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ROBOTIC VACUUM CLEANER

Abstract

A robotic vacuum cleaner includes a main body, a wheel, a drive motor, a gearbox, and a distance sensor. The distance sensor is for sensing a distance between the main body and a surface upon which the wheel is located. The robotic vacuum cleaner includes a suspension system coupling the wheel to the main body. The suspension system includes a first arm coupled to the gearbox at a first pivot point and coupled to the main body at a second pivot point. The suspension system also includes a second arm coupled to the gearbox at a third pivot point and coupled to the main body at a fourth pivot point. The first pivot point is spaced from the third pivot point by a first distance, and the second pivot point is spaced form the fourth pivot point by a second distance greater than the first distance.

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Background/Summary

FIELD OF THE INVENTION

[0001] The present invention relates to a robotic vacuum cleaner.

BACKGROUND OF THE INVENTION

[0002] Robotic vacuum cleaners may be used to autonomously vacuum a room, or series of rooms in a building. During use robotic vacuum cleaners may encounter obstacles which can be traversed to enable continued vacuuming to take place.

SUMMARY OF THE INVENTION

[0003] According to a first aspect of the present invention there is provided a robotic vacuum cleaner comprising a main body, a wheel for enabling movement of the main body, a drive motor for driving the wheel, a gearbox coupling the drive motor to the wheel, a distance sensor located on the main body, the distance sensor for sensing a distance between the main body and a surface positioned below the main body, and a suspension system coupling the wheel to the main body, wherein the suspension system comprises a first arm and a second arm, the first arm coupled to the gearbox at a first pivot point and coupled to the main body at a second pivot point, the second arm coupled to the gearbox at a third pivot point and coupled to the main body at a fourth pivot point, the first pivot point spaced from the third pivot point by a first distance, and the second pivot point spaced form the fourth pivot point by a second distance greater than the first distance.

[0004] Robotic vacuum cleaners may utilise distance sensors to sense a distance to a surface positioned below the robotic vacuum cleaner in use, and in particular may use such a distance sensor to determine when the robotic vacuum cleaner approaches and/or reaches an edge of one surface such that there is a step or drop to another surface. This may, for example, enable the robotic vacuum cleaner to determine when it encounters a step which is too large for the robotic vacuum cleaner to traverse, and hence enable the robotic vacuum cleaner to take appropriate action to avoid the step. Such action may include stopping the drive motor and/or putting the drive motor into reverse.

[0005] However, it has been found that inadvertent triggering of the distance sensor can be experienced by some robotic vacuum cleaners, for example those with a single arm suspension system, in use, where those robotic vacuum cleaners attempt to traverse obstacles that should be traversable. In particular, in such circumstances the robotic vacuum cleaner has been found to rear up relative to the obstacle, thereby increasing a distance between a front end of the robotic vacuum cleaner and the surface upon which the robotic vacuum cleaner is travelling and/or the obstacle that is being traversed. The rearing up of the robotic vacuum cleaner may be caused by a number of factors, including any of a back end of the robotic vacuum cleaner being supported on the surface upon which the robotic vacuum cleaner is travelling, and offset loading on the wheel as a result of contact with the obstacle causing greater frictional force at the pivots of the suspension system.

[0006] An increase in distance between the robotic vacuum cleaner and the surface upon which it is travelling in the manner described above may cause inadvertent triggering of the distance sensor, resulting in the robotic vacuum cleaner abandoning the attempt to traverse the obstacle. This may be undesirable, particularly where the obstacle is a relatively small step change boundary between rooms of a building, as it may result in reduced cleaning coverage for the robotic vacuum cleaner, and/or may result in increased human interaction with the robotic vacuum cleaner to obtain a

desired cleaning coverage.
[0007] It has been found that by providing a robotic vacuum cleaner comprising a suspension system according to the first aspect of the present invention, rearing up of the main body of the robotic vacuum cleaner may be inhibited, which may result in a reduced risk of inadvertent triggering of the distance sensor, and hence may provide increased room coverage in use.
[0008] In particular, as the first pivot point is spaced from the third pivot point by a first distance, and the second pivot point is spaced form the fourth pivot point by a second distance greater than the first distance, offset loading of the wheel may result in an increased moment applied at the first and third pivots, thereby making it easier for the first and second arms to move in response to the wheel contacting an obstacle, and hence enable movement of the suspension system without the robotic vacuum cleaner rearing up.
[0009] The first distance may be measured between respective pivot axes defined by the first and third pivot points, and the second distance may be measured between respective pivot axes defined by the second and fourth pivot points.
[0010] The first and second arms may be directly coupled to the gearbox and directly coupled to the main body at respective ones of the first through fourth pivot points, or may be indirectly coupled to the gearbox and indirectly coupled to the main body at respective ones of the first through fourth pivot points. For example, the first and second arms may be indirectly coupled to the main body via a suspension housing of the suspension system, with the suspension housing coupled to the main body.
[0011] The robotic vacuum cleaner may be movable in a first direction substantially orthogonal to a rotational axis of the wheel, and in a second, opposite, direction substantially orthogonal to the rotational axis of the wheel. The first and third pivot points may be located rearwardly of the second and fourth pivot points when the robotic vacuum cleaner moves in the first direction, and the second and fourth pivot points may be located rearwardly of the first and third pivot points when the robotic vacuum cleaner moves in the second direction.
[0012] It has been found that such a configuration of the suspension system may be influenced by a reaction torque in response to the drive motor. For example, where the wheel is driven by the drive motor in a clockwise direction, the first and second arms may experience torque in an anti-clockwise direction at the first to fourth pivot points, and vice versa. As the robotic vacuum cleaner is driven in a forward direction, for example in the first direction in which the second and fourth pivot points precede the first and third pivot points, the reaction torque may result in reduced downforce on the wheel relative to an arrangement where the first and second distances are equal. As the robotic vacuum cleaner is driven in a rearward direction, for example in the second direction in which the first and third pivot points precede the second and fourth pivot points, the reaction torque may result in increased downforce on the wheel relative to an arrangement where the first and second distances are equal. In such a manner the second distance may be chosen such that downforce is substantially equal for both movement in the first, forward, direction and the second, rearward, direction.
[0013] The second and fourth pivot points may precede the wheel when the robotic vacuum cleaner is driven in the first direction. The wheel may precede the second and fourth pivot points when the robotic vacuum cleaner is driven in the second direction
[0014] The robotic vacuum cleaner may comprise a cleanerhead assembly at a first, front, end of the main body, and a separation system located at a second, rear, end of the main body. The second end of the main body may be substantially opposite to the first end of the main body. The robotic vacuum cleaner may comprise a battery located at the second end of the main body. The cleanerhead assembly may comprise a rotatable brushbar and a brushbar motor for driving the rotatable brushbar. The first end of main body may be substantially flat, and the second end of the main body may be substantially curved, for example such that the main body is substantially D-shaped in plan view. Movement of the robotic vacuum cleaner in the forward direction may be

movement in a direction where the flat end of the main body precedes the curved end of the main body, and movement of the robotic vacuum cleaner in the rearward direction may be movement in a direction where the curved end of the main body precedes the flat end of the main body.

[0015] The distance sensor may be located at the first end of main body, for example adjacent to the cleanerhead assembly, and forward of the cleanerhead assembly in the first direction. The distance sensor may be configured to provide a control signal to a controller of the drive motor, for example to provide a control signal indicative that the drive motor should be stopped and/or put into a reverse direction in response to a distance measured by the distance sensor being over a threshold value. The threshold value may comprise a value of at least 90 mm, 100 mm, 110 mm, or 120 mm.

[0016] The suspension system may be configured to enable movement of the wheel relative to the main body, for example in a direction substantially orthogonal to a surface on which the robotic vacuum cleaner is placed in normal use.

[0017] The first and third pivot points may be offset from one another in a direction orthogonal to a rotational axis of the wheel and orthogonal to a surface on which the robotic vacuum cleaner is travelling in use. The second and fourth pivot points may be offset from one another in a direction orthogonal to a rotational axis of the wheel and orthogonal to a surface on which the robotic vacuum cleaner is travelling in use.

[0018] The second arm may overlie first arm, for example such that the second arm is located above the first arm when the wheel is located on a surface upon which the robotic vacuum cleaner travels in use.

[0019] A ratio of the second distance to the first distance may be in the region of 1.1 to 3.0, for example around 1.5. A ratio of the second distance to the first distance may be in the region of 1.3 to 2.0. A ratio of the second distance to the first distance may be in the region of 1.4 to 1.6, for example in the region of 1.4 to 1.5. Too large a ratio may result in a risk of the robotic vacuum cleaner tipping with the suspension effectively being too loose, whilst too small a ratio may still result in the robotic vacuum cleaner rearing up when attempting to traverse an obstacle in use. A ratio in the region of 1.1 to 3.0, and more particularly around 1.5, may provide a good compromise between these competing factors.

[0020] The first distance may be in the region of 10.0 mm to 16.0 mm, for example around 14.3 mm. The second distance may be in the region of 17.0 mm to 30 mm, for example around 21.3 mm. Such first and second distances may provide the aforementioned benefit of inhibiting rearing up of the robotic vacuum cleaner, whilst maintaining a relatively compact overall size of the suspension system. This may enable the main body of the robotic vacuum cleaner to be relatively compact with a relatively low height clearance, which may enable the robotic vacuum cleaner to fit under pieces of furniture, thereby providing greater cleaning coverage relative to a robotic vacuum cleaner having a main body of relatively increased height.

[0021] The wheel may comprise a diameter in the region of 75 mm to 125 mm, for example around 86 mm. Such a wheel diameter may enable the main body of the robotic vacuum cleaner to be relatively compact with a relatively low height clearance, which may enable the robotic vacuum cleaner to fit under pieces of furniture, thereby providing greater cleaning coverage relative to a robotic vacuum cleaner having a main body of relatively increased height.

[0022] The second distance may be no more than 10% of the wheel diameter, no more than 20% of the wheel diameter, or no more than 40% of the wheel diameter. The first distance may be no more than 5% of the wheel diameter, no more than 15% of the wheel diameter, or no more than 25% of the wheel diameter.

[0023] The first arm may comprise a first end at which the first pivot point is located, and a second end opposite to the first end, wherein the second end is coupled to a spring at a coupling point, and the second pivot point is located intermediate the first and second ends. The first arm may comprise a non-linear shape such that an angle is defined between the coupling point and the second pivot point, for example between the coupling point and an axis passing through the second pivot point and parallel to a bottom surface of the main body, and the angle may be in the region of 90° to 120°, for example around 96°. Such an angle may assist with providing a relatively constant downforce when the robotic vacuum cleaner travels in both the first, front, and second, rearward, directions.

[0024] The spring may comprise a spring constant in the region of 0.75 N/m to 1.25 N/m, for example of around 0.96 N/m. Such a spring force may assist with providing a relatively constant downforce when the robotic vacuum cleaner travels in both the first, front, and second, rearward, directions.

[0025] The wheel may comprise a hub, and the drive motor may be located within the hub. This may provide a relatively compact arrangement, which may reduce a size of the main body compared to, for example, a robotic vacuum cleaner where the drive motor is located external of the hub of the wheel. The hub may comprise a hollow interior within which the drive motor is located. The drive motor may be misaligned with an axis of rotation of the wheel, for example with a rotational axis of the drive motor misaligned with the axis of rotation of the wheel. The gearbox may be located within the hub.

[0026] The wheel may be located at a first side of the main body, and the robotic vacuum cleaner may comprise a further wheel located at a second side of the main body opposite to the first side of the main body, a further drive motor for driving the further wheel, a further gearbox coupling the further drive motor to the further wheel, and a further suspension system coupling the further wheel to the main body, wherein the further suspension system comprises a third arm and a fourth arm, the third arm coupled to the further gearbox at a fifth pivot point and coupled to the main body at a sixth pivot point, the fourth arm coupled to the further gearbox at a seventh pivot point and coupled to the main body at an eighth pivot point, the fifth pivot point spaced from the seventh pivot point by a third distance, and the sixth pivot point spaced from the eighth pivot point by a fourth distance greater than the third distance.

[0027] By providing first and second wheels at opposite sides of the main body, with the first and second wheels operable. for example individually operable, by two separate drive motors, greater control of motion of the robotic vacuum cleaner may be provided compared to, for example, a robotic vacuum cleaner where two wheels are operable by a single drive motor. By providing the further wheel with a suspension system where the sixth pivot point is spaced from the eighth pivot point by a fourth distance greater than the third distance, rearing up of the robotic vacuum cleaner may be inhibited, thereby inhibiting inadvertent triggering of the distance sensor as previously described.

[0028] The further suspension system may comprise substantially the same structure as the suspension system, for example with the first and third distances being substantially the same and the second and fourth distances being substantially the same.

[0029] The robotic vacuum cleaner may comprise a navigation system for determining a route of travel of the robotic vacuum cleaner, and a controller for controlling the drive motor in response to a signal from the navigation system.

[0030] According to a second aspect of the present invention there is provided a robotic vacuum cleaner comprising a main body, a wheel for enabling movement of the main body, a drive motor for driving the wheel, a gearbox coupling the drive motor to the wheel, and a suspension system coupling the wheel to the main body, wherein the suspension system comprises a first arm and a second arm, the first arm coupled to the gearbox at a first pivot point and coupled to the main body at a second pivot point, the second arm coupled to the gearbox at a third pivot point and coupled to the main body at a fourth pivot point, the first pivot point spaced from the third pivot point by a first distance, the second pivot point spaced form the fourth pivot point by a second distance greater than the first distance, and a ratio of the second distance to the first distance is in the region of 1.1 to 3.0.

[0031] It has been found that by providing a robotic vacuum cleaner comprising a suspension system according to the second aspect of the present invention, rearing up of the main body of the robotic vacuum cleaner may be inhibited.
[0032] Furthermore, it has been found that such a configuration of the suspension system may be influenced by a reaction torque in response to the drive motor. For example, where the wheel is driven by the drive motor in a clockwise direction, the first and second arms may experience torque in an anti-clockwise direction at the first to fourth pivot points, and vice versa. As the robotic vacuum cleaner is driven in a forward direction, for example in the first direction in which the second and fourth pivot points precede the first and third pivot points, the reaction torque may result in reduced downforce on the wheel relative to an arrangement where the first and second distances are equal. As the robotic vacuum cleaner is driven in a rearward direction, for example in the second direction in which the first and third pivot points precede the second and fourth pivot points, the reaction torque may result in increased downforce on the wheel relative to an arrangement where the first and second distances are equal. In such a manner the second distance, and hence the ratio of the second distance to the first distance, may be chosen such that downforce is substantially equal for both movement in the first, forward, direction and the second, rearward, direction.
[0033] The robotic vacuum cleaner may comprise a distance sensor for sensing a distance between the main body and a surface positioned below the main body.
[0034] Optional features of aspects of the present invention may be equally applied to other aspects of the invention, where appropriate.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0035] FIG. **1** is a perspective view of a robotic vacuum cleaner;
[0036] FIG. **2** is a schematic underside view of the robotic vacuum cleaner of FIG. **1**;
[0037] FIG. **3** is a perspective view of a wheel assembly of the robotic vacuum cleaner of FIG. **1**;
[0038] FIG. **4** is a first schematic view of a first suspension system of the robotic vacuum cleaner of FIG. **1**;
[0039] FIG. **5** is a second schematic view of the first suspension system of the robotic vacuum cleaner of FIG. **1**;
[0040] FIG. **6** is a schematic view of the first suspension system of FIGS. **4** and **5** when traversing an object;
[0041] FIG. **7** is a first schematic view of a second suspension system of the robotic vacuum cleaner of FIG. **1**;
[0042] FIG. **8** is a second schematic view of the second suspension system of the robotic vacuum cleaner of FIG. **1**;
[0043] FIG. **9** is a plot of difference between downforce in forward and rearward directions versus wheel extension for a variety of suspension configurations; and
[0044] FIG. **10** is a plot of downforce versus moment for a variety of suspension configurations.
DETAILED DESCRIPTION OF THE INVENTION
[0045] A robotic vacuum cleaner **10** is illustrated in FIGS. **1** and **2**. The robotic vacuum cleaner **10** comprises a main body **12**, a cleanerhead assembly **14**, a separation system **16**, a vacuum motor **18**, a battery **20**, a navigation system **22**, a controller **24**, a distance sensor **26**, first **28** and second **30** wheels, first **32** and second **34** drive motors, first **36** and second **38** gearboxes, and first **40** and second **42** suspension systems.
[0046] The main body **12** is generally D-shaped in plan view having a flat front end **44** and a curved rear end **46**. A forward direction of motion of the robotic vacuum cleaner **10** is taken to be

motion where the flat front end **44** precedes the curved rear end **46**, with a rearward direction of motion of the robotic vacuum cleaner **10** taken to be motion where the curved rear end **46** precedes the flat front end **44**. The main body **12** is generally hollow and defines a housing for other of the aforementioned components of the robotic vacuum cleaner. It will be appreciated that other shapes of main body **12** are also envisaged.

[0047] The cleanerhead assembly **14** is located at the flat front end **44** of the main body **12**, and comprises a brushbar **48** and a drive assembly (not shown) for driving the brushbar. The brushbar **48** is exposed through a suction slot in the main body **12**, such that the brushbar **48** can engage with a surface on which the robotic vacuum cleaner **10** travels in use. The separation system **16** is located at the curved rear end **46** of the main body **12**, and comprises a cyclonic separation system, although it will be appreciated that other forms of separation system are envisaged. The vacuum motor **18** comprises a motor driven impeller, and the vacuum motor **18** causes air to be drawn into the cleanerhead assembly **14** via the suction slot, and carried to the separation system **16** via ducting in the main body **12**. Dirt entrained in the air is then separated by the separation system **16**, and the cleansed air is exhausted from the robotic vacuum cleaner **10**.

[0048] The battery **20** provides electrical power to the various electrical components of the vacuum cleaner, such as the vacuum motor **18**, the navigation system **20**, the controller **24**, the distance sensor **26**, and the first **32** and second **34** drive motors. The battery **20** comprises a number of individual batteries and by also be referred to as a so-called battery pack.

[0049] The navigation system **22** comprises an appropriate machine vision system for guiding the robotic vacuum cleaner around a room, or number of rooms, to be cleaned, and typically comprises a number of sensors for sensing a surrounding environment and locating the robotic vacuum cleaner **10** within the surrounding environment. The navigation system **22** determines a suitable cleaning path for the robotic vacuum cleaner, and provides signals utilised by the controller **24** to control the first **32** and second **34** drive motors to manoeuvre the robotic vacuum cleaner **10**. The controller **24** comprises any appropriate controller, and although shown in FIG. **2** as a single controller for simplicity, it will be appreciated that in practice the robotic vacuum cleaner **10** may comprise a number of controllers, each with a dedicated function. In FIG. **2**, the controller **24** also controls the vacuum motor **18**. The controller **24** receives data from the distance sensor **26**, which is used by the controller to control the first **32** and second **34** drive motors.

[0050] The distance sensor **26** is located at the flat front end **44** of the main body **12**, slightly forward of the cleanerhead assembly **14**, and in particular slightly forward of the brushbar **48**, on an underside of the main body **12**. The distance sensor **26** comprises a time-of-flight sensor used to determine a distance between the robotic vacuum cleaner **10**, and in particular an underside of the main body **12** of the robotic vacuum cleaner **10**, and a surface located below the robotic vacuum cleaner **10**. Although illustrated as only a single distance sensor **26**, in practice there may be a number of distance sensors spaced across the width of the front end **44** of the main body **12**. In embodiments, a first distance sensor may be located at the first end of main body, adjacent to the cleanerhead assembly, and forward and to the right hand side of the cleanerhead assembly in the first direction and a second distance sensor may be located at the first end of main body, adjacent to the cleanerhead assembly, and forward and to the left hand side of the cleanerhead assembly in the first direction.

[0051] The first wheel **28** is located at a first, left, side **52** of the main body **12**, and the second wheel **30** is located at a second, right, side **54** of the main body **12**. As illustrated in FIG. **3**, each of the first **28** and second **32** wheels comprises a hub **56** and a tire **58** disposed about a periphery of the hub **56**. The hubs **56** are substantially hollow in form, and each houses the drive motor **32**,**34** and gearbox **36**,**38** for the respective wheels **28**,**30**. Each wheel has a diameter in the region of 75 mm to 125 mm, generally around 86 mm, which may enable the robotic vacuum cleaner **10** to have a relatively low profile. The first **28** and second **30** wheels contact a surface upon which the robotic vacuum cleaner **10** is located in use, and are used to move the robotic vacuum cleaner **10** along that surface.

[0052] The first **32** and second **34** drive motors receive electrical power from the battery **20**, receive control signals from the controller **24**, and are used to drive the respective first **28** and second **30** wheels via the respective first **36** and second **38** gearboxes. Each drive motor **32**,**34** is separately controllable such that the first **28** and second **30** wheels can be independently driven. The first **32** and second **34** drive motors are offset from the rotational axes of the respective first **28** and second **30** wheels.

[0053] In use, the distance sensor **26** is used to detect steps or drops, and to ensure that appropriate action is taken to inhibit the robotic vacuum cleaner **10** from attempting to traverse a step or drop which could result in the robotic vacuum cleaner **10** tipping onto its side or back, and hence being unable to continue a cleaning route without user assistance. Such action includes any of stopping the first **32** and second **34** drive motors, or putting the first **32** and second **34** drive motors into reverse.

[0054] It has been found that when attempting to traverse certain obstacles, for example attempting to traverse an obstacle of a sufficiently low height such that a robotic vacuum cleaner should normally be able to traverse the obstacle, some robotic vacuum cleaners may inadvertently rear up, such that a front end of the robotic vacuum cleaner is lifted relative to the obstacle and/or the surface upon which the robotic vacuum cleaner is travelling. The rearing up of the robotic vacuum cleaner may be caused by a number of factors, including any of a back end of the robotic vacuum cleaner being supported on the surface upon which the robotic vacuum cleaner is travelling, and offset loading on the wheel as a result of contact with the obstacle causing greater frictional force at the pivots of the suspension system. This may particularly be the case for robotic vacuum cleaners having single arm suspension systems.

[0055] An increase in distance between the robotic vacuum cleaner and the surface upon which it is travelling in the manner described above may cause inadvertent triggering of the distance sensor, resulting in the robotic vacuum cleaner abandoning the attempt to traverse the obstacle. This may be undesirable, particularly where the obstacle is a relatively small step change boundary between rooms of a building, as it may result in reduced cleaning coverage for the robotic vacuum cleaner, and/or may result in increased human interaction with the robotic vacuum cleaner to obtain a desired cleaning coverage. The triggering of the distance sensor occurs when a distance measured between the distance sensor and the surface upon which it is travelling is over a threshold value. The threshold value is typically between 90 mm and 120 mm.

[0056] The first **40** and second **42** suspension systems of the robotic vacuum cleaner **10** aim to inhibit such inadvertent triggering of the distance sensor **26**.

[0057] The first suspension system **40** is shown schematically in FIGS. **4** to **6**, and comprises a first arm **60**, a second arm **62**, and a spring **64**. The spring **64** has a spring constant in the region of 0.75 N/m to 1.25 N/m, and more particularly around 0.96 N/m. It will be appreciated that in practice the first arm **60** and the second arm **62** may comprise multiple component parts, for example multiple component parts rigidly connected to one another.

[0058] The first arm **60** has a first end **66**, a second end **68** and is non-linear between the first **66** and second **68** ends. The first arm **60** is coupled to the first gearbox **36** at a first pivot point **70** toward the first end **66** of the first arm **60**, and is coupled to the spring **64** at a coupling point **72** toward the second end **86** of the first arm **60**. An opposite end of the spring **64** is coupled to the main body **12**. The first arm **60** is coupled to the main body **12** at a second pivot point **74** located intermediate the first pivot point **70** and the coupling point **72**. The first arm **60** is shaped such that an angle α is defined between the second pivot point **74** and the coupling point **72**. The angle α is in the region of 90° to 120°, and more particularly around 96°.

[0059] The second arm **62** generally overlies the first arm **60**, and has a first end **76** and a second end **78**. The second arm **62** is coupled to the first gearbox **36** at a third pivot point **80** toward the first end **76** of the second arm **62**, and is coupled to the main body **12** at a fourth pivot point **82** toward the second end **78** of the second arm **62**. Although illustrated in FIGS. **4** to **6** as linear, it will be appreciated that this is schematic only, and that the second arm **66** may be non-linear in practice, for example as illustrated in FIG. **3**.

[0060] The first **60** and second **62** arms enable the first wheel **28** to be raised and lowered relative to the main body **12**.

[0061] As seen in FIGS. **4** to **6**, the third pivot point **80** is located rearwardly of the first pivot point **70**, and the fourth pivot point **82** is located rearwardly of the second pivot point **72**. The first pivot point **72** is spaced from the third pivot point **80** by a first distance A, with the first distance A measured between respective pivot axes of the first **72** and third **80** pivot points. The first distance A is in the region of 10.0 mm to 16.0 mm, and more particularly around 14.3 mm. The second pivot point **74** is spaced from the fourth pivot point **82** by a second distance B, with the second distance B measured between respective pivot axes of the second **74** and fourth **82** pivot points. The second distance B is in the region of 17.0 mm to 30.0 mm, and more particularly around 21.3 mm.

[0062] The second distance B is greater than the first distance A, such that a spacing between the second **74** and fourth **82** pivot points, ie the rearward pivot points, is greater than a spacing between the first **72** and third **80** pivot points, ie the frontward pivot points. Here a ratio of the second distance B to the first distance A is in the region of 1.1 to 3.0, and more particularly around 1.5. In some examples a ratio of 1.43 is utilised. Furthermore, the second distance B is no more than 40% of the diameter of the first wheel **28**.

[0063] Such a configuration of the first suspension system **40** may inhibit rearing up of the main body **12** of the robotic vacuum cleaner, which may result in a reduced risk of inadvertent triggering of the distance sensor **26**, and hence may provide increased room coverage in use. In particular, the second distance B is greater than the first distance A, offset loading of the first wheel **28** when contacting an obstacle may result in an increased moment applied at the first **72** and third **80** pivot points, thereby making it easier for the first **60** and second **62** arms to move in response to the first wheel **28** contacting an obstacle, and hence enable movement of the first suspension system **40** without the robotic vacuum cleaner **10** rearing up.

[0064] Furthermore, the first suspension system **40** may be influenced by a reaction torque in response to the first drive motor **32**. For example, where the first wheel **28** is driven by the first drive motor **32** in an anti-clockwise direction as viewed in FIG. **4**, which may be considered a forward direction, the first **60** and second **62** arms may experience torque in a clockwise direction at the pivot points **72**,**72**,**80**,**82**, and vice versa. As the robotic vacuum cleaner **10** is driven in a forward direction, the reaction torque may result in reduced downforce on the wheel relative to an arrangement where the first A and second B distances are equal, as the first **60** and second **62** arms are biased upwards, with this reaction torque indicated by arrow RT**1** in FIGS. **4** and **6**. As the robotic vacuum cleaner **10** is driven in a rearward direction, the reaction torque may result in increased downforce on the wheel relative to an arrangement where the first and second distances are equal, as the first **60** and second **62** arms are biased downwards, with this reaction torque indicated by arrow RT**2** in FIG. **4**. In such a manner the second distance B may be chosen such that downforce is substantially equal for both movement in the first, forward, direction and the second, rearward, direction.

[0065] Appropriate selection of the spring constant of the spring **64** and the angle α may also aid in providing a relatively equal downforce in both the forward and rearward direction, with the values for the spring constant and the angle α previously discussed having been found to be beneficial in the first suspension system **40**.

[0066] The second suspension system **42** has substantially the same form as the first suspension system **40**, as can be seen in FIGS. **7** and **8**, with the second suspension system **42** comprising third **84** and fourth **86** arms, and a second spring **88**. The third arm **84** has a first end **90**, a second end **92** and is non-linear between the first **90** and second **92** ends. The third arm **84** is coupled to the second gearbox **38** at a fifth pivot point **94** toward the first end **90** of the third arm **84**, and is coupled to the second spring **88** at a second coupling point **96** toward the second end **92** of the third arm **84**. An opposite end of the second spring **88** is coupled to the main body **12**. The third arm **84** is coupled to the main body **12** at a sixth pivot point **98** located intermediate the fifth pivot point **94** and the second coupling point **96**. The third arm **84** is shaped such that an angle β is defined between the sixth pivot point **98** and the second coupling point **96**. The angle β is in the region of 90° to 120°, and more particularly around 96°.

[0067] The fourth arm **86** generally overlies the third arm **84**, and has a first end **100** and a second end **102**. The fourth arm **86** is coupled to the second gearbox **38** at a seventh pivot point **104** toward the first end **100** of the fourth arm **86**, and is coupled to the main body **12** at an eighth pivot point **106** toward the second end **102** of the fourth arm **86**. Although illustrated in FIGS. **7** and **8** as linear, it will be appreciated that this is schematic only, and that the fourth arm **86** may be non-linear in practice, for example similar to that shown in FIG. **3**.

[0068] The third **84** and fourth **86** arms enable the second wheel **30** to be raised and lowered relative to the main body **12**.

[0069] As seen in FIGS. **7** and **8**, the seventh pivot point **104** is located rearwardly of the fifth pivot point **94**, and the eighth pivot point **106** is located rearwardly of the sixth pivot point **98**. The fifth pivot point **94** is spaced from the seventh pivot point **104** by a third distance C, with the third distance C measured between respective pivot axes of the fifth **94** and seventh **104** pivot points. The third distance C is in the region of 10.0 mm to 16.0 mm, and more particularly around 14.3 mm. The sixth pivot point **98** is spaced from the eighth pivot point **106** by a fourth distance D, with the fourth distance D measured between respective pivot axes of the sixth **98** and eighth **106** pivot points. The fourth distance D is in the region of 17.0 mm to 30.0 mm, and more particularly around 21.3 mm.

[0070] The fourth distance D is greater than the third distance C, such that a spacing between the sixth **98** and eighth **106** pivot points, ie the rearward pivot points, is greater than a spacing between the fifth **94** and seventh **104** pivot points, ie the frontward pivot points. Here a ratio of the fourth distance to the third distance is in the region of 1.1 to 3.0, and more particularly around 1.5. In some examples a ratio of 1.43 is utilised.

[0071] The first A and third C distances are substantially equal, and the second B and fourth D distances are substantially equal, thereby providing similar suspension characteristics between the left side **52** and the right side **54** of the main body **12** of the robotic vacuum cleaner **10**.

[0072] In such a manner, the second suspension system **42** may provide similar benefits to the first suspension system **40**, with rearing up of the robotic vacuum cleaner **10** as it traverses an obstacle inhibited, and inadvertent triggering of the distance sensor **26** also inhibited.

[0073] FIG. **9** is a plot which illustrates the difference in downforce between forward and rearward drive directions versus wheel extension for a variety of suspension system configurations. As can be seen, a ratio of the second distance B to the first distance A, and hence also a ratio of the fourth distance D to the third distance C, in the region of 1.5 gives a relatively consistent downforce between forward and rearward drive directions, particularly at a wheel extension of around 17 mm to 20 mm.

[0074] FIG. **10** is a plot which illustrates downforce versus moment for a variety of suspension system configurations. As can be seen, a ratio of the second distance B to the first distance A, and hence also a ratio of the fourth distance D to the third distance C, in the region of 1.5 gives a downforce and moment below that required for the robotic vacuum cleaner **10** to rear-up, ie wheelie, in use.

Claims

1. A robotic vacuum cleaner comprising: a main body; a wheel for enabling movement of the main body; a drive motor for driving the wheel, a gearbox coupling the drive motor to the wheel; a distance sensor located on the main body, the distance sensor for sensing a distance between the main body and a surface upon which the wheel is located; and a suspension system coupling the wheel to the main body; wherein the suspension system comprises a first arm and a second arm, the first arm coupled to the gearbox at a first pivot point and coupled to the main body at a second pivot point, the second arm coupled to the gearbox at a third pivot point and coupled to the main body at a fourth pivot point, the first pivot point spaced from the third pivot point by a first distance, and the second pivot point spaced form the fourth pivot point by a second distance greater than the first distance.

2. The robotic vacuum cleaner as claimed in claim 1, wherein the robotic vacuum cleaner is movable in a first direction substantially orthogonal to a rotational axis of the wheel, and in a second, opposite, direction substantially orthogonal to the rotational axis of the wheel, the first and third pivot points are located rearwardly of the second and fourth pivot points when the robotic vacuum cleaner moves in the first direction, and the second and fourth pivot points are located rearwardly of the first and third pivot points when the robotic vacuum cleaner moves in the second direction.

3. The robotic vacuum cleaner as claimed in claim 1, wherein a ratio of the second distance to the first distance is in the range of 1.1 to 3.0.

4. The robotic vacuum cleaner as claimed in claim 3, wherein a ratio of the second distance to the first distance is approximately 1.5.

5. The robotic vacuum cleaner as claimed in claim 1, wherein the first distance is in the range of 10.0 mm to 16.0 mm.

6. The robotic vacuum cleaner as claimed in claim 5, wherein the first distance is approximately 14.3 mm.

7. The robotic vacuum cleaner as claimed in claim 1, wherein the second distance is in the range of 17.0 mm to 30.0 mm.

8. The robotic vacuum cleaner as claimed in claim **8**, wherein the second distance is approximately 21.3 mm.

9. The robotic vacuum cleaner as claimed in claim 1, wherein the first arm comprises a first end at which the first pivot point is located, and a second end opposite to the first end, wherein the second end is coupled to a spring at a coupling point, and the second pivot point is located intermediate the first and second ends.

10. The robotic vacuum cleaner as claimed in claim 9, wherein the first arm comprises a non-linear shape such that an angle is defined between the coupling point and the second pivot point, and the angle is in the range of 90° to 120°.

11. The robotic vacuum cleaner as claimed in claim 10, wherein the angle is approximately 96°.

12. The robotic vacuum cleaner as claimed in claim 9, wherein the spring comprises a spring constant in the range of 0.75 N/m to 1.25 N/m.

13. The robotic vacuum cleaner as claimed in claim 12, wherein the spring comprises a spring constant of approximately 0.96 N/m.

14. The robotic vacuum cleaner as claimed in claim 1, wherein the wheel comprises a hub, and the drive motor is located within the hub.

15. The robotic vacuum cleaner as claimed in claim 14, wherein the drive motor is misaligned with an axis of rotation of the wheel.

16. The robotic vacuum cleaner as claimed in claim 14, wherein the gearbox is located within the hub.

17. The robotic vacuum cleaner as claimed in claim 1, wherein the wheel is located at a first side of the main body, and the robotic vacuum cleaner comprises: a further wheel located at a second side of the main body opposite to the first side of the main body; a further drive motor for driving the further wheel; a further gearbox coupling the further drive motor to the further wheel; and a further suspension system coupling the further wheel to the main body; wherein the further suspension system comprises a third arm and a fourth arm, the third arm coupled to the further gearbox at a fifth pivot point and coupled to the main body at a sixth pivot point, the fourth arm coupled to the further gearbox at a seventh pivot point and coupled to the main body at an eighth pivot point, the fifth pivot point spaced from the seventh pivot point by a third distance, and the sixth pivot point spaced from the eighth pivot point by a fourth distance greater than the third distance.

18. A robotic vacuum cleaner comprising a main body, a wheel for enabling movement of the main body, a drive motor for driving the wheel, a gearbox coupling the drive motor to the wheel, and a suspension system coupling the wheel to the main body, wherein the suspension system comprises a first arm and a second arm, the first arm coupled to the gearbox at a first pivot point and coupled to the main body at a second pivot point, the second arm coupled to the gearbox at a third pivot point and coupled to the main body at a fourth pivot point, the first pivot point spaced from the third pivot point by a first distance, the second pivot point spaced form the fourth pivot point by a second distance greater than the first distance, and a ratio of the second distance to the first distance is in the range of 1.1 to 3.0.