

AUTONOMOUS MOBILE ROBOT HAVING ROBOT ARM WITH MULTIPLE DEGREES OF FREEDOM FOR ELEVATOR RIDING

FIELD OF THE INVENTION

[0001] The present disclosure relates to an autonomous mobile robot, and more particularly to an autonomous mobile robot having a robot arm with multiple degrees of freedom for riding an elevator without communication ability.

BACKGROUND OF THE INVENTION

[0002] Autonomous Mobile Robots (AMR) are increasingly utilized in a variety of industries and application for handling and moving various goods and materials without human intervention. However, in most applications, AMRs can only operate in a single floor space or level in a building. This is due to the limited capability of AMRs to access, move in and out of and operate elevators.

[0003] Recent urban buildings have introduced smart elevators that can be operated by AMRs through various communication channels. Such AMR typically includes a communication interface for getting elevator information, elevator call, elevator status monitoring, and call monitoring. The challenge still remains for AMRs to access legacy elevators which do not have such communication interface that exist in most urban buildings. Recent works have also proposed solutions of AMR that can ride a legacy elevator, but they either require human intervention (e.g., press button) or require dedicated elevators for AMR without co-sharing with humans.

[0004] Therefore, there is a need of providing an autonomous mobile robot having a robot arm with multiple degrees of freedom to operate

elevators and auto-doorway without the need of precise mobile base positioning, and overcome the drawbacks of the conventional technologies.

SUMMARY OF THE INVENTION

[0005] An object of the present disclosure is to provide an autonomous mobile robot having a robot arm with multiple degrees of freedom to use elevators and auto-doorway without communication ability.

[0006] Another object of the present disclosure is to provide an autonomous mobile robot having a robot arm with multiple degrees of freedom for riding an elevator without human intervention and without communication interface with elevator control system. The autonomous mobile robot includes an actuator unit (i.e., a robot arm) disposed on top of the autonomous mobile robot. With the actuator unit having at least 3 degrees of freedom (DOF) (i.e., pan, tilt, and extend), it is possible to access the elevator call buttons (outside the elevator) the floor buttons (inside the elevator), or the auto-doorway's button while compensating for the variability of the mobile robot's pose. High precision docking of the autonomous mobile robot to the elevator button panel (inside or outside) is not required as the position of the autonomous mobile robot will usually vary in terms of 2D position (X , Y) and orientation (θ). As such, it allows the autonomous mobile robots using 2-dimensional (2D) spatial positioning (e.g., waypoint positioning) to achieve the effective use of the elevators (press the elevator call and floor buttons) and the auto-doorway (tap access card). In addition, the autonomous mobile robot further includes a tactile feedback sensor to sense if the actuator unit has pressed an elevator button and stops the actuator motion (extending) after a button has been pressed. This will provide feedback to the autonomous mobile robot to know when the button

press action has been completed successfully, and also prevent overexerting the robot arm, which may lead to component failure or damage to the elevator button panel.

[0007] A further object of the present disclosure is to provide an autonomous mobile robot having a robot arm with multiple degrees of freedom. While the autonomous mobile robot has approached in different orientations, the actuator unit with at least 3 degrees of freedom has the capabilities of pressing a target button on the button panel, which has multiple columns of buttons. The actuator of the autonomous mobile robot will be able to reach the target button in all columns without re-orientating the mobile robot. In addition, to enhance the performance and effectiveness of the robot arm, the autonomous mobile robot further includes a tactile feedback sensor to sense if the actuator unit has pressed the target button and stops the actuator motion (extending) after the target button has been pressed. This will provide feedback to the autonomous mobile robot to know when the button press action has been completed successfully, and also prevent overexerting the actuator, which may lead to component failure or damage to the elevator button panel. Notably, 3 DOF actuator is minimally required, and there is no need for precise positioning of the autonomous mobile robot. It has more scalability to operate in different elevator models and has advantage of cost effective and interoperability.

[0008] In accordance with an aspect of the present disclosure, an autonomous mobile robot having multiple degrees of freedom for riding an elevator without communication ability is provided. The autonomous mobile robot having multiple degrees of freedom includes a sensing and perception unit, a cognition unit, a control unit and an actuator unit. The control unit is configured to receive task instructions for performing a task

at a target floor and generate control signals comprising floor information of the target floor. The sensing and perception unit is configured to obtain sensing data and provide a perception result indicative of an object related to the elevator from the sensing data according to the control signal. The cognition unit is configured to derive position and orientation of the object relative to the autonomous mobile robot. The actuator unit has multiple joints and an end effector in at least 3 degrees of freedom. The control unit is further configured to send control commands including position and orientation information to the actuator unit, and the actuator unit is configured to receive and execute the control command to perform an operation with the object by the end effector.

[0009] In an embodiment, the sensing and perception unit includes a sensing module configured to obtain one or more images and a perception module configured to identify the object in the one or more images .

[0010] In an embodiment, the sensing module is further configured to obtain one or more images containing a control panel of the elevator, and the perception unit is further configured to identify a button on the control panel of the elevator according to the floor information.

[0011] In an embodiment, the position and orientation information includes a vertical coordinate, a horizontal coordinate and an orientation angle of the object identified.

[0012] In an embodiment, the end effector is driven through the multiple joints, and at least two of the multiple joints are configured to perform motions through a dual motor .

[0013] In an embodiment, the end effector is driven to perform the operation with the object in a perpendicular angle.

[0014] In an embodiment, the multiple joints include a first joint and a second joint for panning or rotating and a third joint for rotating, wherein the first joint is disposed adjacent to top surface of the autonomous mobile robot, and the third joint is connected to drive the end effector connected thereto to perform the operation with the object.

[0015] In an embodiment, the multiple joints further include an additional joint for extending the actuator unit vertically.

[0016] In an embodiment, the multiple joints include a first joint for panning, a second joint, a third joint and a fourth joint for rotating to ensure that the end effector connected to the fourth joint is perpendicular to the object during actuation.

[0017] In an embodiment, the multiple joints include a first joint for extending, a second joint for panning, a third joint for rotating and a fourth joint for rotating to drive the end effector connected to the fourth joint to press the object.

[0018] In an embodiment, the autonomous mobile robot is configured to navigate by 2D spatial positioning and is configured to sense and perform the operation with the object at a fixed location .

[0019] In an embodiment, the end effector includes a tip, and the tip is detachable, replaceable, deformable, soft or anti-abrasion.

[0020] In an embodiment, the actuator unit includes a tactile feedback sensor integrated with the end effector for providing feedback to the control unit.

[0021] In an embodiment, the sensing and perception unit includes a sensing module configured to obtain sensing data.

[0022] In an embodiment, the sensing and perception unit includes a perception module configured to process the sensing data and provide

perception results indicative of one or more objects according to the task instruction.

[0023] In an embodiment, the sensing module is a camera module for capturing the images, and the perception module is configured to process the images according to the task instruction.

[0024] In an embodiment, the autonomous mobile robot is a two-wheel AMR for industrial transportation use, or a four-wheel omni-directional AMR.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The above contents of the present disclosure will become more readily apparent to those ordinarily skilled in the art after reviewing the following detailed description and accompanying drawings, in which:

[0026] FIG. 1 is a structural perspective view illustrating an mobile robot integrated with a cognitive actuation system according to an embodiment of the present disclosure;

[0027] FIG. 2 is a functional block diagram illustrating the cognitive actuation system according to the embodiment of the present disclosure;

[0028] FIG. 3A and FIG. 3B schematically show an embodiment of the present disclosure, in which the mobile robot is instructed to arrive a target level;

[0029] FIG. 4A and FIG. 4B schematically show an exemplary scenario of the mobile robot operating the elevator control panel at the elevator lobby;

[0030] FIG. 5 schematically shows a docking path of the autonomous mobile robot outside the elevator;

[0031] FIG. 6A to FIG. 6C are schematic diagrams examples of the actuator unit pressing the target button while the mobile robot is in different orientations;

[0032] FIG. 7 is a schematic diagram illustrating example of typical position variances of the mobile robot example from the button panel;

[0033] FIG. 8A and FIG. 8B schematically show the mobile robot for controlling an elevator to a target floor;

[0034] FIG. 9 schematically shows a docking path of the mobile robot inside the elevator;

[0035] FIG. 10A and FIG. 10B schematically show different button panels inside the elevator;

[0036] FIG. 11A and FIG. 11B show the actuator unit with 4 DOF for pressing the target button according to the embodiment of the present disclosure;

[0037] FIG. 12A and FIG. 12B schematically show the mobile robot for activating an auto-doorway in a building;

[0038] FIG. 13A and FIG. 13B schematically show the mobile robot for activating a button-activated auto-doorway; and

[0039] FIG. 14A to FIG. 14F show several examples of the actuator units having at least 3 DOF for the mobile robot of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0040] The present disclosure will now be described more specifically with reference to the following embodiments. It is to be noted that the following descriptions of preferred embodiments of this disclosure are presented herein for purpose of illustration and description only. It is not intended to be exhaustive or to be limited to the precise form disclosed. For

example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed. Further, spatially relative terms, such as “upper,” “lower,” “upward,” “downward,” “front,” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly. When an element is referred to as being “connected,” or “coupled,” to another element, it can be directly connected or coupled to the other element or intervening elements may be present. Although the wide numerical ranges and parameters of the present disclosure are approximations, numerical values are set forth in the specific examples as precisely as possible. In addition, although the “first,” “second,” “third,” and the like terms in the claims be used to describe the various elements can be appreciated, these elements should not be limited by these terms, and these elements are described in the respective embodiments are used to express the different reference numerals, these terms are only used to distinguish one element from another element.

For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of example embodiments.

[0041] FIG. 1 is a structural perspective view illustrating a mobile robot integrated with the cognitive actuation system according to an embodiment of the present disclosure. The mobile robot 1 is an AMR with waypoint mobility on the ground floor, and is integrated with a cognitive system 2 with perception and cognition abilities for interactions with elevators having no wireless communication abilities. The cognitive actuation system 2 enables the mobile robot 1 to operate elevator control panels or authentication systems at auto-doorways on its own. For example, the cognitive actuation system 2 may enable the mobile robot 1 to press an elevator call button, without human intervention or direct communication with the elevator, when the mobile robot 1 is instructed to ride an elevator. Preferably but not exclusively, the mobile robot 1 can be a two-wheel AMR for industrial transportation use, or a four-wheel omni-directional AMR. In the embodiment of FIG. 1 and FIG. 2, the mobile robot 1 is depicted as a four-wheel AMR. However, one of ordinary skill in the art may understand the mobile robot with autonomous moving and navigation capabilities may be in various forms.

[0042] As shown in the embodiment of FIG. 2, the cognitive actuation system 2 includes a sensing and perception unit 10, a cognition unit 20, a control unit 30 and an actuator unit 40. Upon receiving a task instruction requiring the mobile robot 1 to perform a specific task at another level different from the current level that the mobile robot 1 resides, the mobile robot 1 may move and ride the elevator on its own with the aid of the cognitive actuation system 2. The control unit 30 is configured to receive

instructions for performing a task at a target floor and generate control signals comprising floor information of the target floor.

[0043] The sensing and perception unit 10 is configured to obtain sensing data of the surrounding environment, for example an elevator lobby, and to process the sensing data so as to produce perception results indicative of desired objects, for example an elevator control panel and/or a call button on the control panel. Preferably but not exclusively, the sensing and perception unit 10 includes at least a sensing module 11 configured to obtain sensing data of the surrounding environment. As shown in the embodiment of FIG. 1, the sensing module 11 is a camera module disposed on the mobile robot 1 for capturing images. In other embodiments of the present disclosure, the sensing module 11 may be an RGB camera, infrared camera, light-field camera, X-ray, LiDAR or any other suitable sensors capable to sense and integrate information of the surrounding environment. In embodiments of the present disclosure, the sensing and perception unit 10 also includes a perception module 12 configured to process the sensing data and provide perception results indicative of one or more objects in the images according to the task instruction. For example, in the case that the task instruction demands the mobile robot 1 to deliver goods to a target floor above the current floor, the perception module 12 may process the images captured at the elevator lobby and identify the “UP” call button on the elevator panel in the images. Also, the perception module 12 may process the images captured in the elevator box and identify the number button of the target floor on the floor panel in the images. The perception module 12 may apply proper processing well-known in the art for object identification according to the type of the sensing module 11. For example, in the case that the sensing

module 11 is a camera module, the perception module 12 may perform image processing of object identification accordingly.

[0044] The cognition unit 20 is connected to the sensing and perception unit 10 and is configured to process the perception results to obtain relative position information of the identified object(s), for example the call button or the number button. In an embodiment of the present disclosure, the cognition unit 20 is configured to perform position determination and coordinate transformation. For example, the cognition unit 20 may determine a position of the control panel relative to the mobile robot 1 in physical space in terms of a vertical coordinate (Z), a horizontal coordinate (X) and an orientation angle (θ). The cognition unit 20 may obtain position(s) of the identified object(s) according to relevant information contained in the sensing data and/or by other processing techniques. For example, in the example that the sensing module 11 is a camera module, the cognition unit 20 may derive the position of the identified object in camera coordinate according to depth information and image processing techniques for object positioning. The position information can be expressed in any suitable 3-dimensional format, for example in the format of horizontal value, vertical value and angle value. Furthermore, the cognition unit 20 may transform the position of the identified object from the camera coordinate to robot coordinate. In other embodiments of the present disclosure, the cognition unit 20 may derive the position of the identified object in robot coordinate directly from image space. Processing and techniques of coordinate transformation are well-known in the art and thus is omitted here for simplicity of the descriptions.

[0045] The control unit 30 is configured to receive one or more instructions for performing a task at a target floor and generate one or more

control signals comprising floor information. In the embodiment, the control unit 30 is connected to the cognition unit 20 and is configured to receive position information of the identified object(s) and send control command including operation and position information to the actuator unit 40. For example, the control units 30 may receive the vertical coordinate, the horizontal coordinate and the orientation angle of the call button on the elevator control panel and generate a corresponding press command to press the call button located at the position indicated by the coordinates and orientation.

[0046] The actuator unit 40 is connected to the control unit 30 and is configured to receive the control command from the control unit 30 and to execute the control command for operating the elevator. The actuator unit 40 is configured to move in at least 3 degrees of freedom of rotational, or rotational and translational, movements corresponding to at least two joint points and two arms. In some embodiments of the present disclosure, the actuator unit 40 is configured have three joints and two arms connected by two joint points. Two joints of the actuator unit 40 are configured to perform rotational motions of the two arms around the two joint points, which provide two degrees of freedom. Each of the two arms can be rotated respectively by rotation of a corresponding joint. A third degree of freedom is provided by a third joint for translational or rotational movement. In some embodiments of the present disclosure, the third joint can be disposed at one of the two joint points for providing translational movement or rotational movement in another direction of the corresponding arm. In other embodiments of the present disclosure, the third joint is disposed at a third point for providing rotation or translational movement of a third arm or end effector.

[0047] For example, the actuator unit 40 is configured have three joints disposed at two joint points connecting to two arms. Two joints of the actuator unit 40 is capable to perform rotational motions of the two arms around the two joint points, which provide two degrees of freedom. Each of the two arms can be rotated respectively by rotation of a corresponding joint. A third degree of freedom is provided by a third joint for translational movement of an arm. The first two joints may rotate in the same direction or different directions depending on the design requirements. In another example, the third degree of freedom is provided as rotational movement around the joint point connected to the base or body of the mobile robot 1.

[0048] Preferably, in embodiments of the present disclosure, the actuator unit 40 is disposed on the main body of the mobile robot 1 with a height from the ground level and similar to the lowest height of the elevator control panel. Typically, the elevator control panels are disposed at a height within reachable range of human arms while standing or sitting in a wheelchair. In all conditions, the elevator control panels will not be placed near ground or ceiling. To allow the mobile robot 1 to operate the control panels easily, the actuator unit 40 is disposed at a height in conform with elevator panel designs. In addition, the available space in the elevator box is limited and floor control panels of different elevators may be disposed at different sides of walls. It is difficult for the mobile robot 1 to move its position in the elevator box for operating the control panel when the elevator box is also occupied by other humans. To allow the mobile robot 1 to operate the control panels disposed at different places, the actuator unit 40 is preferably disposed on top of the mobile robot 1 or a position on the mobile robot 1 that permits rotation of the entire actuator unit 40 on X-Y plane.

[0049] FIG. 3A and FIG. 3B schematically show an embodiment of the present disclosure, in which the mobile robot 1 is instructed to arrive a target floor. As can be observed in FIG. 3A and FIG. 3B, the sensing module 11 of the sensing and perception unit 10 and the actuator unit 40 are arranged nearby each other on the mobile robot 1 with similar heights to the ground in the embodiment. Such arrangement has the advantage that the point of view of the sensing module 11 would be very similar to that of the actuator unit 40, thereby reducing the complexity of transformations from camera coordinate to robot coordinate. In the operation of FIG. 3A, the sensing module 11 captures images containing the control panel 9 and the perception module 12 may process the image to identify a target button 90 according to the task instruction. The cognition unit 20 may perform further processing to determine coordinate and angle position information of the target button 90 relative to the mobile robot 1, particularly to the actuator unit 40. In the operation of FIG. 3B, the control unit 30 received the position information of the target button 90 and send a press control command including the position information to the actuator unit 40. Consequently, the actuator unit 40 moves toward the target button 90 and press on the target button 90.

[0050] In the embodiment of FIG. 3B, the actuator unit 40 has at least 3 degrees of freedom, including a first joint for panning M1, a second joint for tilting M2 and a third joint for extending M3. The first joint is disposed on the main body of the mobile robot 1 and connects to one end of a first arm of the actuator unit 40 for providing rotation of the first arm, the second joint is disposed at the other end of the first arm and connects to one end of a second arm for providing rotation of the second arm, and the third joint is connected to the second arm for providing translation of the second arm. Together the 3 joints drive an end effector 41 connected to the other end of

second arm to press the target button 90. In particular, the actuator unit 40 drives the end effector 41 to press the target button 90 in an angle close to perpendicular. The actuator unit 40 may map the position information of the target button 90 into motions of the three joints and end effector 41 so as to align the end effector 41 substantially in perpendicular with the target button, or as close to perpendicular as possible.

[0051] FIG. 4A and FIG. 4B schematically show an exemplary scenario of the mobile robot 1 operating the elevator control panel at the elevator lobby. FIG. 5 schematically shows a docking path of the mobile robot 1 outside the elevator. In this scenario, the mobile robot 1, upon receiving instruction to arrive at another floor, needs to approach the elevator call button panel 9, detect the elevator call buttons (up or down) and press the target button 90. Referring to FIG. 1 to FIG. 5, when the mobile robot 1 reach the elevator lobby (to take the elevator), it will need to press the elevator call button to call the elevator to its current floor. The mobile robot 1 need to approach the elevator call button panel 9. In the embodiment, the cognitive actuation system 2 senses the elevator call button panel 9 and detects the elevator call buttons (up or down) through the sensing module 11 of the sensing and perception unit 10, and determines position of the elevator call button panel 9 in terms of the vertical coordinate (Z), the horizontal coordinate (X) and an orientation angle (θ) through the cognition unit 20. Preferably but not exclusively, the sensing and perception unit 10 and the cognition unit 20 sense and determine the state and positions of various objects nearby the elevator, such as human location PP, the call-button-panel location PA, and the elevator-door location PB based on, for example point cloud feature technology. The mobile robot 1 may first approach to the call-button-panel location PA (docking outside), and detect the call button panel

9. Then, the control unit 30 of the actuation system 2 on the mobile robot 1 controls the actuator unit 40 to press the target button 90 on the button panel 9, respective position information, in which each of the target button 90 has respective position information relative to the mobile robot 1 at the call panel location PA. After completion of the button pressing process, the mobile robot 1 can be re-positioned to another waiting location for entering the elevator or stay at the call panel location PA.

[0052] Notably, high precision docking of the mobile robot 1 to the elevator button panel 9 is not required as the position of the mobile robot 1 will usually vary in terms of 2D position (X, Y) and orientation angle (θ). As such, the cognitive actuation system 2 can be applied to mobile robots using 2-dimensional (2D) spatial positioning (e.g., waypoint positioning) to achieve the effective use of the elevators (press the elevator call and floor buttons) and the auto-doorway (tap access card). FIG. 6A to FIG. 6C are schematic diagram illustrating examples of the actuator unit 40 pressing the target button while the mobile robot is in different orientations. While the mobile robot 1 has approached in different orientations, the actuator unit 40 with 3 DOF has the capabilities of pressing the target button 90 on the button panel 9. The actuator unit 40 of the cognitive actuation system 2 will be able to reach the target button 90 without re-orientating the mobile robot 1. FIG. 7 is a schematic diagram illustrating example of typical position variances of the mobile robot relative to the button panel. The mobile robot 1 approaches the elevator button panel 9 and operate on the target button 90 in 3-dimensional space. These positions are illustrated in graphical from. From the graph, the typical positional variances of the mobile robot 1 viewed from the call button panel 9 in X, Y in cm. It demonstrates the capabilities of the actuator unit 40 to press the target button while the mobile base of the mobile

robot 1 is in different orientations. Certainly, the present disclosure is not limited thereto.

[0053] FIG. 8A and FIG. 8B schematically show the mobile robot for controlling an elevator to a target floor. FIG. 9 schematically shows a docking path of the mobile robot inside the elevator. In the scenario, the mobile robot 1 needs to approach the elevator floor button panel 9, detect the elevator floor buttons (e.g., level 8) and press the target button 90. Referring to FIG. 1, FIG. 2, FIG. 8A, FIG. 8B and FIG. 9, when the mobile robot 1 is inside the elevator, it will need to press a target button 90 on the elevator floor button panel 9 to instruct the elevator moving to its target destination floor. The mobile robot 1 needs to approach the elevator floor button panel 9 (inside the elevator), detect the elevator floor buttons (e.g., level 8) and press the target button 90. In the embodiment, the cognitive actuation system 2 senses the elevator floor button panel 9 and detects the elevator floor buttons (e.g., level 8) through the sensing and perception unit 10, and positions the button panel 9 in terms of the vertical coordinate (Z), the horizontal coordinate (X) and an orientation angle (θ) through the cognition unit 20. Preferably but not exclusively, the sensing and perception unit 10 and the cognition unit 20 are capable to detect the state and positions, such as the call-button-panel location PA, the elevator-door location PB and the floor-button-panel location PC of the elevator based on point cloud feature technology. The mobile robot 1 can approach to the floor-button-panel location PC (docking inside), and detect the floor button panel 9 firstly. Then, the control unit 30 on the mobile robot 1 controls the end effector 41 of actuator unit 40 to press the target button 90 on the button panel 9 according to the vertical coordinate, the horizontal coordinate and the orientation of the

button panel 9. After completion of the button pressing process, the mobile robot 1 can be positioned to wait for arrival to the target destination floor.

[0054] Notably, for different elevator models the floor button panel 9 (inside the elevator) may have different button arrangements or layouts. FIG. 10A and FIG. 10B schematically show different floor button panels inside the elevator. Since panel layouts of different elevators may be different, the actuator unit 40 of the present disclosure can be set and/or actuated according to the dimensions of the buttons and the button panel measured by the sensing and perception unit 10. FIG. 10A shows an exemplary the button panel having vertical arrangement. The base of the actuator unit 40 can set at a height D_{cFH} relative to the floor FL, for example 950 mm, and the actuator unit 40 has a vertical reaching range D_{cpy} (for example 300 mm) relative to the button panel 9a for pressing a upper most button on the button panel 9a. In the exemplary embodiment the actuator unit 40 is able to reach 90% coverage of the elevator. Similarly, FIG. 10B shows the button panel having horizontal panel arrangement. Preferably but not exclusively, the actuator unit 40 is disposed at a height D_{cFH} nearby a lower edge of the button panel relative to the floor FL, for example 950mm, and the actuator unit 40 has a horizontal reaching range D_{cpx} (for example 150 mm) relative to the width of the floor button panel 9b, so that the actuator unit 40 is able to reach 95% coverage of the elevator. Certainly, the vertical reaching range and the horizontal reaching range are adjustable according to the usage requirements, and the present disclosure is not limited thereto.

[0055] FIG. 11A and FIG. 11B show the actuator unit for upwardly and downwardly pressing the target button according to the embodiment of the present disclosure. As shown in FIG. 11A, in the embodiment, the actuator unit 40a is able to extend in upward direction and fold back at a home

position, for example the actuator unit 40a may consist of a telescopic rod that retracts to its original position upon a button is pushed. As shown in FIG. 11B, in the embodiment, the actuator unit 40a is able to extend in downward direction and fold back to the home position. For the floor button panel 9 of the elevator with multiple columns of buttons higher than the base of the actuator 40a, the actuator unit 40 takes a few seconds in average to press the target button 90 and return to the home position. Furthermore, the actuator unit 40a with at least 3 DOF in the present disclosure will be able to reach all columns without re-positioning or re-orientating the mobile robot 1. Certainly, the present disclosure is not limited thereto.

[0056] In another scenario, when the mobile robot 1 encounters an auto-doorway in a building, the mobile robot 1 just need to activate the door by positioning the mobile robot 1 in front of authentication system of the doorway to swipe or scan the door pass ID card. FIG. 12A and FIG. 12B schematically show the mobile robot for activating an auto-doorway with a card sensor panel. Please refer to FIG. 1, FIG. 12A and FIG. 12B. In the scenario of a card access auto-doorway, the mobile robot 1 needs to approach the card sensor 9c (beside the door), detect the card sensor 9c and position the end effector 41 (holding access card or with RFID tag inside) near the card sensor 9c. In the embodiment, the cognitive actuation system 2 senses and detects the card sensor 9c through the sensing and perception unit 10, and positions the access card sensor 9c in terms of the vertical coordinate (Z), the horizontal coordinate (X) and an orientation angle (θ) through the cognition unit 20. Then, the control unit 30 of the mobile robot 1 controls the end effector 41 of actuator unit 40 to position the access card or an RFID tag in sensing proximity to the card sensor 9c according to the vertical coordinate, the horizontal coordinate and the orientation of the card sensor

9c. Next, the mobile robot 1 may wait for the door to open or press a door open button to open the door.

[0057] FIG. 13A and FIG. 13B schematically show the mobile robot for activating a button-activated auto-doorway. Please refer to FIG. 1, FIG. 13A and FIG. 13B. In the scenario of a button-activated auto-doorway, the mobile robot 1 needs to approach a door-open button 9d, detect the door-open button 9d, and press the door-open button 9d. In the embodiment, the mobile robot 1 senses and detects the door-open button 9d through the sensing and perception unit 10, and identifies the door-open button 9d in terms of the vertical coordinate (Z), the horizontal coordinate (X) and an orientation angle (θ) through the cognition unit 20. Then, the control unit 30 of the mobile robot 1 controls the end effector 41 of actuator unit 40 to press the door-open button 9d according to the vertical coordinate, the horizontal coordinate and the orientation of the door-open button 9d. Certainly, the cognitive actuation system 2 on the mobile robot 1 can be used to activate various auto-doorway, and the actuation steps are adjustable according to the practical requirements. The present disclosure is not limited thereto, and not redundantly described herein.

[0058] From the above, the mobile robot 1 with the actuator unit 40 with multiple degrees of freedom can be implemented on a two-wheel AMR for industrial transportation use, or the other AMR types (e.g., four wheel omni-directional AMR) and can also be implemented with different position. With the actuator unit 40 having at least 3 DOF disposed on the mobile robot 1, it is allowed to access the elevator call buttons (outside elevator) the floor buttons (inside elevator), or the auto-doorway's button while compensating for the variability of the mobile robot's pose.

[0059] FIG. 14A to FIG. 14F show examples of the actuator units having at least 3 DOF for the mobile robot of the present disclosure. In FIG. 14A, the actuator unit 40c has 3 degrees of freedom and includes a first joint for panning M1, a second joint for tilting M2 and a third joint for extending M3. Preferably but not exclusively, the first joint is mounted on a top surface of the mobile robot 1, and the third joint is connected to drive the end effector 41 to press a button. In FIG. 14B, the actuator unit 40d has 3 degrees of freedom and includes a first joint for panning M1, a second joint for rotating M2 and a third joint for rotating M3. In FIG. 14C, the actuator unit 40e has 3 degrees of freedom and includes a first joint for rotating M1, a second joint for panning M2 and a third joint for rotating M3. In FIG. 14C, the actuator unit 40e has 3 degrees of freedom and includes a first joint for panning M1, a second joint for rotating M2 and a third joint for rotating M3. In FIG. 14D, the actuator unit 40f has 4 degrees of freedom and includes a first joint for panning M1, a second joint for rotating M2 and a third joint for rotating M3. Furthermore, the actuator unit 40f includes an additional joint for extending M4 vertically. Preferably but not exclusively, the additional joint is connected to the first joint and configured to be assembled on the mobile robot 1. In FIG. 14E, the actuator unit 40g has 4 degrees of freedom and includes a first joint for panning M1 and rotating M2, a second joint for rotating M3 and a fourth joint M4 for rotating to ensure that the end effector 41 connected to the fourth joint is perpendicular to the target button during actuation. Certainly, the present disclosure is not limited thereto. In FIG. 14F, the actuator unit 40h has 4 degrees of freedom and includes a first joint for panning M1, a second joint for rotating M2 and a third joint for extending M3 to press the target button. Furthermore, the actuator unit 40h includes an additional joint for extending M4 vertically. Preferably but not exclusively,

the additional joint is connected to the first joint and configured to be mounted on the mobile robot 1.

[0060] Notably, each of the above joints is not limited to a conventional joint connected between two arms. In the embodiment, the actuator units 40~40h have at least 3 DOF, the end effectors 41 are driven through the multiple joints, and it allows at least two of the multiple joints to perform two motions through one dual-axis motor. For example, in the actuator unit 40g of FIG. 14E, the panning M1 and the rotating M2 around different axes are provided through one dual-axis motor 42 disposed at the first joint. Furthermore, in order to press the target button steadily, the end effector 41 is controlled to ensure that the end effector 41 driven by the multiple joint is perpendicular to the target button during actuation, as shown in actuator unit 40c of FIG. 14A. In the embodiment as shown in FIG. 14E, the actuator unit further includes bevel gears and sub-links, which are used to rotate the end effector 41 to ensure a perpendicular approach when pressing the target button. Certainly, the motions of the actuator units 40~40h with at least 3 DOF are adjustable according to the practical requirements. The present disclosure is not limited thereto and not redundantly described hereafter.

[0061] On the other hand, the end effectors 41 in the above embodiment may include a tip made of a neoprene or polyurethane (PU) rubber for anti-slip effect, so that the actuator unit 40 can firmly press the target button without slipping. In some embodiments, the tip may detachable, and can be swapped out easily. In some embodiments, the end effector 41 is a soft end effector having a TPU tip, which is able to deform when pressing the target button. In other embodiments, the end effectors 41 may be anti-abrasion, resistant to chemicals and hardening over time. In other embodiments, the actuator unit 40 further includes a spherical end

effector or a capsule-shaped end effector, which are detachable and replaceable. In other words, the shape and size of end effector 41 in the above embodiments can be swapped out easily, and different shapes can be used depending on the target button. Moreover, it allows to embed the RFID tag and/or the tactile feedback sensor 50 into the end effector 41 for various applications. Certainly, the present disclosure is not limited thereto and not redundantly described hereafter.

[0062] Please further refer to FIG. 1, FIG. 2, FIG. 3A and FIG. 3B. In the above embodiment, a tactile feedback sensor 50 is further integrated with the end effector 41 of the actuator unit 40 for button pressing feedback. Since the tactile feedback sensor 50 is integrated with the end effector 41 of the actuator unit 40, it allows to sense if the actuator unit 40 has successfully pressed the target button 90 and stop movements of the actuator unit 40 after the target button 90 has been pressed. Namely, the actuator unit 4 further provide feedback to the control unit 30 to know whether the button pressing action has been completed successfully, and also to prevent overexerting the actuator unit 40, which may lead to component failure or damage to the elevator button panel. Certainly, the present disclosure is not limited thereto and not redundantly described hereafter.

[0063] In summary, the present disclosure provides an autonomous mobile robot having a robot arm with multiple degrees of freedom to use elevators and auto-doorway without communication ability. The autonomous mobile robot includes an actuator unit disposed on the autonomous mobile robot. With the actuator unit having at least 3 degrees of freedom (DOF) (i.e., pan, tilt, and extend), it is possible to access the elevator call buttons (outside the elevator), the floor buttons (inside the elevator), or the auto-doorway's button while compensating for the

variability of the mobile robot's pose. High precision docking of the autonomous mobile robot to the elevator button panel (inside or outside) is not required as the position of the mobile robot will usually vary in terms of 2D position (X , Y) and orientation angle (θ). As such, it allows the autonomous mobile robots using 2-dimensional (2D) spatial positioning (e.g., waypoint positioning) to achieve the effective use of the elevators (press the elevator call and floor buttons) and the auto-doorway (tap access card). In addition, the autonomous mobile robot further includes a tactile feedback sensor to sense if the actuator unit has pressed an elevator button and stops the actuator motion (extending) after a button has been pressed. This will provide feedback to the autonomous mobile robot to know when the button press action has been completed successfully, and also prevent overexerting the actuator unit, which may lead to component failure or damage to the elevator button panel. While the mobile robot has approached in different orientations, the actuator unit with at least 3 degrees of freedom has the capabilities of pressing a target button on the button panel, which has multiple columns of buttons. The actuator unit of the autonomous mobile robot will be able to reach the target button in all columns without re-orientating the mobile robot. In addition, to enhance the performance and effectiveness of the cognitive actuation system, the autonomous mobile robot further includes a tactile feedback sensor to sense if the actuator unit has pressed the target button and stops the actuator motion (extending) after the target button has been pressed. This will provide feedback to the autonomous mobile robot to know when the button press action has been completed successfully, and also prevent overexerting the actuator unit, which may lead to component failure or damage to the elevator button panel. Notably, 3 DOF actuator unit is minimally required, and there is no need for

precise positioning of the autonomous mobile robot. It has more scalability to operate in different elevator models and has advantage of cost effective and interoperability.

[0064] While the disclosure has been described in terms of what is presently considered to be the most practical and preferred embodiments, it is to be understood that the disclosure needs not be limited to the disclosed embodiment. On the contrary, it is intended to cover various modifications and similar arrangements included within the spirit and scope of the appended claims which are to be accorded with the broadest interpretation so as to encompass all such modifications and similar structures.

WHAT IS CLAIMED IS:

1. An autonomous mobile robot having robot arm with multiple degrees of freedom for riding an elevator without communication ability, comprising:

a control unit, configured to receive a task instruction for performing a task at a target floor and generate a control signal comprising floor information of the target floor;

a sensing and perception unit, configured to obtain sensing data and provide a perception result indicative of an object related to the elevator from the sensing data according to the control signal;

a cognition unit, configured to derive position and orientation of the object relative to the autonomous mobile robot; and

an actuator unit, having multiple joints and an end effector in at least 3 degrees of freedom;

wherein the control unit is further configured to send a control command comprising position and orientation information to the actuator unit, and the actuator unit is configured to receive and execute the control command to perform an operation with the object by the end effector.

2. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the sensing and perception unit comprises a sensing module configured to obtain one or more images and a perception module configured to identify the object in the one or more images.

3. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 2, wherein the sensing module is further configured to obtain one or more images containing a control panel of the elevator, and the perception unit is further configured to identify a button on the control panel of the elevator according to the floor information.

4. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the position and orientation information comprises a vertical coordinate, a horizontal coordinate and an orientation angle of the object.
5. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the end effector is driven through the multiple joints, and at least two of the multiple joints are configured to perform motions through a dual motor.
6. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the end effector is driven to perform the operation with the object in a perpendicular angle.
7. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the end effector comprises a tip, and the tip is detachable, replaceable, deformable, soft or anti-abrasion.
8. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the actuator unit further comprises a tactile feedback sensor integrated with the end effector for providing feedback to the control unit.
9. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the multiple joints comprise a first joint and a second joint for panning or rotating and a third joint for rotating, wherein the first joint is disposed on a top surface of the autonomous mobile robot, and the third joint is connected to drive the end effector connected thereto to perform the operation with the object.
10. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 8, wherein the multiple joints further comprise an additional joint for extending vertically.

11. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the multiple joints comprise a first joint for panning, a second joint, a third joint and a fourth joint for rotating to drive the end effector connected to the fourth joint.
12. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the multiple joints comprise a first joint for extending, a second joint for panning, a third joint for rotating and a fourth joint for rotating to drive the end effector connected to the fourth joint.
13. The autonomous mobile robot having robot arm with multiple degrees of freedom according to claim 1, wherein the autonomous mobile robot is configured to navigate by 2D spatial positioning and is configured to sense and perform the operation with the object at a fixed location.