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Apparatus and method for performing a process on a structure

Abstract

An apparatus and method for performing a process on a structure is disclosed. The apparatus includes a main body suspended in a vertical direction from an elevated portion of the structure using rope. The apparatus also includes first and second articulated legs attached to the main body from a hip joint and articulates the legs using hip actuators which are coupled to the hip joints. Each of the legs include a foot end to facilitate establishing contact between the apparatus and the surface of the structure to support the main body on the structure's surface. The apparatus further includes a processing end effector to perform a process on the structure's surface. The apparatus goes through a sequence of actions to move along various surfaces of the structure and perform a process on the surface using the end effector. The sequence of actions may be performed autonomously using a control unit.

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Background/Summary

TECHNICAL FIELD

(1) The present disclosure relates generally to performing a process on structures and more particularly relates to apparatus and methods for performing processes on the exterior of tall structures.

BACKGROUND

(2) Many robotic systems have been suggested to automate performing a process on structures such

as the façade of commercial or residential buildings, bridges, stadiums, oil and gas structures, and warehouses. The processes for which automation has been proposed are numerous and include structure washing or cleaning, structure painting, and structure inspection. Automating such tasks and processes is particularly more reasonable for large structures as the manual processing is very laborious and often pose serious dangers and safety risks to the human operators.

(3) Thus, robotic systems have provided interesting and viable solutions especially by providing repeatable and systematic processing routines. Different robotic solutions have been developed to date to perform a process on structures such as elevators that descend or ascend using a crane on top of buildings and are equipped with industrial robots on the elevator, cable robots or spider robots which are driven along the structure using cables, crawling robots which attach to the surface of the structure and sweep the structure to perform a process on its surface.

(4) While these robotic systems provide solutions for performing automated processes on the structures, many of them are not suitable for all type of terrains on the structure. For example, no existing solutions have been found that can automatically pass obstacles on the structures such as balconies or other type of obstacles and usually are helped with human operators to avoid the obstacles and go around them.

SUMMARY

(5) In accordance with one disclosed aspect, there is provided an apparatus for performing a process on a structure. The apparatus comprises: a main body suspended in generally a vertical direction from an elevated portion of the structure using at least one rope, wherein the rope is coupled to the main body from a hanging point and the length of the rope between the main body and the elevated portion of the structure is configured to retract or extend to cause movement for the apparatus in generally the vertical direction; a first and second articulated legs, each of the first and second articulated legs having a hip end and a foot end, and the first and second articulated legs being coupled to the main body from their respective hip end, and wherein the first articulated leg is operably configured to make contact with a first portion of the structure from its respective foot end to provide support for the main body, and the second articulated leg is operably configured to make contact with a second portion of the structure from its respective foot end to provide support for the main body; a hip actuator operably coupled to the hip end of each of the first and second articulated legs, the hip actuator configured to cause rotational movement between the main body and the respective first and second articulated legs; and at least one processing end effector operably disposed on the apparatus and configured to perform the process on the structure. The processing end effector may be operably disposed on the main body or the articulated leg.

(6) The apparatus is further configured for a sequence of operations comprising: adjusting the elevation of the apparatus by retracting or extending the at least one rope and causing the apparatus to ascend or descend in generally a vertical direction; actuating the hip actuator of the first articulated leg and establishing contact between the foot end of the first articulated leg and the first portion of the structure; while the foot end of the first articulated leg is in contact with the first portion of the structure, establishing contact between the foot end of the second articulated leg and the second portion of the structure by actuating the hip actuator of the second articulated leg; and while the foot ends of the first and second articulated legs are in contact with the first and second portions of the structure respectively, performing the process on the structure using the processing end effector.

(7) The apparatus may further comprise a step after establishing contact between the foot end of the first articulated leg and the first portion of the structure, and before establishing contact between the foot end of the second articulated leg and the second portion of the structure, the step comprising while the foot end of the first articulated leg is in contact with the first portion of the structure, moving the main body relative to the first portion of the structure by actuating the hip actuator of the first articulated leg or by changing the elevation of the main body using the rope or by a combination thereof.

(8) The apparatus may be configured to ascend or descend in generally a vertical direction using the at least one rope and perform the process on generally vertically spaced apart locations of the structure using the processing end effector.
(9) Any or both of the first or second articulated legs may further include a structure-adhering end effector disposed on their respective foot end and configured to cause temporary attachment of the respective foot end to the structure. The structure-adhering end effector may include one or more active or passive suction cups to cause temporary attachment of the foot end to the structure. The foot end may further include the processing end effector in addition to the structure-adhering end effector.
(10) Any or both of the articulated legs may be coupled to the main body using a sliding joint, the sliding joint configured to cause linear movement between the main body and the respective first and second articulated legs.
(11) Any or both of the first or second articulated legs may be configured to push against the structure using their respective foot end and cause the main body to move with respect to the structure. Any of the articulated legs may further comprise a leg link extending from the respective hip end to the respective foot end of the leg, and the leg link may be coupled to the respective foot end using an ankle joint. The length of the leg link may be adjustable, and the leg link may comprise more than one link which are coupled to one another using one or more knee joints. The ankle joint of each leg may allow relative passive or actuated movement of the foot end with respect to the leg link in one or more of yaw, pitch, and roll directions.
(12) The apparatus may further comprise a rope actuator disposed on the main body and operably configured to retract or extend the rope and cause change in the elevation of the apparatus in generally a vertical direction.
(13) The apparatus may further comprise at least one articulated arm disposed on the main body from a first end of the arm, and the arm having a second end wherein the processing end effector is disposed on the second end of the arm. The articulated arm may be configured to push against the structure and cause locomotion of the apparatus with respect to the structure.
(14) The processing end effector may be various processing heads such as a window cleaning end effector comprising at least one brush head, or a material dispensing head configured to dispense or spray a material on the structure.
(15) The apparatus may further include a rope connector disposed on the main body and configured to move the hanging point with respect to the main body.
(16) Additionally, the apparatus may further include a controller unit such as microprocessor, operably configured to control the movement of the apparatus.
(17) In accordance with another disclosed aspect, there is provided a method to perform a process on a structure using an apparatus, the apparatus comprising: a main body suspended in generally a vertical direction from an elevated portion of the structure using a rope, wherein the rope is coupled to the main body from a hanging point and the length of the rope between the main body and the elevated portion of the structure is configured to retract or extend to change the elevation of the apparatus; a first and second articulated legs, each of the first and second articulated legs having a hip end and a foot end, the first and second articulated legs are disposed on the main body from their respective hip end, and wherein the first articulated leg is operably configured to make a contact with a first portion of the structure from its respective foot end to provide support for the main body, and the second articulated leg is operably configured to make contact with a second portion of the structure from its respective foot end to provide support for the main body; a hip actuator operably coupled to the hip end of each of the first and second articulated legs, the hip actuator configured to cause rotational movement between the main body and the respective first and second articulated legs; and at least one processing end effector operably disposed on the apparatus and configured to perform the process on the structure; wherein the method comprises: adjusting the elevation of the apparatus by retracting or extending the rope and causing the

apparatus to ascend or descend in generally a vertical direction; actuating the hip actuator of the first articulated leg and establishing contact between the foot end of the first articulated leg and the first portion of the structure; while the foot end of the first articulated leg is in contact with the first portion of the structure, establishing contact between the foot end of the second articulated leg and the second portion of the structure by actuating the hip actuator of the second articulated leg; and while the foot ends of the first and second articulated legs are in contact with the first and second portions of the structure respectively, performing the process on the structure using the processing end effector.

(18) The method may further comprise a step after establishing contact between the foot end of the first articulated leg and the first portion of the structure and before establishing contact between the foot end of the second articulated leg and the second portion of the structure, the step comprising: while the foot end of the first articulated leg is in contact with the first portion of the structure, moving the main body relative to the first portion of the structure by actuating the hip actuator of the first articulated leg or by changing the elevation of the main body using the rope or by a combination thereof.

(19) The apparatus may further comprise a rope connector disposed on the main body and configured to move the hanging point with respect to the main body, and the method may further comprise moving the rope connector. The apparatus may further include a controller unit and the method may further include controlling the rope connector movement using commands generated by the controller unit.

(20) The method may further comprise: loading a map of the structure to the controller unit; segmenting, by the controller unit, the map into vertical reachable zones wherein the vertical reachable zones are spaced apart in generally a horizontal direction; selecting, by the controller unit, a first vertical reachable zone; suspending the apparatus from a first elevated portion of the structure corresponding to the first vertical reachable zone; causing ascension or descension of the apparatus using the rope to move the apparatus to a similar elevation of a first target area within the first vertical reachable zone; causing the first and second articulated legs to make contact to a first and second location within the first target area using their respective foot ends, the first and second locations being distant from one another; and performing the process on the first target area using the processing end effector.

(21) The method may further comprise segmenting, by the controller unit, the first vertical reachable zone into multiple target areas and causing the apparatus to move to a second target area upon completing the process on the first target area to perform the process on the second target area. Moving to the second target area may comprises: while the foot end of the second articulated leg is in contact with the first target area, removing the foot end of the first articulated leg from the first target area, moving the foot end of the first articulated leg to the second target area, and establishing contact between the foot end of the first articulated leg and a location within the second target area; and while the foot end of the first articulated leg is in contact within the second target area, moving the main body toward the second target area by actuating the hip actuator of the first articulate leg, or by actuating the hip actuator of the second articulated leg, or by changing the elevation of the main body using the rope, or by a combination thereof.

(22) Alternatively, moving to the second target area may comprise: removing contact between the foot end of either or both of the first and second articulated legs and the first target area; causing ascension or descension of the apparatus to move the apparatus to similar elevation of the second target area; and moving the foot end of the first articulated leg, or the foot end of the second articulated leg, or the foot end of both the first and second articulated legs to the second target area and establishing contact between the foot end and a location within the second target area.

(23) The method may further comprise causing the apparatus to move to a second vertical reachable zone by suspending the apparatus from a second elevated portion of the structure corresponding to the second vertical reachable zone.

(24) The method may further include suspending the apparatus from an anchor device disposed on the first elevated portion of the structure and moving the apparatus from a first vertical reachable zone to a second vertical reachable zone by causing the anchor device to move from the first elevated portion of the structure to the second elevated portion of the structure.
(25) In accordance with yet another aspect, a system for performing a process on a structure is also disclosed. The system comprising an apparatus comprising: a main body suspended in generally a vertical direction from an anchor point using at least one rope, wherein the rope is coupled to the main body from a hanging point and the length of the rope between the main body and the anchor point is configured to retract or extend to adjust the apparatus's elevation in generally the vertical direction; at least one articulated leg having a hip end and a foot end, the articulated leg coupled to the main body from the hip end, the articulated leg operably configured to make a contact with a portion of the structure from the foot end and provide support for the main body; a hip actuator operably configured to cause rotational movement between the main body and the articulated leg; and at least one processing end effector operably disposed on the apparatus and configured to perform the process on the structure. The system further comprising a control unit operably connected to the apparatus and configured to generate control commands for the hip actuator and the apparatus's elevation, in response to receiving an input indicating moving the apparatus to a target location on the structure; and wherein, the control unit generates the control commands by monitoring at least one constraint parameter and avoiding passing a given threshold of the at least one constraint parameter. The at least one constraint parameter may be the force exerted from the foot end to the portion of the structure or the tension in the rope or both.
(26) Other aspects and features will become apparent to those ordinarily skilled in the art upon review of the following description of specific disclosed embodiments in conjunction with the accompanying figures.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) In the following, embodiments of the present disclosure will be described with reference to the appended drawings. However, various embodiments of the present disclosure are not limited to the arrangements shown in the drawings.
(2) FIG. **1** is a perspective view of an apparatus for performing a process on a structure according to a first disclosed embodiment;
(3) FIGS. **2**A to **2**G are a series of views depicting the apparatus of FIG. **1**;
(4) FIGS. **3**A to **3**C are a series of views showing another embodiment of the apparatus of FIG. **1**;
(5) FIG. **3**D is a top view showing another embodiment of the apparatus of FIGS. **3**A to **3**C;
(6) FIG. **3**E is a top view showing another embodiment of the apparatus of FIGS. **3**A to **3**C;
(7) FIGS. **4**A to **4**C are a series of views showing another embodiment of the apparatus of FIG. **1**;
(8) FIG. **5**A is a flowchart showing exemplary blocks of instruction for directing the apparatus of FIG. **1** to perform a process;
(9) FIG. **5**B shows a perspective view of the apparatus of FIG. **1** performing the process of FIG. **5**A;
(10) FIG. **5**C is a flowchart showing exemplary blocks of instructions for directing the apparatus of FIG. **5**B performing a maneuver process;
(11) FIGS. **5**D to **5**G are a series of perspective views showing the apparatus of FIG. **1** performing the maneuver process of FIG. **5**C;
(12) FIG. **6** shows a perspective view of the ankle mechanism of the apparatus of FIG. **3** according to an embodiment;
(13) FIGS. **7**A and **7**B show the ankle of the apparatus of the FIG. **3** according to another

embodiment;
(14) FIGS. **8**A to **8**D are a series of views showing another embodiment of an apparatus for performing a process on a structure;
(15) FIG. **9** is a side view showing another embodiment of an apparatus for performing a process on a structure;
(16) FIG. **10** is a flowchart showing exemplary block of instructions for a control strategy of the apparatus of FIG. **1**.
DETAILED DESCRIPTION
(17) Referring to FIG. **1**, a perspective view of an apparatus, for performing a process on a structure **180** is generally shown at **100** according to a first disclosed embodiment. The apparatus's main body **102** is suspended from an upper portion of the structure **180** using a weight-bearing rope or cable **104**, and temporarily makes contact with the surface of the structure **180** using two articulated legs **110** at a pair of structure-adhering feet **130**. The structure **180** may be a tall building and the apparatus may be configured to wash the façade or windows of the building, for example.
(18) The rope **104** may be made from high strength metallic threads or fiber ropes or any other flexible material suitable for bearing large tensile forces. The rope **104** is coupled to an anchor device **101**, such as a crane, on the upper portion of the structure **180**, the anchor device **101** may be configured to cause ascension or descension of the apparatus **100** along the height of the structure **180**. The anchor device **101** may be disposed on the structure **180** or may be disposed on a different structure such as a separate crane or an aerial vehicle.
(19) The anchor device **101** may include an actuator, such as a winch, to unwind or rewind the rope **104** and control the ascension and descension of the apparatus **100**. Alternatively, the main body **102** may include an actuator to control the ascension and descension of the apparatus **100** while the rope **104** is fixedly attached to the anchor device **101**. In some embodiments, the anchor device **101** may also move in horizontal direction along the structure **180** and cause the apparatus **100** to move in the horizontal direction or assist the apparatus **100** in such movements. In these embodiments, the anchor device **101** may be a remote-controlled car that moves along the edge of an upper portion of the structure **180** on a rail, for example.
(20) The apparatus **100** further comprises a pair of articulated legs **110** extended out of the main body **102**. Each leg **110** is coupled to the main body **102** through a hip joint **118** and is configured to make contact with the structure **180** at a foot end **130**. The articulated legs **110** are configured to support the weight and other forces, such as wind disturbance, exerted on the apparatus **100** by leaning against the surface of the structure **180** at the foot ends **130**, while the apparatus **100** is suspending from the rope **104**. While the foot ends **130** are in contact with the structure **180**, the articulated legs **110** may be additionally configured to cause locomotion or steering of the apparatus **100** along the structure **180** by articulating the leg with respect to the main body **102** at the hip joint **118**. In other words, the apparatus **100** may be configured to walk on the structure **180**, similar to a legged robot, while suspended from the rope **104**. In some embodiments the apparatus **100** may rappel along the structure **180** by pushing the foot ends **130** against the structure **180**.
(21) In the embodiment shown in FIG. **1**, the foot ends **130** are equipped with structure-adhering means such as one or more suction cups (as shown by **335** in FIG. **7**A, for example) to cause temporary attachment of the articulated leg **110** to the surface of the structure **180**. The suction cups may be active and cause suction by being connected to a vacuum pump to actively provide suction, for example. In some embodiments, the suction cups may be passive and cause suction by creating a seal on the edges of the foot end and the structure and thereby, causing vacuum in the entrapped volume between the foot end and the structure. In other embodiments, the structure adhering-foot **130** may be other than suction cups and may be made from other adhering materials or materials that generate bonding forces such as magnetic materials or gecko-like textured materials that resist shear force but do not resist normal force. In some embodiments, the foot end **130** of one or more articulated legs **110** may not be equipped with structure-adhering means and may just facilitate

contact between the foot end **130** and the structure **180**. In such cases, the articulated leg **110** may establish a non-adhering contact, such as a frictional contact, with the structure **180** and the foot end **130** while the foot end **130** is able to provide support for the apparatus **100**, for example by partially bearing the weight of apparatus **100**.

(22) The apparatus **100** can generally move up and down in vertical direction by unwinding and rewinding the rope **104**, and can generally move horizontally using the articulated legs **110**. The legs **110** can also move the apparatus away from the structure **180** by pushing the foot end **130** against the structure **180** and throwing the apparatus **100** and the foot end **130** away from the structure **180**, for example. Alternatively, the articulated legs **110** can also move the apparatus away from the structure **180** by articulating at least one articulated leg **110**, which is attached to the structure **180** using the structure-adhering foot ends **130**, with respect to the main body **102** at the hip joint **118** and thus moving the main body **102** away from the structure. Hence, the apparatus **100** can locomote along the structure **180** even if the structure has bumps, obstacles, steep slopes, or curvatures.

(23) In some embodiments, the apparatus **100** may be suspended from upper portions of the structure **180**, using more than one rope **104** to provide more support for the apparatus **100**. Additional ropes **104** may be coupled to one or more of the articulated legs **110**.

(24) Referring to FIGS. **2**A to **2**D a series of views depict the apparatus **100** of FIG. **1** for performing a process on a structure **180**. Referring to FIG. **2**A, a perspective view of the apparatus **100** is shown. In the embodiment shown, the apparatus **100** comprises a main body **102** suspended from an elevated portion of the structure **180** via the rope **104**.

(25) In the embodiment shown in FIG. **2**A to **2**C, each leg **110** includes two leg links **112** connected to each other through a knee joint **114**. In other embodiments each leg **110** may include only 1 leg link (as shown in FIG. **4**A), or may include more than 2 leg links. Also, in other embodiments, the number of the leg links **112** may differ from one leg **110** to another, for example, one leg **110** may include 2 links **112** while the other leg may include only one leg link. The leg links **112** may be constructed out of any type of structural material such as steel, aluminum, or carbon-fiber with any cross-sectional profile such as hollow square, rectangular, or round tubular profiles. The leg links **112** may also be constructed from structural trusses such as steel, aluminum, or carbon fiber trusses, for example. The articulated leg **110** may include joint actuators (not shown in the Figure) operably coupled to one or more of the hip joints **118**, knee joint **114**, and ankle joint **116** to actively control the articulation of the leg **110**.

(26) The apparatus **100** further comprises a processing arm **140** extending out of the main body **102** and configured to operably perform a process on the structure **180**. The processing arm **140** is coupled to the main body **102** at a shoulder joint **148** from one end and in the other end is equipped with a processing head **150**. In the embodiment shown in FIGS. **2**A to **2**C, the processing arm **140** includes two arm links **142** connected to one another through an elbow joint **144**, however, in other embodiments, the processing arm **140** may include any number of arm links **142** other than two. The elbow joint **144** may be actuated and actively move the arm links **142** with respect to each other, or alternatively, may passively facilitate movement of the arm links **142** with respect to one another. The processing arm **140** is actuated with respect to the main body **102** using one or more shoulder actuator (as shown in FIGS. **4**A to **4**C) to actively control the position of the processing head **150** with respect to the main body **102**. In some embodiments, the apparatus **100** may include more than one processing arms similar to the processing arm **140**, for example, wherein each processing arm may be configured to perform a similar process or different processes by using different processing heads **150**.

(27) In some embodiments, the apparatus **100** may not include a processing arm **140**, and a processing head **150** may be directly attached to the main body **102** or the articulated legs **110**. For example, the main body **102**, may be equipped with an inspecting sensor such as Lidar, sonar, thermal or vision sensor to perform inspection processes on the structure **180**. In yet another

example, the main body **102**, may be equipped with a fire extinguisher, to put out a fire on the structure **180**, for example.
(28) The processing head **150** is coupled to the arm **150** at a wrist joint **146** configured to allow one or more degrees of freedom for the processing head **150** with respect to the arm **140**. The wrist joint **146** may be active (actuated) or passive (not actuated). In other embodiments, the wrist joint **146** may not allow movement of the processing head **150** with respect to the arm **140**. In the embodiment shown in FIGS. **2**A to **2**C, the processing head **150** includes a rotating brush configured to clean the structure **180** surface, however, in other embodiments the processing head **150** may perform another process or function, such as painting, spraying, laminating, sanding, scrubbing, visual inspection, on the structure **180**. In some embodiments the processing head **150** may additionally include one or more nozzles (not shown in Figures) that spray or eject fluids. The cleaning head **150** is particularly advantageous to clean windows of a building.
(29) In some embodiments, the processing head **150** may be connected to external supplies. For example, the processing head **150** may be connected to one or more washing liquid tanks, remote from the apparatus **100**, via a tether line or flexible piping or tubing.
(30) In some embodiments, the processing head **150** may additionally perform a process on the structure-adhering feet **130** as well, for example, the processing head **150** may clean dirty or dusty foot ends **130** such that the foot ends **130** do not contaminate the already cleaned zones or do not affect the cleaning process of the apparatus **100**. In such embodiments, the dirty foot end **130** may be detached from a surface and be rotated toward the processing head **150** while another foot end is in contact with the surface of the structure **180**.
(31) In some embodiments, the processing arm **140** may be used to cause locomotion of the apparatus **100**. In such embodiments, the processing head **150** may lean against the structure **180** and the processing arm **140** may push against the structure **180** from the processing head **150** and thereby, push the main body **102** or the whole apparatus **100** away from structure **180**, for example.
(32) Referring to FIG. **2**B, a top view of the apparatus **100** is shown. In this embodiment, one leg **110** is attached to the structure **180** using the structure-adhering foot end **130**, while the other leg **110** is suspended in the air from the foot end. In the embodiment shown in FIG. **2**B, the weight of the main body **102** is suspended from the rope **104** and is supported at the foot end **130** of one of the legs **110**.
(33) Referring to FIG. **2**C, a side view of the apparatus **100** is shown. The apparatus **100** may further include an embedded control unit **106** (as shown at **406** in FIG. **4**C) inside the main body **102** configured to control the operation of the apparatus **100**. The apparatus **100**, further includes a power supply unit (not shown in figures) such as Lithium-ion or fuel cell batteries configured to provide electric power for the operation of the electronic components of the apparatus **100**. The power supply unit may also be configured to generate power from renewable sources, such as solar panels, or non-renewable source such as an internal combustion engine that works with gas. Alternatively, the electric power may be supplied to the apparatus **100** using an external power unit through wired or wireless power transmission.
(34) Referring to FIG. **2**D, a block diagram depicting the embedded controller **106** of the apparatus **100** is shown. The controller **106** includes a microprocessor **200**, a memory **202**, and an input output (I/O) **204**, all of which are in communication with the microprocessor **200**. The I/O **204** may include a wireless interface **206** (such as an IEEE 802.11 interface) for wirelessly receiving and transmitting data communication signals between the controller **106** and a remote network **208** such as local network or cloud network. The I/O **204** may also include one or more wired network interfaces **210** (such as an Ethernet or USB interfaces) for connecting to sensor drivers **212** and actuator drivers **214**. The sensor drivers **212** mainly receives analog and/or digital signals from the sensors (such as mapping sensors **8 65** as shown in FIG. **8**A) on-board or off-board the apparatus **100** and direct the sensory signals to the I/O **204** and eventually microprocessor **200** as digital signals.

(35) Examples of other sensors on the apparatus **100** include: encoders or potentiometers on all moving joints, particularly actuated joints configured to provide data related to the kinematics of the legs **110** and the arm **140**; vision camera coupled to the main body **102** for mapping of the surroundings of the apparatus **100**, annotating the elements in the surrounding environment such as the type of objects and their material or localizing the apparatus **100** within a map or simultaneous mapping and localization (SLAM); vision camera coupled to the anchor device **101** for mapping and localization of the apparatus **100**; attitude and heading reference system (AHRS) or inertial measurement unit (IMU) coupled to the main body **102** or the rope **104** configured to improve the accuracy and responsiveness of the mapping and localization; positioning sensors such as ultrawide band sensors coupled to the main body configured to assist in localization and positioning of the apparatus **100**; proximity sensors such as ultrasonic or infrared proximity sensors coupled to the structure-adhering feet **130** to provide real-time for obstacle or collision avoidance and assisting the feet **130** in attachment to a structure **180** surface; and torque, force, or strain sensors coupled to the feet **130** or processing head **150** configured to provide real-time data on the amount of force or strain applied to the structure **180**. Moreover, temperature, humidity, and wind sensors may also be coupled to the apparatus **100** or the anchor device **101** to assist in controlling the performance of the apparatus **100**. Additionally, the apparatus may include sensors that provide feedback signals regarding the proper attachment of the feet **130** to the structure **180**. For example, in embodiments that the apparatus **100** includes suction cups to attach to the structure **180**, the apparatus **100** may include one or more pressure sensors operably coupled to suction cups to provide feedback on the attachment of the suction cups to the structure **180**, for example, a significant drop in pressure sensor signal may indicate that the proper attachment between the feet **130** and the structure **180** is lost. Moreover, sensors coupled to the rope, such as strain sensors, may be used to monitor the tension in the rope.
(36) Any one of the mentioned sensors or a combination of them may be used to assist the apparatus **100** in performing a process on the structure **180**.
(37) The data from the sensory signals may be stored on the memory **202** and/or used in the memory-stored programs codes **203** which carry out various functions of the microprocessor **200** and subsequently control the operation of the apparatus **100**. Such program codes may be implemented on flash memory of the microprocessor **200**, for example. The programs codes **203** may include 2D/3D mapping (i.e. generating and updating a 2D/3D map of the surroundings of the apparatus **100**), localization (i.e. calculating the location of the apparatus within a map), path planning (i.e. calculating and planning a path for the apparatus to navigate through, calculating the most optimum path to move the apparatus along the structure with minimized energy and time), navigation (i.e. locomoting and moving the apparatus in a particular direction), and processing programs (i.e. a set of instructions for the processing arm **140** and processing head **150** to perform a certain process on the structure **180**, for example, a washing program that instructs the processing head **150** and the processing arm **140** to first spray a washing liquid over an area on the surface of the structure **180** and then rotate a brush head while moving the processing arm **140** to scrub and clean the surface over the area). Such program codes **203** may instruct the microprocessor **200** to generate command signals for the actuators of the apparatus **100**. In some embodiments, some or all of the functions, computations, and processing may be carried out in an external control system such as an edge computing system, IoT device, or cloud **208** which are communicating with the controller **106**, for example, via the wireless interface **206**.
(38) The actuator drivers **214** may include one or more actuator drivers which mainly receive the command signals sourced from the microprocessor **200** and generate control signals for various actuators of the apparatus such as leg actuators (including the hip actuator), arm actuators, rope actuator, and the processing head actuators. Such control signals may control the angles and velocities of the joints in the legs, for example. The actuator drivers **214**, may be configured to enable complex behaviors and operations such as performing a self-balancing maneuver in which

the leg movements can help the apparatus to suspend in balance when the feet **130** are not attached to the structure **180** and prevent the main body **102** to rotate around the rope **104** axis.
(39) In other embodiments (not shown), the controller **106** may be partly or fully implemented using a hardware logic circuit including discrete logic circuits, an application specific integrated circuit (ASIC), and/or a field-programmable gate array (FPGA), for example.
(40) Referring to FIG. **2**E, according to some embodiments, the apparatus **100** may further include a rope connector **105** disposed on the main body **102**, connecting the main body **102** to the rope **104**. The rope connector **105** is hingedly coupled to the main body **102** and is configured to offset the hanging point **104***a* where the apparatus **100** is attached to the rope **104**. The rope connector **102** allows the hanging point **104***a* to move with respect to the main body **102** which could help with the balance of the apparatus especially during dynamic maneuvers. For example, as the apparatus's center of gravity is changed due to the movement of the articulated legs **110** or the processing arm **140**, for example, the rope connector **105** may move to vertically align the hanging point **104***a* with the apparatus's center of gravity such that undesired tilts or rotations (roll and pitch) of the main body **102** from the hanging point **104***a* are prevented or compensated. Or, in cases where the articulated legs **110** are attached to the structure **180**, the rope connector **105** may move to optimally change the load distribution exerted from the feet **130** to the structure **180**.
(41) In FIG. **2**E, the rope connector **105** is hingedly coupled to the main body **102** and allows for the hanging point **104***a* to move in direction **109** with respect to the main body **102**. The rotation of the rope connector **105** may be actuated using an actuator coupled to the hinged location of the connector **105** and the main body **102**. In other embodiments, as shown in FIGS. **2**F and **2**G, the rope connector **105** may facilitate other degrees of freedom for the movement of the hanging point **104***a* with respect to the main body **102**. For example, as shown in FIG. **2**F, the rope connector is additionally configured to pivot in direction **109***b* with respect to the main body **102** and as shown in FIG. **2**G, the rope connector **105** is additionally configured to include a prismatic joint to extend or retract the length of the connector **105**. The additional degrees of freedom as shown in FIGS. **2**F and **2**G, may be passive or actuated.
(42) The actuated joints of the rope connector **105** may be controlled using the commands generated from the controller **106**. For example, sensory data related to the pitch or roll of the main body **102**, or the kinetics of the articulated legs **110**, may be processed in the controller **106** and the controller **106** may generate control signals to drive the movement of the rope connector **105** to obtain optimal load or position balance for the apparatus **100**, for example.
(43) Referring to FIGS. **3**A to **3**C another embodiment of an apparatus for performing a process on a structure is shown generally at **300**. The apparatus **300** is a variation of the apparatus **100** of FIGS. **1** and **2**, and may include elements similar to those of apparatus **100** but within the respective **300** series of numbers, whether or not those elements are shown. FIG. **3**A shows a perspective view of the apparatus **300**, while FIGS. **3**B and **3**C show a top view or side view of the apparatus **300** respectively. The articulated leg **310** comprises a first leg link **312** and a second leg link **313** which are rotatably coupled to each other via a knee joint **314**. The leg **310** is coupled to the main body **302** at the hip joint **318** and coupled to the foot end at the ankle joint **316**. In the embodiment shown in FIGS. **3**A to **3**C, the first leg link **312** is actuated around a hip axis **319** using a hip actuator (not shown in FIG. **3**) inside the main body **302**. The second leg link **313** is actuated around a knee axis using a linear actuator **322** which is extended from the hip joint **318** to the knee joint **314**. The structure-adhering foot **330** is actuated around an ankle yaw axis **326** using a foot linear actuator **323** which is extended from the knee joint **314** to the ankle joint **316**. In other embodiments the hip joint **318**, knee joint **314**, and ankle joint **316** may be able to cause actuated rotations around other axes or around more than one rotation axis.
(44) In the embodiment shown in FIG. **3**A, the shoulder joint **348** can facilitate rotation of the processing arm **340** in **2** generally perpendicular directions **352** (shown in FIG. **3**B) and **353** (shown in FIG. **3**C) to allow the processing head **350** to access a broader area on the structure while

the apparatus is fixed to the structure.
(45) Referring to FIG. **3**D, a top view of another embodiment of the apparatus **300** is shown. In this embodiment, the articulated leg **310** is actuated using a cable mechanism, such as a Bowden cable in an underactuated cable mechanism, in which a leg cable **322***a* runs along the articulated leg **310** and extends from the hip joint **318** to the ankle joint **316**. An actuator (not shown in figures) is coupled to the leg cable **322***a*, for example using a pulley, to wind and unwind the cable and hence control the position of the foot end **330** with respect to the main body **302**. The cable may be configured to manipulate the articulated leg **310** toward a particular region on the structure **180**. When, the foot end **330** is attached to a structure surface, the leg cable **322***a* may cause locomotion of the apparatus **300**, for example, the main body **302** may be pulled toward the foot end **330** by pulling the cable **322***b*.
(46) Referring to FIG. **3**E, a top view of another embodiment of the apparatus **300** is shown. In this embodiment, the articulated leg **310** may comprise light leg links which are powerful enough to move the foot end **330**. The weight of the main body **302** may be mainly supported by the rope **304**. The articulated leg **310** may be actuated using low power actuators (not shown in the figure) operably coupled to one or more of the hip joints **318**, knee joint **314**, and ankle joint **316** to move the foot end **330** and attach it to a structure. The apparatus **300** may further comprise a body cable **328** affixed to the main body **302** from one end and affixed to the foot **330** from another end. The body cable **328** may be coupled to an actuator (not shown in the figure) to wind or unwind the body cable and cause locomotion of the main body toward or away from the foot end **330**.
(47) Referring to FIGS. **4**A to **4**C another embodiment of an apparatus for performing a process on a structure is shown generally at **400**. The apparatus **400** is a variation of the apparatus **100** of FIGS. **1** and **2**, and may include elements similar to those of apparatus **100** but within the respective **400** series of numbers, whether or not those elements are shown. The apparatus **400** includes a pair of articulated legs **410**, each comprising one leg link **412**. The leg link **412** is coupled to the main body **402** from a hip joint **418** and coupled to a foot end **430** from an ankle joint **416**. The foot **430** is actuated with respect to the leg link **412** using a linear actuator **422** which is extended from the hip joint **418** to the ankle joint **416**. The leg link **412** is actuated with respect to the main body **402** at the hip joint **418** using a rotary actuator **468** (shown in FIGS. **4**B and **4**C).
(48) FIG. **4**B shows a partial cross sectional side view of the apparatus **400** while illustrating an exemplary view from the inside of the main body **402**. FIG. **3**C also shows a partial cross section view of the apparatus **400** from a perspective view. A shoulder joint **448** couples a processing arm **440** to the main body **402**. The shoulder joint **448** can facilitate actuation of the processing arm **440** in two perpendicular directions similar to the directions **352** and **353** as shown in FIGS. **3**B and **3**C. The actuation of the processing arm **440** in direction **353** is facilitated by a first shoulder actuator **472** affixed inside the enclosure of the main body **402**. The first shoulder actuator **472** drives a first shaft **474** which is coupled to a secondary shaft **475** using a belt, chain, gear system, or any other mechanical rotation coupling mechanism (not shown in figures) and subsequently cause the actuation of the shoulder joint **448** around axis **475** in a direction similar to direction **353**. The processing arm **440** is actuated in direction **352** using a second shoulder actuator **478** affixed inside the enclosure of the main body **402**.
(49) Referring to FIG. **5**A, a flowchart **510** depicts example blocks of instruction constituting a procedure for operating the apparatus **400** to perform a process on a structure **580**. The blocks may represent instructions to an operator of the apparatus **400** or may represent codes that may be read from the program codes **203** for directing the microprocessor **200** to perform various functions. The actual code to implement each block may be written in any suitable program language, such as C, C++, C#, Java, and/or assembly code, for example. In a preferred embodiment, the procedure **510** is performed by a control unit such as the apparatus control unit **406** to facilitate autonomous operation of the apparatus **400**.
(50) Referring to FIG. **5**B, a perspective view shows the apparatus **400** performing the procedure

510. The procedure **510** starts at block **512** when a map of the structure surface is provided to the apparatus **400**. The map may be provided to the control unit **406**, for example. The map may be a simulated 2D or 3D map of the structure **580** built by a computer aided design (CAD) or a may be a digital 2D or 3D map constructed by using mapping sensors such as lidar or camera. At block **514**, the received map is segmented into vertical reachable zones (one zone is shown at **582** in FIG. 5B) which is the combination of all areas on the structure **580** where the apparatus **400** can reach when suspended from a fixed location on an elevated portion of the structure **580**. The vertical reachable zone **582** is stretched in generally a vertical direction since the apparatus **400** is able to ascend or descend along the vertical direction when suspending from an anchor device **501** on the structure **580**. The width of the vertical reachable zone **582** is determined by the ability of the apparatus **400** to move in horizontal direction along the structure using its legs **410**.

(51) At block **516**, a vertical reachable zone **582** which is not processed, either fully or partially, is selected so that the apparatus **400** could perform the process along the zone **582**. The zone **582** may be selected and confirmed by an operator or may be chosen by the apparatus control unit **406**. At block **518**, the apparatus **400** is suspended from the elevated portion of the structure corresponding to the selected zone **582**. At block **520**, the apparatus **400** receives commands to start the process in the zone. At block **522**, the zone **582** is segmented further into processing target areas **584** (several target areas are shown in FIG. 5B). A target area **584** is an area of the structure **580** at which the apparatus **400** can perform the process without requiring to detach its structure-adhering feet **430** from the surface of the structure. Ideally, the target area **584** is maximized to minimize the time and energy while performing the process on the zone **582**. The segmentation of the zone **582** into target areas **584** may be done by the control unit **406** or by an external processing unit or by an operator, for example. At block **524**, the apparatus **400** is moved to an unprocessed target area **584**. The robot may use both the ascender or descender on the apparatus or the articulated legs **410**. At block **526**, the apparatus **400** performs the process, such as surface cleaning and inspecting, on the target area **584**. For example, the processing arm **440** moves the processing head **450** to a top corner of the target area **584** and then the processing arm **440** sweeps the processing head **450** across the target area **584** while zigzagging the processing head **450** and while the processing head **450** is performing the process on the target area **584**. At block **528**, once the process is done on the target area **584**, the target area is marked as done, by the control unit **406** for example.

(52) At block **530**, it is checked, for example by the control unit **406**, if all the target areas **584** within a vertical reachable zone **582** are processed and marked as done. If no, the procedure **510** goes to block **524** to perform the process on another target area **584**, and if yes, the procedure **510** proceeds to block **532**. At block **532**, it is checked, for example by the control unit **406**, whether all vertical reachable zones **582** on the structure are processed or not. If no, the procedure **510** goes to block **516** to select another zone **582**, and if yes, the procedure **510** proceeds to block **534** indicating the end of the procedure.

(53) Referring to FIG. 5C, a flowchart depicting example blocks of instruction for directing the apparatus **400** to perform an autonomous maneuver on the structure **580** is shown at **550**. The blocks may represent instructions to an operator of the apparatus **400** or may represent codes that may be read from the program codes **203** for directing the microprocessor **200** to perform various functions. The actual code to implement each block may be written in any suitable program language, such as C, C++, C#, Java, and/or assembly code, for example. In a preferred embodiment, the procedure **550** is performed by a control unit such as the apparatus control unit **406** to facilitate autonomous operation of the apparatus **400**.

(54) Referring to FIGS. 5D to 5G a series of perspective views show the apparatus **400** performing the maneuver procedure **550** on a structure **580** while also maneuvering over an obstacle **507**.

(55) The maneuver shown in FIGS. 5D to 5G is in generally a horizontal direction along the structure **580**. As shown in FIG. 5D, the apparatus is suspended from the structure **580** using a rope **404** and while a left leg **410** and a right leg **411** are attached to the structure surface, left of an

obstacle **507**, using a foot end **430** at each leg. The process **550** starts at block **552** by reading a local map of the surrounding environment of the apparatus **400**. The local map may be constructed using mapping sensors (such as mapping sensors **86 5** in FIG. **8**A). At block **554**, a next target area for performing the process on the structure **580** is identified. As shown in FIG. **5**D, area **584** is identified as the next target area for the apparatus **400** to perform a process on. At block **556**, suitable attachable areas for the structure-adhering feet **430** are identified on the next target area **584**. At block **558**, a trajectory is planned for moving the structure-adhering feet **430** to the attachable areas.

(56) At block **560**, the move plan is executed and the structure-adhering feet **430** are moved to the attachable areas. As shown in FIG. **5**E, the apparatus **400** has detached the right leg **411** from the structure surface and actuate both legs **410** and **411** from their corresponding hip joints to allow locomotion of the apparatus **400** in generally the horizontal direction. The right leg **411** is maneuvered in such a way to move over and pass the obstacle **507** and then attach to the target area **584** on the right side of the obstacle **507**. During this leg movement, the ankle joint **416** may be also moved actively. The main body **402** of the apparatus **400** may rotate or ascend or descend in generally a vertical direction during the locomotion in the horizontal direction. As shown in FIG. **5**F, the left leg **410** is detached from the structure and the main body **402** of the apparatus **400** is driven closer to the right leg **411**. As shown in FIG. **5**G, the left leg **410** is moved over and passed the obstacle **507** and is attached to the target area **584** on the right side of the obstacle **507**. During this maneuver, the rope **404** facilitates the movement of the main body **402** in the direction of the maneuver. At block **562**, the attachment of the structure-adhering feet **430** is confirmed and if the feet **430** are not in the planned position, the move at block **560** is repeated until the feet **430** are in the suitable attachment area. At block **564**, the procedure **550** is concluded by indicating the end of the maneuver. Now referring to FIG. **6**, a detailed view of the ankle joint **316** of the apparatus of FIG. **3** is shown according to an embodiment. The ankle joint **316** allows for rotation of the structure-adhering foot **330** in three directions with respect to the leg link **313**. In the embodiment shown in FIG. **6**, the foot **330** may rotate, with respect to the leg link **313**, around the yaw axis **326**, roll axis **332***a*, and pitch axis **332***b*. The three rotational directions may be active (actuated) or passive (not actuated). In the embodiment shown in FIG. **6**, the foot **330** rotation around the yaw axis **326** is controlled using a link extending out of the foot linear actuator **323**. This active degree of rotation facilitates orientation adjustment of the structure-adhering foot **330** in better aligning with a surface of the structure (**180** as shown in FIGS. **1** and **2**), for example. The passive degrees of rotation also, facilitates smooth orientation adjustments of the structure-adhering foot **330** without transferring the rotation to the leg link **313**, for example. For example, assuming the foot end **330** is equipped with active suction cups, once the suction cups are activated, the structure-adhering foot **330** may rotate around the roll axis **332***a* and pitch axis **332***b* to seamlessly adhere to a surface of the structure (**180** as shown in FIGS. **1** and **2**). In this example, the active suction, may require rotation of the structure-adhering foot **330** around the yaw direction **327** as well, thus, it may be advantageous to use a back-drivable mechanism for actuation of the ankle joint **316** in the yaw direction. The free rotation of the structure-adhering feet **330** around these axes with minimal resistance, may exert minimal force to the structure **180** when the feet **330** is attaching to the structure **180**. The passive or active degrees of freedom of the feet **330** also facilitate improved maneuver of the main body **302** while the structure-adhering feet **330** is attached to the structure **180** and without requiring the feet **330** to be detached from the structure.

(57) The maneuver shown in FIGS. **5**D to **5**G represent maneuvers in generally a horizontal direction along the structure **580**. However, similar steps may be taken for maneuvers in generally a vertical direction. For maneuvers in the vertical direction, in addition to using articulated legs **411** to cause locomotion of the apparatus **400**, the rope **404** may cause the locomotion and ascension and descension of the apparatus **400** in the vertical direction. For example, the foot ends **330** may be completely detached from a completed target area **584**, then the apparatus **400** may descend to a

next target area by using the rope **404**, and then attach the foot end **330** to the next target area.

(58) Referring to FIGS. **7**A and **7**B now, an embodiment of the ankle joint **316** with back-drivable mechanism for actuation in the yaw direction **327** is shown. A rotary actuator **323***b*, such as a brushless DC motor, affixed to the leg link **313**, is operably coupled to the ankle joint **316** using bevel gears to rotate the structure-adhering foot **330** in the yaw direction **327**.

(59) The structure-adhering foot **330** in FIGS. **7**A and **7**B comprises of 4 suction cups **335** mounted on a foot frame **334** to increase the adhesion force between the structure-adhering foot **330** and a surface of a structure (**180** as shown in FIGS. **1** and **2**).

(60) Referring to FIGS. **8**A to **8**D another embodiment of an apparatus for performing a process on a structure is shown generally at **800**. The apparatus **800** may include elements similar to those of apparatus **100** but within the respective **800** series of numbers, whether or not those elements are shown. Referring to FIG. **8**A, the apparatus **800** includes a pair of articulated legs **810**, each comprising one leg link **812**. The leg link **812** is coupled to the main body **802** from a hip joint **818** and coupled to a foot end **830** from an ankle joint **816**. The foot end **830** may be actuated with respect to the leg link **812** using a linear or rotary actuator (not shown in figures) which is located inside the enclosure **831** of the foot end **830**.

(61) Referring to FIG. **8**B, the apparatus **800** is suspended from an elevated portion **181** of the structure **180** using 3 ropes **804**. The ropes **804** may be anchored to the elevated portion **181**. The apparatus **800** may use 3 pulleys **803**, corresponding to each rope **804**, to control the movement of the apparatus **800** in generally the vertical direction. The pulleys **803** may be actuated. Separately actuated pulleys **803** may provide control for pitching and rolling the apparatus **800** (i.e. controlling the rotation of the apparatus **800**).

(62) The apparatus **800** may further include 3D lidar sensors **86 5** to, for example, construct a map of the surrounding environment of the apparatus **800**, localize the apparatus **800** on a map of the structure **180**, identify the next zone on the structure **180** which the apparatus should perform a process, and detect obstacles. Alternatively, the mapping sensors **86 5** may be other types of sensors such as vision RGB camera or RGBD cameras, ultrasonic sensors, radar sensors, infrared sensors, or any combination of the mentioned sensors.

(63) In the embodiment shown in FIGS. **8**A to **8**D, the foot end **830** includes structure-adhering means **835** (such as suction cups) configured to facilitate attachment of the apparatus **800** to the structure, as well as the processing head **850**, as shown in FIG. **8**C. In such embodiments, the apparatus **800** performs a process on the structure **180** while the foot end **830** is adhered to a surface of the structure **180**.

(64) Referring to FIG. **8**C, the enclosure **831** of the foot end **830** is partially removed to show the structure-adhering means **835** and the processing head **850**. In the embodiment shown in FIGS. **8**C and **8**D, 3 sets of vertically spaced apart suction cups are provided as the structure-adhering means **835**. Each set comprises a pair of suction heads **835***a* and **835***b* such that if a suction head **835***a* gets dirty or ineffective, the suction pair can rotate in direction **835***c* and expose the other suction head **835***b* to the structure **180** surface. The suction cups may be active, i.e. connected to a vacuum pump, or passive, or a combination of active and passive suction cups.

(65) In the embodiment shown in FIG. **8**C, the processing head **850** comprises of a brushing head **856** and washing jets **858**. The processing head **850** may be attached to a cartesian mechanism **854** that drives the processing head **850** in the vertical **854***a* and horizontal direction **854***b*.

(66) The structure-adhering means **835** may be movable in direction **835***d* to allow the movement of the processing head in the vertical direction **854***a*. Each of the **3** structure-adhering means **835** may slide in direction **835***d* actively using an actuator, for example. Alternatively, a set of structure-adhering means **835** may be retracted passively using a push force by the processing head **850** when the processing head moves against the set **835**, for example. While one of the structure-adhering sets **835** may be retracted, the other two sets are extended and can facilitate attachment to the structure **180**.

(67) Referring to FIG. **9**, a side view of another embodiment of an apparatus for performing a process on a structure **180** is shown generally at **900**. The apparatus **900** may include elements similar to those of apparatus **100** but within the respective **900** series of numbers, whether or not those elements are shown. The apparatus **900** includes main body **902** suspended from a rope **904**. The rope may allow the apparatus to move in generally a vertical direction along the structure **180**. The apparatus **900** includes a processing head **950**, such as a cleaning brush, coupled to the main body **902** and configured to perform a process on the structure **180**.
(68) The apparatus **900** further includes one articulated leg **910** such as multi-degree of freedom leg coupled to a side of the main body **902** from a hip joint **918**. The leg includes a structure-adhering foot end **930** to facilitates attachment of the apparatus **900** to the structure **180** and facilitate proper engagement of the processing head **950** with the structure, for example. While the structure-adhering foot end **930** is attached to the structure **180**, the articulated leg **910** may also cause locomotion of the apparatus **900** by articulating the leg. The hip joint **918** may slide freely or forcibly along a vertical direction **919***a* to allow changing the point of exerted force from the articulated leg to the main body **902**. The sliding movement of this hip joint **918** may also assist in reducing or preventing the weight of the main body to be exerted on the articulated leg and hence on the structure **180**. The hip joint **918** may slide in other directions in other embodiments. In some embodiments, the apparatus **900** may include one articulated leg attached to each side of the main body **902** to facilitate improved maneuver and locomotion of the apparatus **900** along the structure **180**.
(69) Referring to FIG. **10**, a flowchart **1000** depicts an embodiment of a blocks of instructions constituting a control strategy for the apparatus **100** to perform a process on the structure **180**. The blocks may represent codes that may be read from the program codes **203** for directing the microprocessor **200** to perform various functions. The actual code to implement each block may be written in any suitable program language, such as C, C++, C#, Java, and/or assembly code, for example. In a preferred embodiment, the procedure **1000** is performed by a control unit such as the apparatus control unit **106** to facilitate autonomous or semi-autonomous operation of the apparatus **100**.
(70) The control strategy **1000** starts at block **1010** when high-level input commands, such as the desired position of the apparatus **100** on the structure **180** or the contact point between a foot end **130** and the structure **180**, are provided to the control unit **106** by an operator of the apparatus **100** or a software through a wired or wireless I/O port, for example. At block **1020**, the control unit **106** processes the input commands and calculates different paths and options for the apparatus **100** to reach the input commands. The control unit **106** may use a software model, such as a mathematical model of the apparatus's dynamic or static behavior or apparatus's kinetics and kinematics to calculate the different paths. The software model may also provide estimates and predictions for internal parameters, such as linear and angular position and force in the apparatus's joints, tension in the rope, the status of the structure-adhering foot end **130** in attachment to the surface of the structure **180**, interface force or torque between the foot end **130** and the surface of the structure **180**, and applied voltage and current to the actuators, for a calculated path. The control unit **106** uses an optimization logic to select an optimum path. In some embodiments, the control unit **106** can run the software model enough times along with the optimizing logic to minimize or maximize an objective function, the objective function, for example, being the time duration of the apparatus's maneuver, energy consumption of the maneuver, or the maximum load that would be exerted on the surface of the structure **180** by the foot end **130** during the maneuver. The objective function may be provided by the apparatus's manufacturer or operator.
(71) At block **1030**, the control unit **106** considers certain constraint parameters, such as the tension in the rope **104** or the force applied between a foot end **130** and the structure **180**, and compares the calculated constraint parameters, which are obtained by the software model, with a corresponding provided threshold of the constraint parameter. At block **1040**, if the selected path does not meet the

constraint thresholds, the control unit **106** rejects the selected path and send a report to the operator. For example, a maximum threshold for the tension in the rope may have been provided and the control unit **106** compares the calculated rope tensions for the duration of the selected path with the provided maximum threshold, and if the calculated parameter crosses the maximum threshold, then the control unit **106** does not execute the selected path and report to the operator to select another input command. Alternatively, the control unit may select another path. The thresholds may be provided by the manufacturer of the apparatus **100** or the operator or may be derived by the software model.
(72) At block **1050**, however, if the selected path meets the constraint thresholds, the control unit **106** generate and execute command signals for the apparatus **100** to locomote to through the selected path. At block **1060**, the control unit **106** continues to monitor the actual or predicted constraint parameters for crossing the acceptable thresholds using the apparatus's sensors, or the software model, or a combination thereon. At block **1070**, the controller determines if a constraint parameter is violating or is predicted to violate a threshold. If no the control strategy continues the execution of commands at block **1080**, otherwise the execution is stopped and the operator is notified at block **1090**.
(73) In other embodiments, in addition to the high-level input commands by the operator, low level commands, such as angular position of a certain joint or the elevation of the apparatus **100**, may be provided by the operator as well.
(74) While specific embodiments have been described and illustrated, such embodiments should be considered illustrative only and not as limiting the disclosed embodiments as construed in accordance with the accompanying claims.

Claims

1. An apparatus for performing a process on a structure, the apparatus comprising: a main body configured to be suspended in a generally vertical direction from an anchor device using a tether coupled at a first end to the main body at a hanging point and at a second end to the anchor device wherein retracting and extending the tether shortens and lengthens, respectively, the length of the tether between the main body and the anchor device for ascending and descending the apparatus in the generally vertical direction; first and second articulated legs, each of the first and second articulated legs having a hip end and a foot end, wherein the first and second articulated legs are coupled to the main body at the hip end of the corresponding articulated leg, and wherein the first articulated leg at its corresponding foot end is operably configured to make contact with a first portion of the structure to provide support for the main body and the second articulated leg at its corresponding foot end is operably configured to make contact with a second portion of the structure to provide support for the main body; a hip actuator operably coupled to the hip end of each of the first and second articulated legs, the hip actuator configured to cause rotational movement between the main body and the respective first and second articulated legs; and at least one processing end effector operably connected to the main body and configured to perform the process on the structure; a control unit operably connected to the apparatus and configured to generate control commands, the control commands when executed by the apparatus cause the apparatus to one or more of contact the structure, adjust a disposition of the apparatus relative to the structure, and perform the process on the structure using the processing end effector, wherein adjusting the disposition of the apparatus comprises one or more of: adjusting the elevation of the apparatus by one or more of retracting or extending the tether and actuating the hip actuator for causing the apparatus to ascend or descend in the generally vertical direction; and rotating the apparatus relative to the structure by one or more of actuating the hip actuator and retracting or extending the tether; and wherein contacting the structure comprises one or more of: actuating the hip actuator to establish contact between the foot end of the first articulated leg and the first portion

of the structure; actuating the hip actuator to establish contact between the foot end of the second articulated leg and the second portion of the structure.
2. The apparatus of claim 1, wherein the processing end effector is operably disposed on the main body.
3. The apparatus of claim 1, wherein at least one of the first and second articulated legs include a structure-adhering end effector disposed at the corresponding foot end, the structure-adhering end effector configured to temporarily attach the corresponding foot end to the structure.
4. The apparatus of claim 1, wherein the processing end effector is disposed at the foot end of at least one of the first and second articulating legs.
5. The apparatus of claim 1, wherein the tether is one or more of a rope and cable.
6. The apparatus of claim 1, wherein at least one of the first or second articulated legs comprises a leg end effector rotatably connected to a leg link of the corresponding articulated leg by an ankle joint, the ankle joint configured to allow relative movement of the leg end effector with respect to the leg link and wherein the ankle joint is operably coupled to an ankle joint actuator configured to cause rotation of the leg end effector with respect to the leg link in one or more of yaw, pitch, and roll directions.
7. The apparatus of claim 1, wherein the apparatus further comprises at least one articulated arm having a first end and a second end, wherein the articulated arm is coupled to the main body at the first end and is coupled to the processing end effector at the second end.
8. The apparatus of claim 1, wherein the processing end effector comprises one or more of a window cleaning end effector comprising at least one brush head, and a material dispensing head configured to dispense a material on the structure.
9. The apparatus of claim 1, wherein the apparatus further comprises a rope connector disposed on the main body and configured to move the hanging point with respect to the main body based on one or more of a desired rotation of the apparatus and an imbalance of the apparatus.
10. The apparatus of claim 1, wherein one or more of the first and second articulated legs are coupled to the main body using a sliding joint, the sliding joint configured to cause linear movement between the main body and the respective first and second articulated legs.
11. A method for performing a process on a structure using an apparatus, the apparatus comprising: a main body configured to be suspended in a generally vertical direction from an anchor device using a tether coupled at a first end to the main body at a hanging point and at a second end of the tether to the anchor device wherein retracting and extending the tether respectively shortens and lengthens the length of the tether between the main body and anchor device to change the elevation of the apparatus; first and second articulated legs, each of the first and second articulated legs having a hip end and a foot end, wherein the first and second articulated legs are disposed on the main body at the hip end of the corresponding articulated leg, and wherein the first articulated leg is operably configured to make a contact with a first portion of the structure at its respective foot end to provide support for the main body, and the second articulated leg is operably configured to make contact with a second portion of the structure at its respective foot end to provide support for the main body; a hip actuator operably coupled to the hip end of each of the first and second articulated legs, the hip actuator configured to cause rotational movement between the main body and the respective first and second articulated legs; and at least one processing end effector operably connected to the main body and configured to perform the process on the structure; a control unit operably connected to the apparatus and configured to generate control commands when executed by the apparatus cause the apparatus to one or more of contact the structure, adjust a disposition of the apparatus relative to the structure, and perform the process on the structure using the processing end effector, the method comprising: adjusting the elevation of the apparatus by one or more of retracting or extending the tether and actuating the hip actuator for causing the apparatus to ascend or descend in the generally vertical direction; rotating the apparatus relative to the structure by one or more of actuating the hip actuator and retracting or extending the tether;

actuating the hip actuator of the first articulated leg and establishing contact between the foot end of the first articulated leg and the first portion of the structure; actuating the hip actuator to establish contact between the foot end of the second articulated leg and the second portion of the structure; and performing the process on the structure using the processing end effector.
12. The method of claim 11, wherein the apparatus further comprises a rope connector disposed on the main body and configured to move the hanging point with respect to the main body, and the method further comprising moving the rope connector based on one or more of a desired rotation of the apparatus and an imbalance of the apparatus.
13. The method of claim 11, wherein the apparatus further comprises an articulated arm configured to push against the structure and cause locomotion of the apparatus with respect to the structure and wherein the articulated arm is coupled to the main body at a first end and to the processing end effector at the second end.
14. The method of claim 11 further comprising: loading a map of the structure to the control unit; segmenting, by the control unit, the map into vertical reachable zones wherein the vertical reachable zones are spaced apart in generally a horizontal direction; selecting, by the control unit, a first vertical reachable zone; suspending the apparatus from the anchor device at a first elevated region corresponding to the first vertical reachable zone; causing ascension or descension of the apparatus using the tether to move the apparatus to a similar elevation of a first target area within the first vertical reachable zone; causing the first and second articulated legs to make contact to a first and second location within the first target area using their respective foot ends, the first and second locations being distant from one another; and performing the process on the first target area using the processing end effector.
15. The method of claim 14 further comprising: moving the apparatus to a second target area of the first vertical reachable zone, the second target area at least partially distinct from the first target area, wherein moving to the second target area comprises: removing contact between the first target area and the foot end of one or more of the first and second articulated legs; moving the main body toward the second target area by one or more of actuating the hip actuator and causing ascension or descension of the apparatus to move the apparatus to similar elevation of the second target area; and moving the foot end of one or more of the first and second articulated legs to the second target area and establishing contact between the corresponding foot end and a third location within the second target area; and performing the process on the second target area using the processing end effector.
16. The method of claim 14 further comprising moving the apparatus to a second vertical reachable zone by one or more of suspending the apparatus from the anchor device at a second elevated region corresponding to a second vertical reachable zone and moving the anchor device from the first elevated region to a second elevated region.
17. A system for performing a process on a structure, the system comprising: an apparatus comprising: a main body suspended in generally a vertical direction from an anchor device using at least one tether, wherein the tether is coupled to the main body from a hanging point and the length of the tether between the main body and the anchor point is configured to retract or extend to adjust the apparatus's elevation in generally the vertical direction; at least one articulated leg having a hip end and a foot end, the articulated leg coupled to the main body from the hip end, the articulated leg operably configured to make a contact with a portion of the structure from the foot end and provide support for the main body; a hip actuator operably configured to cause rotational movement between the main body and the articulated leg; and at least one processing end effector operably disposed on the apparatus and configured to perform the process on the structure; and a control unit operably connected to the apparatus and configured to generate control commands for the hip actuator and the apparatus's elevation, in response to receiving an input indicating moving the apparatus to a target location on the structure; wherein, the control unit generates the control commands by monitoring at least one constraint parameter and avoiding crossing a given threshold

of the at least one constraint parameter.
18. The system of claim 17, wherein the at least one constraint parameter is one or more of a force exerted from the foot end to the portion of the structure and a tension in the tether.
19. The system of claim 17, wherein the apparatus further comprises a rope connector disposed on the main body and configured to move the hanging point with respect to the main body, and wherein the control unit is further configured to generate control commands for the rope connector movement.
20. The system of claim 17, configured to one or more of: adjust the elevation of the apparatus by retracting or extending the tether causing the apparatus to ascend or descend in generally a vertical direction; establish contact between the foot end of the articulated leg and the portion of the structure by the control commands while the at least one constraint parameter is being monitored and crossing a threshold of the at least one constraint parameter is avoided wherein the control commands include commands to one or more of move the hip actuator or change the apparatus's elevation; while the foot end of the articulated leg is in contact with the portion of the structure, perform the process on the structure using the processing end effector.