

METHODS AND DEVICES FOR CLEANING VERTICAL GLASS PANELS

PRIORITY CLAIM

[0001] This application claims priority from Singapore Patent Application No. 10201809639P filed on 30 October 2018.

TECHNICAL FIELD

[0002] The present invention generally relates to robot systems, and more particularly relates to robotic systems, methods and devices for cleaning vertical glass panels.

BACKGROUND OF THE DISCLOSURE

[0003] In modern construction, the use of glass panels for facades instead of concrete walls is gaining popularity due to its elegant appeal. Unfortunately, the disadvantage of such facades is the need for frequent cleaning to maintain decent appearance over time. Buildings' architectures have evolved rapidly, but the process of cleaning vertical glass facades has remained over the years a classical manual task which involves labor intensive processes. In addition, the traditional cleaning methods for glass facades is a dangerous task for window cleaners, especially when window cleaning is required in high rise buildings.

[0004] Labor shortages, risk and productivity issues are driving a recent trend to develop and deploy robotic systems for cleaning glass facades. Robotics offer a viable solution to improving productivity and safety in cleaning vertical or near vertical glass facades. Over the past few decades, numerous efforts have been put forward to develop different types of facade cleaning robots. Various adhesion and locomotion mechanisms for facade cleaning robots have been presented including

adhesion techniques such as vacuum suckers, grasping grippers, impellers and negative pressure to hold the robot against vertical surfaces and locomotion mechanisms such as sliding frames, chain tracks, wheeled, and multiple legged mechanisms. These adhesion and locomotion techniques however lack an ability to navigate over surfaces having obstacles or frames and cladding between glass façade sections. In addition, single purpose glass cleaning robots are not able to easily address different façade sizes or variable structures and materials of facades or purposes of façade inspection or maintenance in addition to façade cleaning.

[0005] Thus, there is a need for a robotic vertical façade cleaning, maintenance and inspection system having variable suction control and modular construction for improved cleaning surface and robust ability to navigate surfaces having variable structures and materials. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

SUMMARY

[0006] According to at least one aspect of the present embodiments, a robotic device for traversing vertical or near vertical surfaces is provided. The robotic device includes three or more modular structures, each of the three or more modular structures including means for adhering a pad structure of the modular structure to the vertical or near vertical surfaces. Each of the modular structures also includes means for translational motion of the modular structure across the vertical or near vertical surfaces and means for maneuvering the modular structure over obstacles. The means for maneuvering the modular structure over obstacles includes means for detecting the

obstacles and means for raising the pad structure in relation to the modular structure so that, in response to detecting the obstacles, the means for raising the pad structure raises the pad structure while the means for translational motion moves the raised pad structure over the obstacle.

[0007] According to another aspect of the present embodiments, a robotic device for traversing vertical or near vertical surfaces is provided. The robotic device includes three or more modular structures, each of the three or more modular structures including means for adhering a pad structure of the modular structure to the vertical or near vertical surfaces. Each of the modular structures also includes means for translational motion of the modular structure across the vertical or near vertical surfaces and means for maneuvering the modular structure over obstacles. The means for adhering the pad structure to the vertical or near vertical surfaces includes a flexible suction cup mounted on the pad structure and variable vacuum means for creating a variable vacuum between the flexible suction cup and the vertical or near vertical surfaces.

[0008] And according to a further aspect of the present embodiments, a method for navigating a robotic device over obstacles on vertical or near vertical surfaces is provided. The robotic device includes three or more modular structures, each of the three or more modular structures including means for adhering a pad structure of the modular structure to the vertical or near vertical surfaces and means for translational motion of the modular structure across the vertical or near vertical surfaces. The method includes detecting the obstacles and raising the pad structure in relation to the modular structure so that, in response to detecting the obstacles, the pad structure is raised while the means for translational motion moves the raised pad structure over the obstacle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments and to explain various principles and advantages in accordance with present embodiments.

[0010] FIG. 1, comprising FIGs. 1A and 1B, depicts illustrations of a modular structure of a robotic device in accordance with present embodiments, wherein FIG. 1A depicts a front planar view of the modular structure and FIG. 1B depicts a front top perspective view of the modular structure.

[0011] FIG. 2 depicts a front top perspective view of the three-pad modular structure in accordance with the present embodiments.

[0012] FIG. 3 depicts a flow diagram of the process of the modular structure of FIG. 2 as it navigates over positive and/or negative obstacles in accordance with the present embodiments.

[0013] FIG. 4, comprising FIGs. 4A, 4B and 4C, depicts illustrations of the modular structure of FIG. 2 demonstrating its ability to navigate over positive and/or negative obstacles in accordance with the present embodiments, wherein FIG. 4A depicts a front top perspective view of the three pad modular structure with the left module raised, FIG. 4B depicts a front planar view of the three module structure with the middle module raised, and FIG. 4C depicts an enlarged front planar view of the raised middle module of the three module structure.

[0014] FIG. 5, comprising FIGs. 5A and 5B, depicts planar views of the three-pad modular structure in accordance with the present embodiments, wherein FIG. 5A is a

bottom planar view of the three-pad modular structure and FIG. 4B is a top planar view of the three-pad modular structure depicting independent rotation of each pad of the three-pad modular structure.

[0015] FIG. 6 depicts a front left top perspective view of the three-pad modular structure in accordance with the present embodiments depicting independent rotation of one pad of the three-pad modular structure.

[0016] FIG. 7 depicts an enlarged front top right perspective view of one pad of the three-pad modular structure in accordance with present embodiments showing the mechanics of positional maintenance and rotational motion.

[0017] FIG. 8 depicts an enlarged front top right perspective view of one pad of the three-pad modular structure in accordance with present embodiments showing additional details of the pad.

[0018] And FIG. 9 depicts a top front perspective view of the lifting mechanism of a pad of the three-pad modular structure in accordance with present embodiments.

[0019] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale.

DETAILED DESCRIPTION

[0020] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description. It is the intent of present embodiments to present a modular robotic device for building façade or cladding maintenance, inspection and cleaning. The robotic device can be used for facade cleaning, inspection and surveillance applications in both indoor and outdoor

settings that require a robot to navigate over positive and/or negative obstacles. For example, the robotic device has particular application for cleaning vertical or near vertical glass panels utilizing its robust climbing ability and improved ability to transition between glass panels with variable active suction, where near vertical glass panels are at an angle of between 65 degrees and 115 degrees to the ground.

[0021] The robotic device in accordance with present embodiments from prior art devices in its ability to navigate over positive and/or negative obstacles, its ability to cross between facade panels and its modular mechanism. These advantages of the present embodiments are accomplished by a sensory system that allows the robotic device to know its orientation and position with regards to the frame and differentiate between a metal frame and glass.

[0022] In addition, a robotic device in accordance with the present embodiments includes "n" number of modular structures or modules interconnected by four longitudinal bars which maintain the position of the modules relative to one another. Each modular structure is equipped with a novel suction system based on plastic cups that keeps the robotic device adhered to a vertical surface using a vacuum blower. A lead screw mechanism advantageously allows the distance between the module and the adhesion surface to be modified in order to navigate over obstacles. Translational mobility of the robotic device is achieved using a caterpillar wheel mechanism and the rotational mobility is achieved using servo motors mounted on each module. The lead screw mechanism, the caterpillar wheel mechanism and the servo motors are exemplary functional elements and those skilled in the art will understand that similar elements can be substituted to perform the functions of these functional element in accordance with the present embodiments described herein.

[0023] Referring to FIG. 1A, a front planar view 100 of a modular structure or module 102 of a robotic device in accordance with present embodiments is depicted. The robotic device includes "n" number of pads 104 interconnected to form the robotic device. An exemplary modular structure 102 includes three pads 104 and the pads 104 are identical so that they are interchangeable and inter-connectable through fast connections 106 in order for the robotic device to be controlled as a single robotic body. The pads 104 are joined together with longitudinal bars 108. The longitudinal bars 108 are made of carbon fiber or any similarly rigid material. Each pad 104 maintains its position using connectors 110 such as steel oppressors or similar rigid connectors which form a base 112 of a pad lifting mechanism 114, the pad lifting mechanism 114 including a lead screw mechanism 116 for lifting the pad 104.

[0024] Referring to FIG. 1B, a front top perspective view 150 of the module 102 of the robotic device in accordance with present embodiments is depicted. Each of the pads 104 can be raised or lowered by its corresponding lead screw mechanism 116 which is driven by a stepper motor 118. The pad lifting mechanism 114 is mounted on a structure of three equidistant bars 120 that maintain the pad lifting mechanism 114 in an unvarying posture during and after lift and during descent. An interconnecting frame structure 122 includes the longitudinal bars 108 connecting to each base 112 of the pad lifting mechanisms 114. Each of the three equidistant bars 120 slides through slip cylinders 124 formed in the bases 112 of the pad lifting mechanisms 114. The bars 120 are attached to rubbing rings 126 (for example by screwing thereto). The pads 104 are rotary structures containing suction and locomotion systems for adhesion and translation. The pads 104 are able to rotate under control of the rotating rubbing rings 126 mounted on the structure of the three bars 120.

[0025] Referring to FIG. 2, a front top perspective view 200 depicts the module 102 when all of the pads 104 are on a flat surface. For climbing vertical surfaces, the modular robotic device consists of "n" number of the pads 104 interconnected by longitudinal bars of carbon fiber similar to the bars 108 connecting the pads 104 to each other in the module 102. Each module 102 is interconnected to other modules using a VGA serial terminal port for fast data connections and a male/female DC 24V power supply connector (not shown).

[0026] To maintain adherence to a vertical surface, an active suction system is used. A 24V centrifugal commercial blower with the capacity of 8kPa is attached to each pad 104 to generate adhesion to the vertical surface. A plastic cup of Thermoplastic Polyurethane (TPU) material is attached to each blower and generates the friction and, consequently, the adhesion to the surface using the vacuum produced by the blower. Locomotion of the device is achieved by an interchangeable system consisting of caterpillar wheels controlled by a DC motor and standard fixed wheels controlled by servo motors.

[0027] In order to transit from one glass panel to the next or to lift over obstacles, each module is lifted one at a time during the transition as the wheels move the robotic device. This process of navigating over obstacles or transitioning to a new glass panel is described in a flowchart 300 of FIG. 3. The process starts 302 when an obstacle is detected 304. In accordance with the present embodiments, the obstacle could advantageously be a positive or negative obstacle which the robotic device must traverse or an uneven transition from one vertical panel to a next vertical panel.

[0028] When the obstacle is detected 304, the robotic device moves to the obstacle 306 and then orientates 308 one or more leading modules until a pad of the one or more leading modules intersects (perpendicularly or, at least, non-parallelly) the

obstacle by, for example, touching the obstacle. Once orientated 308 relative to the obstacle, servo motors are activated to raise 310 the pad of the one or more leading modules. The servo motor is activated until the pad is fully raised 312. Referring to FIG. 4A, a front top perspective view 400 of one of the three-pad modular structures 102 shows a pad 104 at the left position 402 fully raised by a servo motor 404 attached to the lead screw mechanism 116.

[0029] Referring back to the flowchart 300 of FIG. 3, once the pad is fully raised 312, the module 102 is moved forward 314 so that the pad 104 in the raised position 402 passes over the obstacle and the next pad 104 intersects or touches the obstacle. In accordance with the present embodiments, each three-pad modular structure 102 is advantageously designed and constructed to maintain a firm position of the pads 104 during and after the lift, even as two of the three pads 104 adhere to the vertical surface while the pad 104 in the position 402 is raised above the vertical surface as seen in FIG. 4A.

[0030] When the next pad 104 has moved forward 314 to intersect the obstacle, the raised pad 104 is lowered 316 and the next intersecting pad 104 is raised 318 until it is fully raised 320. Referring to FIG. 4B, a front planar view 430 of the three-pad modular structure 102 shows that the pad 104 at the left position 402 has been lowered and that the pad 104 at a middle position 432 has been raised.

[0031] FIG. 4C depicts an enlarged front planar view 460 of the pad 104 at the middle position 432. Each of the pads 104 can be lifted from the vertical surface up to a predetermined elevation. The elevation is developed using a linear actuator that uses the stepper motor 404 to move the pad along the lead screw mechanism 116. Limit switches are used to stop the linear motors when a maximum limit or when the predetermined elevation has been reached. In accordance with one aspect of the

present embodiments, the predetermined elevation is approximately 100mm. Those skilled in the art will realize that the predetermined elevation is determined by the construction of the three-pad modular structure 102 and needs to be defined such that the structure 102 continues to maintain a firm position of the unraised pads 104 against the vertical surface during and after the lifting of the raised pad(s) 104.

[0032] Referring back to the flowchart 300 of FIG. 3, after the pad 104 at the second position 432 is fully raised 320, processing determines whether all of the pads 104 have transitioned 322 over the obstacle. If all of the pads 104 have not transitioned 322 over the obstacle, the process of moving forward 314, lowering 316 the raised pad 104, and raising 318 the next pad 104 is repeated. When all of the pads 104 of all of the one or more three-pad modular structures 102 have transitioned 322 over the obstacle, the last pad 104 is lowered 324 and the process of navigating over obstacles or transitioning to a new glass panel ends 326.

[0033] While each of the one or more modules have been depicted as three-pad modular structures 102, those skilled in the art will realize that three or more pads 104 can be included in each of the one or more modules so long as the number of pads is sufficient to maintain a firm position of the unraised pads 104 against the vertical surface during and after the lifting of the raised pad(s) 104.

[0034] Referring to FIG. 5A a bottom planar view 500 depicts the three-pad modular structure 102. In order to adhere to vertical surfaces, suction is generated by a commercial blower 502 mounted on a cup 504 screwed to each pad 104. When a vacuum is generated inside an internal space between the cup 504 and the vertical surface, friction is created which keeps each of the one or more three-pad modular structures 102 of the robotic device adhered in a vertical position to the vertical surface. The locomotion of the three-pad modular structures 102 is accomplished by

a modular assembly 506 which may include one or both of caterpillar bands controlled by DC motors and wheels 508 controlled by servo motors 510. This locomotion assembly 506 allows for translational motion (such as moving forward in step 314 of the flowchart 300 (FIG. 3)) as well as rotational motion.

[0035] FIG. 5B depicts a top planar view 550 of the three-pad modular structure 102 where the pads 104a and 104c have been rotated in relation to the pad 104b. FIG. 6 depicts a front left top perspective view 600 of the three-pad modular structure 102 depicting independent rotation of the pad 104c of the three-pad modular structure 102 in accordance with the present embodiments.

[0036] Referring to FIG. 7, the mechanics of positional maintenance and rotational movement is depicted in an enlarged front top right perspective view 700. The rotation and position are maintained by a helicoidally bearing 702 system of concentric bearings vertically aligned and equidistant. A commercial T-shaped holder 704 is attached to the pad 104 to hold the bearing 702. The bearings 702 are assembled in a structure of three equidistant bars 706 screwed to the pad 104.

[0037] While navigating the vertical surface (e.g., window glass), the robotic device needs to know its distance from window frames and other obstacles. Distance sensors 708 are placed on all four sides of each pad 104. Information from these sensors 708 can be used to map the area of the glass facade or other vertical surface and to know the orientation of the robotic device (which can be derived from distance to the frames because most of facades tend to be square or rectangular).

[0038] Referring to FIG. 8, an enlarged front top right perspective view 800 of the three-pad modular structure 102 in accordance with present embodiments depicts additional details of the pad 104c. As discussed above, suction is generated by the commercial blower 502 mounted on the cup 504 screwed to each pad 104 (FIG. 5A).

A speed controller 802 (such as a Roboclaw speed controller card manufactured by Basicmicro Company of California USA) is used to control the blower 502. In addition, a motor controller 804 (such as the Roboclaw speed controller card) is used to control the DC motor for the caterpillar bands and/or the wheels. On the edge of each pad 104, a group of limit switches 806 are placed so that the robotic device does not continue advancing after contacting an obstacle such as the frame of a window. Thus, the obstacle detection step 302 (FIG. 3) is triggered by signals from one of the limit switches 806. Additional distance sensors 808 are placed in the lower part of each pad 104 to estimate the distance from the pad 104 to the vertical surface at different points of the pad 104 in order to maintain the pad surface of the pad substantially parallel to the vertical surface.

[0039] Referring to FIG. 9, a top front perspective view 900 of an elevation system including a lifting mechanism 902 of a pad 104 of the three-pad modular structure 102 in accordance with present embodiments is depicted. The lifting mechanism 902 is secured to the upper section 904 of the pad 104 using three 's' shaped pieces 906, screwed to the equidistant bars 116 and an upper base 908. In the upper part of the module 904, there is a pair of distance sensors 910 used to capture the distance of movement of the pad 104 during lifting (e.g., raising steps 310, 318 (FIG. 3)). An inertial measurement unit 912 is used to determine axial acceleration and orientation of the pad 104.

[0040] Thus, it can be seen that the present embodiments provide methods, devices, and systems for cleaning, maintenance and inspection of vertical surfaces such as glass facades of buildings. The robotic devices and systems in accordance with the present embodiments provide variable suction control and modular construction for

improved adhesion to vertical surfaces and a robust ability to navigate across surfaces having variable structures, materials and positive or negative obstacles.

[0041] While exemplary embodiments have been presented in the foregoing detailed description of the present embodiments, it should be appreciated that a vast number of variations exist. It should further be appreciated that the exemplary embodiments are only examples, and are not intended to limit the scope, applicability, operation, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing exemplary embodiments of the invention, it being understood that various changes may be made in the function and arrangement of steps and method of operation described in the exemplary embodiments without departing from the scope of the invention as set forth in the appended claims.

CLAIMS

What is claimed is:

1. A robotic device for traversing vertical or near vertical surfaces comprising:
three or more modular structures; and
an interconnecting frame structure comprising two or more longitudinal bars connected to each of the three or more modular structures, each of the three or more modular structures comprising:
means for adhering a pad structure of the modular structure to the vertical or near vertical surfaces;
means for translational motion of the modular structure across the vertical or near vertical surfaces; and
means for maneuvering the modular structure over obstacles, wherein the means for maneuvering the modular structure over obstacles comprises:
means for detecting the obstacles; and
means for raising the pad structure of the modular structure in relation to the interconnecting frame structure to a raised position so that, in response to detecting one of the obstacles, the means for raising the pad structure raises the pad structure of the modular structure to the raised position and maintains the pad structure in the raised position while the means for translational motion of other modular structures moves the interconnecting frame structure until the raised pad structure is moved over the detected obstacle,
wherein the interconnecting frame structure is maintained at a constant distance from and parallel to the vertical or near vertical surface and, when a pad structure of a modular structure is in its raised position, the interconnecting frame structure

maintains the pad surface of the pad structure substantially parallel to the vertical or near vertical surface.

2. The robotic device in accordance with Claim 1 wherein the means for raising the pad structure comprises an elevation system coupled to the interconnecting frame structure, the modular structure and the pad structure for raising the pad structure in relation to the interconnecting frame structure.

3. The robotic device in accordance with Claim 2 wherein the elevation system comprises:

a lead screw mechanism; and

a motor coupled between the lead screw mechanism and the pad structure.

4. The robotic device in accordance with Claim 3 wherein the elevation system further comprises sensing means for detecting movement of the pad structure during raising and lowering of the pad structure by the elevation system.

5. The robotic device in accordance with any of the preceding claims wherein the means for adhering the pad structure to the vertical or near vertical surfaces comprises:

a flexible suction cup mounted on the pad structure; and

variable vacuum means for creating a variable vacuum between the flexible suction cup and the vertical or near vertical surfaces.

6. The robotic device in accordance with Claim 5 wherein the flexible suction cup comprises a flexible thermoplastic polyurethane material.

7. The robotic device in accordance with Claim 5 or Claim 6 wherein the variable vacuum means creates a variable vacuum for variable suction control based on an orientation of the robotic device.

8. The robotic device in accordance with any of the preceding claims wherein the means for translational motion across the vertical or near vertical surfaces comprises one or both of caterpillar bands or wheels operating under the control of motors.

9. The robotic device in accordance with Claim 8 wherein the motors comprise one or more of DC motors or servo motors, and wherein the caterpillar bands are controlled by DC motors and the wheels are controlled by servo motors.

10. A robotic device for traversing vertical or near vertical surfaces comprising: three or more modular structures; and

an interconnecting frame structure comprising two or more longitudinal bars connected to each of the three or more modular structures, each of the three or more modular structures comprising:

means for adhering a pad structure of the modular structure to the vertical or near vertical surfaces;

means for translational motion of the modular structure across the vertical or near vertical surfaces; and

means for maneuvering the modular structure over obstacles, wherein the means for adhering the pad structure to the vertical or near vertical surfaces comprises:

a flexible suction cup mounted on the pad structure; and

variable vacuum means for creating a variable vacuum between the flexible suction cup and the vertical or near vertical surfaces, and

wherein the interconnecting frame structure is maintained at a constant distance from and parallel to the vertical or near vertical surface by the two or more longitudinal bars connected to each of the three or more modular structures.

11. The robotic device in accordance with Claim 10 wherein the variable vacuum means creates a variable vacuum for variable suction control based on an orientation of the robotic device.

12. The robotic device in accordance with Claim 10 or Claim 11 wherein the flexible suction cup comprises a flexible thermoplastic polyurethane material.

13. The robotic device in accordance with any of Claims 10 to 12 wherein the means for maneuvering the modular structure over obstacles comprises:

means for detecting the obstacles; and

an elevation system coupled to the interconnecting frame structure, the modular structure and the pad structure for raising the pad structure in relation to the interconnecting structure and the modular structure so that, in response to detecting one of the obstacles, the elevation system raises the pad structure of the modular structure while the means for translational motion of other modular structures moves the interconnecting frame structure until the raised pad structure is moved over the

detected obstacle.

14. The robotic device in accordance with Claim 13 wherein the elevation system further comprises sensing means for detecting movement of the pad structure during raising and lowering of the pad structure by the elevation system.

15. The robotic device in accordance with Claim 13 or Claim 14 wherein the elevation system comprises:

a lead screw mechanism; and

a motor coupled between the lead screw mechanism and the pad structure.

16. A method for navigating a robotic device over obstacles on vertical or near vertical surfaces, the robotic device comprising three or more modular structures and an interconnecting frame structure comprising two or more longitudinal bars connected to each of the three or more modular structures, each of the three or more modular structures comprising means for adhering a pad structure of the modular structure to the vertical or near vertical surfaces and means for translational motion of the modular structure across the vertical or near vertical surfaces, wherein the method comprises:

detecting the obstacles; and

raising a pad structure of one of the modular structures in relation to the interconnecting frame structure to a raised position so that, in response to detecting one of the obstacles, the pad structure of the one of the modular structures is raised to the raised position while the means for translational motion of other modular structures moves the

interconnecting frame structure until the raised pad structure is moved over the detected obstacle to an opposite side of the detected obstacle.

17. The method in accordance with Claim 16 further comprising lowering the raised pad to the vertical or near vertical surfaces at the opposite side of the detected obstacle.

18. The method in accordance with Claim 17 wherein the steps of raising and lowering the pad comprise activating a motor to move the pad along a lead screw mechanism.