnetic surface.

Surface transition commences in Figure 4A in which the driven wheel 22 approaches a second ferromagnetic surface 2 which is non-parallel to the first ferromagnetic surface 1. The ferromagnetic surfaces 1, 2 may be disposed at an acute angle, right-angle or obtuse angle to each other. The driven wheel 22 is actuated by one or more motors to perform a surface transition to the second ferromagnetic surface 2 to land the driven wheel 22 on the second ferromagnetic surface 2 (see Figure 4A). At this time, the driven wheel 22 is in magnetic adhesion contact with the second ferromagnetic surface 2, i.e. overhead surface, while the first non-driven wheel 24 remains in magnetic adhesion contact with the first ferromagnetic surface 1, i.e. vertical surface; the second non-driven wheel 26 is free of contact with any ferromagnetic surface.

As the surface transition progresses in Figure 4B, the driven wheel 22 is further rotated along the second ferromagnetic surface 2, and the second non-driven wheel 26 is also brought into or disposed in magnetic adhesion contact with the first ferromagnetic surface 1. At this time, both the first and the second non-driven wheel 24, 26 are disposed in magnetic adhesion contact with the first ferromagnetic surface 1.

Subsequently, as the surface transition further progresses in Figure 4B, a sufficient driving force or torque is generated by the robot 20 to overcome the adhesive force F_{Hreq1} at the first non-driven wheel 24 in order to detach this wheel 24 from the first ferromagnetic surface 1 and land this wheel 24 on the second ferromagnetic surface 2, thus leaving only the second non-driven wheel 26 in magnetic adhesion contact with the first ferromagnetic surface 1. After both the driven wheel 22 and first non-driven wheel 24 land on the second ferromagnetic

surface 2 as shown in Figure 4C, the robot 20 has performed a successful surface transition. At this time, the second non-driven wheel 26 remains disposed in magnetic adhesion contact with the first ferromagnetic surface 1 at a location thereon, wherein the value of a_t or a minimum distance between this location and the second ferromagnetic surface 2 is greater than a radius of the first non-driven wheel 24. Thereafter, a sufficient driving force F_d or torque is generated by the robot 20 to overcome the adhesive force F_{Hreq2} at the second non-driven wheel 26 in order to detach this wheel 26, as well as the robot 20, from the first ferromagnetic surface 1.

Comparing Figure 4C embodying one example robot 20 of the invention and Figure 1B embodying a conventional mobile robot 10, it will be noted that since the second non-driven wheel 26 is positioned above the first non-driven wheel, the minimum a_t at the position illustrated in Figure 4C – will always be greater than the minimum a_t shown in Figure 1B. With this increased minimum a_t , an adhesive force F_{Hreq2} at the second non-driven wheel 26 in Figure 4C is decreased as compared to an adhesive force F_{Hreq} at the non-driven wheel 14 in the robot 10 of Figure 1B. This decreased F_{Hreq2} in turn decreases the driving force F_d required to detach the second non-driven wheel 26 from the first surface 1. Furthermore, force F_{Hreq1} required at the first non-driven wheel 24 to lift off the first non-driven wheel 24 of the robot 20 of Figure 4B will also be lower than force F_{Hreq} required to lift off rear wheel 14 of robot 10 of Figure 1B since the body of the robot 20 of Figure 4B is behaving like a lever, with the second non-driven wheel 26 acting as a pivot point. Accordingly, in the robot 20 of Figure 4C, by increasing minimum a_t value, the required F_d for surface transition is decreased while the maximum payload allowable is increased, as compared to the robot 10 of Figure 1B.

Experimental Result

Experiments were performed using a mobile robot prototype having three wheel sets (at least one driven or front wheel 22, at least a first non-driven or rear wheel 24, and at least a second non-driven or supplemental wheel 26). The first non-driven wheel 24 has a maximum magnetic attraction force of about 230N while the second non-driven wheel 26 has a maximum magnetic attractive force of about 160N. The second non-driven or supplementary wheel 26 is positioned relative to the first non-driven or rear wheel 24 with parameters at $h = 100\text{mm}$ and $l_2 = 30\text{mm}$.

From the experiment, the mobile robot prototype, with a total gross weight of about 20kg located approximately at the center of the chassis, was also able to perform a successful V2O transition. The maximum driving force F_d required to lift off the second non-driven or supplemental wheel after the V2O transition was measured to be around 165N.

On the other hand, the same carriage, with a total gross weight of about 20kg, but with the absence of the second non-driven or supplemental wheel, has a maximum payload of less than 10kg. In order to have the same payload without the second non-driven or supplemental wheel, the maximum magnetic force of the non-driven or rear wheel is calculated to be around 500N, assuming same robot dimensions or parameters, and setup. This would mean that, for a conventional robot with two wheel sets, the driving force required to detach the non-driven or rear wheel, from the first or source ferromagnetic surface, after a successful transition would be at least two times higher.

Figure 5 shows a graph illustrating the following:

- As shown by the left column 51, the torque required by two front-drive motors to detach the non-driven or rear wheel of a conventional 2-wheel design (driven front wheels and non-driven rear wheel) of a robot chassis of 20kg, such as that shown in Figure 1B, is more than 8 Nm.
- As shown by the middle column 52 and right column 53, the torques required by two front-driven motors to detach the first non-driven or rear wheel and second non-driven or supplemental wheel, both of a 3-wheel design (driven front wheels and non-driven rear wheels and non-driven supplemental wheels) of a robot chassis of 20kg, such as that shown in Figure 4B, are more than 4 Nm and less than 4 Nm respectively.

Hence, it is to be appreciated that provision of the second non-driven or supplemental magnetic wheel and its protrusion relative to the first non-driven or rear wheel at least in the lengthwise direction has a benefit of increasing the maximum payload of the chassis as well as a reduction of the required driving force for detachment of the rear and/or supplemental wheel(s), at least upon V2O transition.

Embodiments of the invention provide several advantages including, but not limited to, the following:

- The invention does not require additional mechanism, e.g. an active or passive lifter mechanism, to aid surface transition, thus reducing the overall complexity and size of the robot.
- As compared to a conventional mobile robot with two wheel sets, e.g. mobile robot 10 in Figures 1A to 1B, a mobile robot with three wheel sets according to the invention, e.g. mobile robot 20 in Figures 3, 4A to 4C, requires a lower or reduced driving force for carrying the same payload and/or increases the payload capacity while requiring the same required driving force.
- A mobile robot with three wheel sets according to the invention facilitates surface transitioning between two surfaces with acute or obtuse angle between each other.

Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the invention. Furthermore, certain terminology has been used for the purposes of descriptive clarity, and not to limit the disclosed embodiments of the invention.

What is claimed is:

1. A mobile robot capable of performing surface transition on ferromagnetic surfaces, the robot comprises:

a chassis;

5 at least one driven wheel rotatably mounted to the chassis and operative to drive the chassis to transit from a first ferromagnetic surface to a second ferromagnetic surface which is non-parallel thereto; and

 at least a first and a second non-driven wheel rotatably mounted to the chassis,

10 wherein rotation axes of the driven wheel and the first non-driven wheel are mutually spaced apart in a lengthwise direction,

 wherein rotation axes of the first and the second non-driven wheel are mutually spaced apart in an elevation direction which is orthogonal to the lengthwise direction, and

15 wherein a distance, along the lengthwise direction, between an outer edge of the second non-driven wheel and the rotation axis of the driven wheel is greater than a distance, along the lengthwise direction, between an outer edge of the first non-driven wheel and the rotation axis of the driven wheel, such that the second non-driven wheel is arranged to be in magnetic adhesion contact with the first
20 ferromagnetic surface when the driven wheel and the first non-driven wheel are in concurrent magnetic adhesion contact with the second ferromagnetic surface.

2. The mobile robot of claim 1, wherein the rotation axes of the first and the second non-driven wheel are mutually spaced apart in the lengthwise direction.

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3. The mobile robot of any one of claim 1 to claim 2, wherein the rotation axes of the first and the second non-driven wheel are mutually spaced apart by a distance greater than a radius of the first non-driven wheel.

4. The mobile robot of any one of claim 1 to claim 2, wherein the rotation axes of the first and the second non-driven wheel are mutually spaced apart by a distance greater than a diameter of the first non-driven wheel.

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5. The mobile robot of claim 1, wherein a diameter of the second non-driven wheel is greater than a diameter of the first non-driven wheel.

6. The mobile robot of any one of claim 1 to claim 5, wherein the first and the
10 second ferromagnetic surface form an angle being one of an acute angle, an obtuse angle and a right angle.

7. The mobile robot of any one of claim 1 to claim 6, wherein the first and the second ferromagnetic surface are part of an interior of a confined space structure.

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8. A method of operating mobile robot capable of performing surface transition on ferromagnetic surfaces, the method comprises:

performing, by a mobile robot, surface transition from a first ferromagnetic surface to a second ferromagnetic surface which is non-parallel thereto by:

20 rotating at least one driven wheel to move the driven wheel from the first to the second ferromagnetic surface and to actuate a first and a second non-driven wheel rotate, wherein the driven wheel, the first and the second non-driven wheel are rotatably mounted to a chassis of the mobile robot;

25 detaching the first non-driven wheel from the first ferromagnetic surface and landing the first non-driven wheel onto the second ferromagnetic surface;

while the driven wheel and the first non-driven wheel are in magnetic adhesion contact with the second ferromagnetic surface, disposing the

second non-driven wheel in magnetic adhesion contact with the first ferromagnetic surface at a location therein, wherein a minimum distance between the location and the second ferromagnetic surface is greater than a radius of the first non-driven wheel; and

5 detaching the second non-driven wheel from the first ferromagnetic surface.

9. The method of claim 8,

wherein rotation axes of the driven wheel and the first non-driven wheel are mutually
10 spaced apart in a lengthwise direction,

wherein rotation axes of the first and the second non-driven wheel are mutually spaced apart in an elevation direction which is orthogonal to the lengthwise direction.

10. The method of claim 9, wherein the rotation axes of the first and the second
15 non-driven wheel are mutually spaced apart in the lengthwise direction.

11. The method of any one of claim 9 to claim 10, wherein the rotation axes of the first and the second non-driven wheel are mutually spaced apart by a distance greater than a radius of the first non-driven wheel.

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12. The method of any one of claim 9 to claim 10, wherein the rotation axes of the first and the second non-driven wheel are mutually spaced apart by a distance greater than a diameter of the first non-driven wheel.

25 13. The method of claim 9, wherein a diameter of the second non-driven wheel is greater than a diameter of the first non-driven wheel.

14. The method of any one of claim 8 to claim 13, wherein the first and the second ferromagnetic surface form an angle being one of an acute angle, an obtuse angle and a right angle.

- 5 15. The method of any one of claim 8 to claim 14, wherein the first and the second ferromagnetic surface are part of an interior of a confined space structure.

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