AXLE ASSEMBLY FOR CONNECTING AT LEAST ONE WHEEL TO A MOBILE ROBOT MOVABLE ON A FERROMAGNETIC SURFACE, MOBILE ROBOT AND METHODS

The present invention relates to an axle assembly for connecting at least one wheel to a mobile robot movable on a ferromagnetic surface. The present invention also relates to a mobile robot. Moreover, the present invention relates to a method of performing an operation on a ferromagnetic surface. Furthermore, the present invention relates to a method of adapting a mobile robot so that the mobile robot becomes attachable to a ferromagnetic surface.

Background

Nowadays, mobile robots are used for performing different types of operations on ferromagnetic surfaces. These operations can be observed in many situations, such as when inspecting and/or cleaning a hull of a floating vessel or the outer surfaces in maritime and offshore applications. These operations can also be observed in land, for example when inspecting or cleaning a tower of a wind turbine for generating electricity, a storage tank in industrial parks, or an underground fuel tank in a petrol station. In many situations the ferromagnetic surfaces are non-horizontal. Typically, a mobile robot suitable for inspecting a ferromagnetic surface has wheels or tracks which run along the surface, and the mobile robot must stay attached to the surface as the operations are performed. To ensure that it does not fall from the surface, the mobile robot comprises magnets, such as permanent magnets and/or electromagnets, to create a magnetic force that is strong enough to hold the robot against the surface. Moreover, these operations are sometimes performed under adverse conditions, such as complex hydrodynamic conditions experienced at a splash zone of a semi-submerged structure or while the structure (e.g. a floating vessel) is traveling through sea water. Therefore, the adhesion of the mobile robot to the surface must be robust enough to withstand adverse conditions.

In practice, it can be challenging for a mobile robot to travel over corners, edges, curved portions or other non-flat features of a ferromagnetic surface and maintain a strong attachment to the surface over the entire traversal of the non-flat feature. While travelling on non-flat features of a ferromagnetic surface, the magnetic pull force between the robot and the surface can be inadvertently reduced due to the magnets not being oriented at a right angle relative to the surface during the traversal. Contrastingly, on a flat surface, the

robot is typically held with the maximum magnetic pull force, as the magnets are substantially positioned at a right angle to the surface. The risk of inadvertent detachment on non-flat features is disadvantageous because detachment causes the operations being performed to be stopped and requires further intervention to retrieve and set the mobile robot again onto the ferromagnetic surface and continuing the operation from the point where it was interrupted.

An example of a mobile robot 300 known from the prior art is illustrated in Fig. 1A. The mobile robot 300 is illustrated as moving on a non-horizontal ferromagnetic surface 410 (for example, the hull of a ship). The mobile robot is connected to an umbilical cable 301 (see upper portion of Fig. 1A) that provides power and communication to the mobile robot 300. Although the umbilical 301 is illustrated as being stretched, the mobile robot 300 is not substantially suspended by the umbilical 301. Two magnets 121a,121b are included in mobile robot 300, and these attach the mobile robot 300 to the ferromagnetic surface 410 as the mobile robot 300 moves on the surface 410. The magnets 121a,121b are respectively connected to the axle 101a,101b of a different wheel 200a,200b of the mobile robot 300. Specifically, each magnet 121a,121b is fixedly attached to the mobile robot 300 so that, on a flat surface, the magnet 121a,121b would be oriented at a right angle with the flat surface. However, as already mentioned, when traversing a non-flat feature 420, the alignment of the magnets 121a.121b will not be ideal. The ferromagnetic surface 410 includes a non-flat feature 420, as may be seen in the middle region of Fig. 1A. Fig. 1A illustrates one moment during a traversal of the non-flat feature 420 in which the magnets 121a,121b are not oriented at a right angle with the ferromagnetic surface 410 (see angle α (*alpha*) in Fig. 1A). This misalignment produces an inadvertent reduction of the pull force generated between the magnets 121a,121b and the ferromagnetic surface 410.

A known approach for dealing with the non-flat feature problem is shown in the document WO 2013154426 A1, which discloses a cleaning unit for, inter alia, cleaning a hull of a ship (see example illustrated in Fig. 1 of the document). The cleaning unit (see reference numeral 20 in Fig. 2A of the document) includes a frame connecting three wheels for moving the cleaning unit on the hull and three cleaning heads for spraying water and removing unwanted matter from the hull. The cleaning heads can pivot relative to the frame of the cleaning unit (see curved profile in Fig. 2C in the document) and these include internal magnets (see reference numeral 46 on the bottom-left corner in Fig. 3C of the document) for generating an attractive force between the cleaning unit and the hull. Thus,

an apparatus is disclosed which can travel over non-flat features. However, this known approach has a few technical disadvantages.

Firstly, as can be seen in Fig. 2A of the above-mentioned document, the arrangement of the cleaning heads and the wheels of the cleaning unit (see reference numerals 24 in Fig. 2A of the above-mentioned document) requires a reinforcement of the frame of the cleaning unit. This is needed in order to connect, in a sufficiently robust manner, the set of cleaning heads with the frame and wheels of the cleaning unit. The reinforcement of the frame is however disadvantageous, because, in addition to increasing the manufacturing cost of the cleaning unit, it adds complexity and significant weight. The added weight of the cleaning unit also increases the dependency on stronger magnets, and this drawback is further amplified when a bigger cleaning unit needs to be manufactured.

Secondly, it is observed in practice that this approach does not work well for all non-flat features of the ship's hull. In highly curved features, there is a risk that the cleaning heads may inadvertently cause a wheel of the cleaning unit to raise from the hull. This can happen due to the cleaning heads being arranged between the all cleaning unit wheels, and because of the distances between the wheels and the cleaning heads. An alternative cleaning unit is described in page 9, line 3 to 16 of the above-mentioned document, in which a subframe and suspension are provided for relative motion between the cleaning heads and the remaining components of the cleaning unit. This solution is however complex, requires components to be added to the cleaning unit and, again, adds weight from the suspension and subframe to the cleaning unit, which is highly disadvantageous.

Thirdly, it can be observed in Fig. 2A of the above-mentioned document that the cleaning heads take up a lot of useful space between the frame of the cleaning unit and the hull. Thus, the cleaning head arrangement imposes constraints on the amount and arrangement of tools that can be provided on the cleaning unit. Also, increasing the number of tools provided on the cleaning unit may lead to an increase in the amount of cleaning heads that are needed. This adversarial relation between the number of cleaning heads and the number of tools that can be provided on the cleaning unit is disadvantageous.

General description

The invention will now be disclosed and has for its object to remedy or to reduce at least one of the drawbacks of the known prior art, or at least provide a useful alternative to the known prior art. The object is achieved through features, which are specified in the description below and in the claims that follow. The invention is defined by the independent patent claims, and the dependent claims define advantageous embodiments of the invention.

According to a first aspect of the invention, there is provided an axle assembly for connecting at least one wheel to a mobile robot movable on a ferromagnetic surface. The axle assembly comprises: an axle for revolving the at least one wheel; and at least one magnet for exerting a pull force between the axle assembly and a portion of the ferromagnetic surface. The axle assembly is adapted to pivot the at least one magnet about a rotation axis parallel to the axle, the at least one magnet being pivotable in reaction to a shape change of the portion of the ferromagnetic surface while the mobile robot moves on the ferromagnetic surface.

Providing the at least one magnet as being pivotable minimizes inadvertent reductions in magnetic force when the mobile robot moves on non-flat features of the ferromagnetic surface. Also, it is advantageous that the pivoting of the at least one magnet can happen during the entire path on a non-flat feature, thus guaranteeing that the pull force orientation is optimized at all mobile robot positions on the ferromagnetic surface.

Moreover, it has been realized that, by providing an axle assembly having at least one magnet that is pivotable about a rotation axis parallel to the axle, it is possible to overcome the problems observed in known prior art. Namely, the need to reinforce a substantial portion of the mobile robot, such as a portion of a body frame, is removed, which in turn contributes to achieving an improved ratio between the weight of the mobile robot and the pull force exerted by the at least one magnet. Also, the mobile robot has a better quality of traversal over highly curved ferromagnetic surfaces, e.g. on the bulbous bow of a ship's hull. This is a result from removing the possibility of the at least one magnet inadvertently causing the at least one wheel to be raised from the surface. Moreover, at least one wheel connected to the mobile robot by an axle assembly embodiment has the advantage of being compact in composition with the axle assembly, and this space efficiency allows more space on the mobile robot to be used for providing tools suitable for monitoring or

actuating on the ferromagnetic surface, e.g. a tool for high-pressure water jet, a camera, a scrubber tool, etc.

The axle assembly may comprise at least one bracket for connecting the axle assembly to the mobile robot, the at least one bracket comprising at least one slot for guiding the at least one magnet in a pendular path. This embodiment achieves a robust solution for bearing strong forces from the at least one magnet while still allowing the latter to be pivotable. The bracket may be directly connected to a fixed part of the mobile robot, such as a body frame. Also, the bracket may be adapted to connect the axle assembly to the mobile robot in many ways, such as in a fixed or fastened manner or in a rotatable manner, such as in a hinging manner. The bracket may also or in alternative be connected to a movable part of the mobile robot, such as a part of a steering system.

The at least one magnet may be connected to a pivot on the axle assembly. This embodiment is advantageous in that it is a simple solution for enabling the at least one magnet to be pivotable. This connection to the pivot may be in addition or in alternative to the bracket comprising a slot for guiding the at least one magnet in a pendular path.

The at least one magnet may be concentrically pivotable with the at least one wheel. Thus, the forces from the at least one magnet can be transmitted directly to the rotation axis of the at least one wheel. This embodiment is also advantageous in that it minimizes the need for reinforcing any part of the mobile robot due to the forces exerted on the mobile robot between the at least one magnet and the axle.

The at least one magnet may be arranged on the axle assembly so that a wheel surrounds the at least one magnet when the at least one wheel is connected by the axle assembly to the mobile robot. Thus, this embodiment is advantageous in that it has a compact spatial occupation with an improved integration of the axle assembly and the wheel surrounding the at least one magnet.

The at least one magnet may be freely pivotable so that the pull force passively pivots the at least one magnet towards the portion of the ferromagnetic surface. This embodiment is advantageous in that no additional actuations are needed to achieve the optimization effect over the rotation of the at least one magnet. Thus, the adherence is maintained by the at least one magnet with an orientation that maximizes the magnetic pull force applied

on the mobile robot for adherence to the surface. Moreover, this embodiment achieves a simple design by not requiring a power source for orienting the at least one magnet towards the ferromagnetic surface.

The at least one magnet may be a permanent magnet or an electromagnet.

The axle assembly may comprise at least one bearing for revolving the at least one wheel.

The axle assembly may comprise an actuator for changing a distance between the at least one magnet and the ferromagnetic surface. Thus, the axle assembly can also include means for facilitating the detachment of the mobile robot from the ferromagnetic surface after it has been attached thereto. This feature can be implemented by providing actuators for controlling the distance between the at least one magnet and the ferromagnetic surface and/or orienting the at least one magnet away from the ferromagnetic surface.

According to a second aspect of the present invention, there is provided a mobile robot comprising at least one axle assembly as described in the first aspect of the present invention.

According to a third aspect of the present invention, there is provided a method of performing an operation on a ferromagnetic surface. The method comprises the steps of:
- providing a mobile robot as described in the second aspect of the present invention;
- provisioning the mobile robot with at least one tool for performing the operation;
- attaching the mobile robot to the ferromagnetic surface;
- controlling the mobile robot to move on the ferromagnetic surface and traverse at least one non-flat feature.

The ferromagnetic surface may be part of any of: a hull of a floating vessel; an offshore structure; a storage tank; a tower of a wind turbine; or a pipe.

According to a fourth aspect of the present invention, there is provided a method of adapting a mobile robot so that the mobile robot becomes attachable to a ferromagnetic surface. The method comprises the steps of:
- providing the mobile robot;

- providing at least one axle assembly as described in the first aspect of the present invention;
- installing the at least one axle assembly on the mobile robot.

Brief description of the figures

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

Figure 1A is a schematic elevation view of a mobile robot comprising axle assemblies as known from the prior art;

Figure 1B is a schematic elevation view of a mobile robot embodiment comprising a plurality of first axle assembly embodiments;

Figures 2A-2B are schematic views of a second axle assembly embodiment and a wheel (Fig. 2A shows a perspective view and Fig. 2B shows an elevation view);

Figures 3A-3B are schematic views of the second axle assembly embodiment shown in Figures 2A-2B when traversing a non-flat feature of a ferromagnetic surface (Fig. 3A shows a perspective view and Fig. 3B shows an elevation view);

Figure 4 is a schematic perspective view of a portion of a mobile robot embodiment including a plurality of embodiments of the second axle assembly shown in Figs. 2A-3B; and

Figure 5 is a schematic elevation view of a rear side of another mobile robot embodiment comprising a third axle assembly embodiment.

Detailed description

Turning now to Figure 1B, it shows a mobile robot embodiment 300 traversing a non-flat feature 420 on a ferromagnetic surface 410. It can be seen that the ferromagnetic surface 410 is non-horizontal. The mobile robot 300 includes wheels 200a,200b for moving on the ferromagnetic surface 410. On the elevation view shown in Fig. 1B, only two wheels 200a,

200b are observable. The mobile robot 300 has a power and data connection established via an umbilical cable 301, which may also advantageously function as a safety rope. Alternatively, the umbilical cable 301 can be removed and its power and communication functions can be achieved by adapting the mobile robot 300 to include one or more batteries for supplying electric energy and a wireless communication device for enabling wireless communication with the mobile robot 300.

For each wheel 200a,200b, the mobile robot 300 includes a first axle assembly embodiment for connecting the respective wheel 200a,200b to the mobile robot 300. Each first axle assembly embodiment includes an axle 101a,101b for revolving the wheel 200a,200b, a magnet 121a,121b for exerting a pull force between the axle assembly and a portion of the ferromagnetic surface 410, and a pivot connection 103a,103b for pivoting the magnet 121a,121b about the axle 101a,101b.

As can be observed in Fig. 1B, at the moment that is illustrated the magnets 121a,121b are pivoted towards the ferromagnetic surface 410 and thus provided with an orientation (see the β (beta) angles in Fig. 1B) that substantially optimizes the magnetic pull force between the axle assembly embodiments and the ferromagnetic surface 410. The magnets 121a,121b will keep on aligning throughout the entire traversal over the non-flat feature 420 and thus the attachment quality is substantially increased.

Figs. 2A and 2B show a second axle assembly embodiment 100 and a wheel 200 including a tire 201 and a rim 202. The axle assembly 100 includes: an axle 101 for revolving the wheel 200; a set of five magnets 121a-121e arranged as a magnet block 120, the magnet block 120 being suitable for exerting a pull force between the axle assembly 100 and a portion of a ferromagnetic surface 410; and a bracket 110 that is suitable for fixing the axle assembly 100 to a mobile robot 300.

The axle 101 is a single shaft adapted to provide, on one end, a connection for the wheel 200 (the connection between axle 101 and wheel 200 is visible on Fig. 4). The axle 101 crosses through the bracket 110, which includes at least one bearing (not visible) for revolving the axle 101 and connected wheel 200.

The magnet block 120 is an arrangement of five magnets 121a-121e. Alternatively, the at least one magnet 121 feature of the axle assembly 100 can be provided with only one

magnet 121 or with any other number of magnets 121, the number of magnets being defined as desired when implementing the axle assembly 100. Also, each of the magnets 121 may be implemented as a permanent magnet or an electromagnet.

The bracket 110 includes two holes 113a,113b that are suitable for fixing the bracket to the mobile robot 300 using a bushing fastener 114 for each hole 113a,113b. This connection embodiment may be more easily observed below with reference to Fig. 4. Thus, the bracket 110 is suitable for fixing the axle assembly 100 to the mobile robot 300. Some mobile robot embodiments 300 may be suitable for having the bracket 110 fixed to a body frame or another non-movable portion of the mobile robot 300. Other mobile robot embodiments 300 may be suitable to have the bracket 110 fixed on a moving part of mobile robot 300, such as a portion of a steering system.

The bracket 110 and the magnet block 120 are adapted so that the magnet block 120 may perform a pendular path on the bracket 110. The magnet block 120 includes four pins (of which only two 122a,122b are observable in the Figs. 2A-2B), and the bracket 110 includes two slots 111a,111b for guiding the pins of the magnet block 120 in the pendular path. The slots 111a,111b are provided so that the magnet block 120 is pivotable about a rotation axis 102 parallel to the axle 101. Also, it can be observed that the pendular path is concentrical with the rotation axis 102 of the axle 101. This configuration is advantageous in that it achieves a constant distance between the magnet block 120 and the ferromagnetic surface 410 along the entire pendular path. Other slot designs may be provided. For example, the path along which the magnet block 120 pivots may not be concentrical with the axle 101. Those slots designs would also solve the non-flat feature problem, even though they are not ideal due to the variable distance between the magnet block 120 and the ferromagnetic surface 410 along the pendular path. Also, the slots 111a,111b may be further designed differently, for example by occupying a wider or smaller arc (i.e. a longer or shorter pendular path). Moreover, the magnet block 120 may be pivotable about the rotation axis 102 of the axle 101 by means of pivot connection 103 as shown in Fig. 1B. Such a pivot connection 103 could be provided in addition or alternative to the slots 111a,111b on the bracket 110.

The bracket 110 of the axle assembly 100 shown in Figs. 2A-2B also includes a housing 112 that is useful for including electronic components for controlling and/or driving the axle assembly 100. Various kinds of electronic components may be provided within the housing

112, such as sensors, actuators, controllers, computational units, memories and power units.

It can be seen that the magnets 121a-121e shown in Figs. 2A and 2B are at a position substantially in the middle of the pendular path. The magnet block 200 will move along the pendular path should the axle assembly 100 and connected wheel 200 be installed on a mobile robot 300 and the latter traverse a non-flat feature 420 of a ferromagnetic surface 410. Figs. 3A and 3B show the magnet block 120 at a position of the pendular path in reaction to the non-flat feature 420.

In Figs. 3A and 3B, the magnet block 120 is positioned at one end of the pendular path, in comparison to the position shown in Figs. 2A and 2B. By comparing Figs. 2B and 3B, it can be seen that the magnet block 120 is provided at the same distance from the periphery of the wheel tire 201 in both figures. Thus, it can be seen that the pendular path is concentrical with the rotation axis 102 of the axle 101.

In the embodiment shown in Figs. 2A-3B, it is possible to observe that the pull forces form the magnet block 120 are efficiently transmitted to the axle 101, as there is a direct mechanical path between the pivoting arrangement of the magnet block 120 and the axle 101. Thus, there is no need to the reinforce parts of the mobile robot 300 for the purpose of also sustaining forces between the magnet block 120 and the wheel 200. Also, due to the compact arrangement of the axle assembly, there is a minimization of the probably that the magnet block 120 will come into contact with a highly curved ferromagnetic surface 410 before the wheel 200, and thus cause the wheel to separate from ferromagnetic surface 410.

The axle assembly 100 may also be adapted so that the magnet block 120 is pivotable within the wheel 200. In such an embodiment, the rim 202 surrounds the axle assembly 100 and the magnet block 120 generates a magnetic force through the rim 202 and tire 201 of the wheel 200. In practice, it has been observed that such an embodiment also achieves a good attachment quality between the axle assembly 100 and the ferromagnetic surface 410, and it is also highly advantageous in that it eliminates the possibility of the magnet block 120 coming into contact with the ferromagnetic surface 410.

The embodiment shown in Figs. 2A-3B can provide the magnet block 120 to pivot freely within the slots 111a,111b. Such an embodiment is advantageous in that the magnet block 120 positions itself along the pendular path in reaction to the forces that the magnet block 120 generates itself with the ferromagnetic surface 410. Thus, no additional actuations are needed to achieve the optimization effect over the rotation of the magnet block 120. In addition or alternatively, the axle assembly 100 may include actuators for facilitating the magnetic disconnection of the axle assembly 100 from the ferromagnetic surface 410. This can be achieved in many ways. For example, the axle assembly 100 may be adapted to allow distance changes between the at least one magnet 121 and the ferromagnetic surface 410. Thus, the axle assembly 100 may further include at least one actuator for controlling the magnetic gap between the at least one magnet 121 and the ferromagnetic surface 410. Alternatively or in addition, the axle assembly 100 may include rotation actuators for controllably actuating on the orientation of the magnet block 120 and thus cause a disorientation of the magnet block 120 to reduce the magnetic force and allow an easier separation of the axle assembly 100 from the ferromagnetic surface 410.

In Figure 4, a rear of a mobile robot 300 is shown including two wheels 200a,200b, wherein each wheel 200a,200b is connected to the mobile robot 300 by an axle assembly embodiment. The two axle assembly embodiments are partially visible in Fig. 4, having some portions appearing from behind the wheel 200a illustrated on the bottom-right corner in Fig. 4 and others appearing out of part of the mobile robot's 300 body illustrated on the upper-left corner in Fig. 4.

Turning to the bottom-right corner in Fig. 4, it is possible to see one of the rear wheels 200a. The wheel 200a is connected to an end of an axle of an axle assembly embodiment. The wheel 200a has a tire 201a for providing traction on a ferromagnetic surface 410 and a rim 202a that is connected to the axle end at the center of the rim 202a. Thus, the wheel 200a is both rotatable about the axle rotation axis 102 and connected to the mobile robot 300. Also, it is possible to see how a part of the axle assembly is connected to the mobile robot 300. As described above with reference to the embodiment shown in Figs. 2A-3B, the axle assembly includes a bracket that is connected to the mobile robot 300. Two bushing fasteners are provided for fastening the holes 113a,113b (visible in Figs. 2A-3B) on the bracket to the mobile robot 300. One bushing fastener 114a is visible on the rear of the mobile robot 300, and the other bushing fastener is hidden behind the wheel 200a on the bottom-right corner in Fig. 4. These two bushing fasteners enable the bracket to

connect the respective axle assembly to the mobile robot 300 in a hinging manner. Specifically, in this embodiment the axle assembly is rotatable about a roll rotation axis 115a, which is parallel to the longitudinal direction of the mobile robot 300. Thus, this embodiment is advantageous in that the wheels 200a,200b can be adapted to curved surfaces such as the outer surface of a large diameter pipe or a tower of a wind turbine for generating electricity. It can be seen that the wheel 200b illustrated at the top left corner in Fig. 4 is similarly connected to the mobile robot 300 through an axle assembly embodiment (only partially visible) and a bushing fastener 114b that achieves a roll rotation axis 115b.

Figure 5 shows a rear side of another mobile robot embodiment 300. The mobile robot 300 may also comprise an umbilical cable 301 connection for establishing a power and/or communication channel. Alternatively, any of these umbilical cable functions may be achieved with other technical means, such as by providing at least one battery and/or a wireless communication interface onboard the mobile robot 300.

The mobile robot 300 includes an axle assembly 100 embodiment for connecting two wheels to the mobile robot 300. The two wheels, of which only the respective tires 201a,201b are visible in Fig. 5, are similar to the ones illustrated in the preceding figures and allow the mobile robot 300 to move on a ferromagnetic surface. The wheels are connected to an axle aligned in a transversal direction to the mobile robot 300, and the axle enables the wheels to revolve around a rotation axis 102.

The axle assembly also includes a magnet block 120 that is supported by two arms 103a,103b. It can be seen in Fig. 5 that the magnet block 120 is positioned under the mobile robot 300; that is, the magnet block 120 is positioned between the body of the mobile robot 300 and the ferromagnetic surface (not shown in Fig. 5). The two arms 103a,103b provide a pivot connection that enables the magnet block 120 to be pivotable about the rotation axis 102. The pivotable connection is independent of the rotation of the axle and wheels.

Therefore, the magnet block 120 can be extended in order to increase the magnetic adhesion. This axle assembly embodiment can be valuable in critical missions in which the mobile robot 300 is subjected to highly adversarial conditions, such as when operating on a splash zone of a hull.

Generally, the terms used in this description and claims are interpreted according to their ordinary meaning the technical field, unless explicitly defined otherwise. Notwithstanding, the terms “comprises” and “comprising” and variations thereof mean that the specified features, steps or integers are included. These terms are not interpreted to exclude the presence of other features, steps or integers. Furthermore, the indefinite article “a” or “an” is interpreted openly as introducing at least one instance of an entity, unless explicitly stated otherwise. An entity introduced by an indefinite article is not excluded from being interpreted as a plurality of the entity.

The features disclosed in the foregoing description, or in the following claims, or in the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for obtaining the disclosed results, as appropriate, may, separately, or in any combination of such features, be utilized for realizing the invention in diverse forms thereof.

While the invention has been described in conjunction with the embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure. Accordingly, the embodiments of the invention set forth above are considered to be illustrative and not limiting. Various changes to the described embodiments may be made without departing from the scope of the claims.

CLAIMS

1. An axle assembly (100) for connecting at least one wheel (200) to a mobile robot (300) movable on a ferromagnetic surface (410),

wherein the axle assembly (100) comprises:

- an axle (101) for revolving the at least one wheel (200); and

- at least one magnet (121) for exerting a pull force between the axle assembly (100) and a portion of the ferromagnetic surface (410), and

wherein the axle assembly (100) is adapted to pivot the at least one magnet (121) about a rotation axis (102) parallel to the axle (101), the at least one magnet (121) being pivotable in reaction to a shape change of the portion of the ferromagnetic surface (410) while the mobile robot (300) moves on the ferromagnetic surface (410).

2. Axle assembly according to claim 1,

wherein the axle assembly comprises at least one bracket for connecting the axle assembly to the mobile robot, the at least one bracket comprising at least one slot for guiding the at least one magnet in a pendular path.

3. Axle assembly according to any of the preceding claims,

wherein the at least one magnet is connected to a pivot on the axle assembly.

4. Axle assembly according to any of the preceding claims,

wherein the at least one magnet is concentrically pivotable with the at least one wheel.

5. Axle assembly according to any of the preceding claims,

wherein the at least one magnet is arranged on the axle assembly so that a wheel surrounds the at least one magnet when the at least one wheel is connected by the axle assembly to the mobile robot.

6. Axle assembly according to any of the preceding claims,

wherein the at least one magnet is freely pivotable so that the pull force passively pivots the at least one magnet towards the portion of the ferromagnetic surface.

7. Axle assembly according to any of the preceding claims,
wherein the at least one magnet is a permanent magnet or an electromagnet.

8. Axle assembly according to any of the preceding claims,
wherein the axle assembly comprises at least one bearing for revolving the at least one wheel.

9. Axle assembly according to any of the preceding claims,
wherein the axle assembly comprises an actuator for changing a distance between the at least one magnet and the ferromagnetic surface.

10. A mobile robot (300) comprising at least one axle assembly (100) as described in any of the preceding claims.

11. A method of performing an operation on a ferromagnetic surface (410),
the method comprising the steps of:
- providing a mobile robot (300) as described in claim 10;
- provisioning the mobile robot (300) with at least one tool for performing the operation;
- attaching the mobile robot (300) to the ferromagnetic surface (410);
- controlling the mobile robot (300) to move on the ferromagnetic surface (410) and traverse at least one non-flat feature (420).

12. Method according to claim 11,
wherein the ferromagnetic surface is part of any of:
- a hull of a floating vessel;
- an offshore structure;
- a storage tank;
- a tower of a wind turbine; or
- a pipe.

13. A method of adapting a mobile robot (300) so that the mobile robot (300) becomes attachable to a ferromagnetic surface (410),

the method comprising the steps of:

- providing the mobile robot (300);
- providing at least one axle assembly (100) as described in any of the claims 1 to 9;
- installing the at least one axle assembly (100) on the mobile robot (300).