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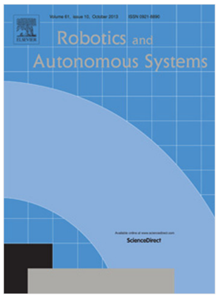

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Experimental Investigation on Climbing Robot Using Rotation-flow Adsorption Unit

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***Abstract*— Traditional climbing robots that use vacuum suckers have some technical problems, e.g., inability to climb coarse walls, frictional resistance and abrasion of suckers, and poor obstacle-surmounting ability. In this study, a new negative pressure adsorption mechanism is applied to the design of a climbing robot. This mechanism generates and maintains negative pressure and adsorption force by using the air's rotational inertia effect; therefore, the structure incorporating this mechanism is called the rotational-flow adsorption unit. The most important characteristic of the adsorption unit is that it can function without being in contact with the wall, which fundamentally solves these technical problems associated with traditional climbing robots. In this study, we designed a square-shaped rotational-flow adsorption unit to improve the robot's load ability (18% increase in the adsorption force) and designed a soft skirt structure to improve the robot's obstacle-surmounting ability (e.g., passing through 15-mm-high bulges). Finally, we fabricated a prototype of the climbing robot and tested it on several actual walls (extremely coarse wall, wall containing deep groove, and wall containing large bulges). The test results show that our prototype robot can move stably on coarse walls and can pass over large grooves and bulges easily.**

***Index Terms*—climbing robot, adsorption unit, rotational flow, load ability, obstacle-surmounting ability**

1. Introduction

Climbing robots can replace people in completing highly dangerous tasks that require strength, such as cleaning and inspecting high-rise buildings, evaluating and diagnosing storage tanks in nuclear power plants and petrochemical facilities, and performing welding and maintenance of ship hulls [1-4]. Therefore, these robots are widely used in various engineering applications. In the past few decades, many researchers have proposed various types of climbing robots. According to the principle of adsorption employed in these robots, they are mainly classified as propulsion-type [5-7], magnetic-type [8-13], biomimetic-type [14-20], electrostatic-type [21-23], vacuum-type [24-29] and mixed type[30, 31] wall-climbing robots.

(1) The propulsion-type climbing robot uses a propeller to generate exhaust behind it along the wall; thus, reverse thrust is generated, which pushes the robot along the wall. However, because the propeller and its driving mechanism are large and heavy, additional hoisting rope needs to be used to balance the robot's weight, which reduces the ability and range of the robot's movement on the wall.

(2) Magnetic adhesion solutions, including permanent magnetization or electrical magnetization, can provide a large adsorption force, strong load capacity, and good stability during movement. In addition, permanent magnetic adhesion does not consume energy when generating the adsorption force. However, the limitation of magnetic adhesion is that it can only work on surfaces made of magnetic materials.

(3) Robots based on biomimetic adhesion attach themselves onto a wall by simulating the surface structure of biological feet (e.g., those of geckos and ants). The advantages of these robots are that they can work on almost any surface—wet or dry, smooth or rough—and do not consume any additional energy. The disadvantages of these robots are that the bionic gripper currently used in these robots is sensitive to dusty surface conditions and can provide only a small adsorption force, which results in the robot having a weak load capacity.

(4) The climbing robot based on electrostatic adsorption has advantages such as low noise and low power consumption. However, the electrostatic adsorption method can generate only a small adsorption force, and because the adsorption electrode is driven by a high voltage, electrode breakdown can occur easily. Researchers are now trying to devise methods to reduce the driving voltage of the adsorption electrode while ensuring that the adsorption force is not reduced.

Compared to the four abovementioned adsorption methods, vacuum adsorption (vacuum sucking) is more commonly used for developing climbing robots. Vacuum adsorption generates negative pressure by using a vacuum generator or an impeller and can produce a large adsorption force on walls made of various materials. Nevertheless, vacuum adsorption has an obvious drawback. The vacuum adsorption unit needs to be in close contact with the wall to realize vacuum sealing and this creates some problems. First, if the wall is rough or has any grooves on it, vacuum leaking will occur and the vacuum adsorption unit will fail. Second, if there is a bulge on the wall (even if its height is small), the vacuum adsorption unit will fail to pass over it. Lastly, the close contact between the vacuum adsorption unit and wall will produce a frictional force, which will impede the robot's movement and cause abrasions on the vacuum adsorption unit. To solve these technical problems, researchers have proposed many solutions. For example, Hillenrand divided the vacuum cavity into multiple child cavities [32]. Each child cavity was connected to the vacuum source through a valve and had a pressure sensor. When the pressure sensor of a child cavity detected a large drop in negative pressure, it concluded that this child cavity was experiencing a vacuum leak (e.g., when a child cavity was above a groove), and the valve of this leaking child cavity would be closed to prevent the leaking from influencing the vacuum source and other child cavities. This design helped the robot to walk well on walls with grooves on it. Miyake proposed a vacuum-based wet adhesion technique [33], which worked well with rough walls; it involved filling a liquid between the vacuum adsorption unit and wall, which substantially reduced the frictional force and abrasion of the vacuum adsorption unit. In the climbing robot developed by