

CLIMBING ROBOTS: A SURVEY OF TECHNOLOGIES AND APPLICATIONS

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The interest in the development of climbing robots is growing rapidly. Motivations are typically to increase the operation efficiency by obviating the costly assembly of scaffolding or to protect human health and safety in hazardous tasks. Climbing robots are starting to be developed for applications ranging from cleaning to inspection of difficult to reach constructions. These robots should be capable of travelling on different types of surfaces, with varying inclinations, such as floors, walls, ceilings, and to walk between such surfaces. Furthermore, these machines should be capable of adapting and reconfiguring for various environment conditions and to be self-contained. Regarding the adhesion to the surface, they should be able to produce a secure gripping force using a light-weight mechanism. This paper presents a survey of different applications and technologies proposed for the implementation of climbing robots.

Keywords: Robotics, Climbing, Walking, Suction, Adhesion.

1. Introduction

Climbing robots are useful devices that can be adopted in a variety of applications like maintenance, building, inspection and safety in the process and construction industries. These systems are mainly adopted in places where direct access by a human operator is very expensive because of the need for scaffolding, or very dangerous due to the presence of a hostile environment.

A wall climbing robot should not only be light but also have large payload so that it may reduce excessive adhesion forces and carry instrumentations during navigation.

Up to now a lot of research has been devoted to wall climbing robots and various types of experimental models have been already proposed. The major two issues in the design of wall climbing robots is their locomotion

and adhesion methods.

With respect to the locomotion type, three types are often considered: the crawler type, the wheeled type and the legged type. Although the crawler type is able to move relatively faster, it is not adequate to be applied in rough environments. On the other hand, the legged type easily copes with obstacles found in the environment, whereas generally its speed is lower and requires complex control systems.

According to the adhesion method, these robots are generally classified into four groups: magnetic, vacuum or suction cups, gripping to the surface and propulsion type. Recently, new methods for assuring the adhesion, based in biological findings, have been proposed. The magnetic type principle implies heavy actuators and is used only for ferromagnetic surfaces. The vacuum type principle is light and easy to control though it presents the problem of supplying compressed air. An alternative, with costs in terms of weight, is the adoption of a vacuum pump. The propulsion type robots are used in very restricted applications.

Bearing these facts in mind, the paper is organized as follows. Section two presents several climbing robots applications. Sections three and four present the main locomotion principles, and the main technologies for adhering to surfaces that these robots adopt, respectively. Section five introduces some new architectures for climbing robots and, finally, section six outlines the main conclusions.

2. Climbing Robots Applications

Climbing robots are mainly adopted in places where direct access by a human operator is very expensive, because of the need for scaffolding, or very dangerous, due to the presence of an hostile environment.

In the last decades, different applications have been envisioned for these robots, mainly in the technical inspection, maintenance and failure or breakdown diagnosis in dangerous environments. These tasks are necessary in the outside of tall buildings, bridges,^{1,2} nuclear power plants³ or pipelines,⁴ for scanning external surfaces of gas or oil tanks^{4,5} and offshore platforms,² for performing non-destructive tests in industrial structures,^{6,7} and also in planes^{1,8,9} and ships.^{1,10} Furthermore, they have been applied in civil construction repair and maintenance,² in the prevention and fire fighting actions, in anti-terrorist actions,¹¹ in cleaning operations in sky-scrapers,¹²⁻¹⁵ for cleaning the walls and ceilings of restaurants, community kitchens and food preparation industrial environments,¹⁶ in the transport of loads inside buildings¹⁷ and for reconnaissance in urban environments.¹⁸ Finally, their

application has also been proposed in the education¹⁹ and human care² areas.

3. Principles of Locomotion

3.1. *Locomotion using Sliding Segments (Crawling)*

With respect to the locomotion type, the simpler alternatives usually make use of sliding segments, with suction cups that grab to surfaces, in order to move.^{3,6,8,12,13,15,16} The main disadvantage that can be attributed to this solution is the difficulty in crossing cracks and obstacles.

3.2. *Locomotion using Wheels*

Another possibility of locomotion is to use wheels.^{4,5,14} These robots can achieve high velocities. The main drawback of some of the wheeled robots that use the suction force for adhesion to the surface, is that they need to maintain an air gap between the surface where they are moving and the robot base. This creates problems with the loss of pressure, or problems with the friction with the surface (if the air gap is too small or if some material is used to prevent the air leak).²⁰

3.3. *Locomotion using Legs*

A final alternative for implementing the locomotion is the adoption of legs. Legged climbing robots, equipped with suction cups or magnetic devices on the feet, have the disadvantage of low speed and require complex control systems, but allow the creation of a strong and stable adhesion force to the surface. These machines also have the advantage of easily coping with obstacles or cracks found in the environment where they are moving.²⁰ Structures having from two up to eight legs are predominant for the development of these tasks. The adoption of a larger number of limbs supplies redundant support and, frequently, raises the payload capacity and safety. These advantages are achieved at the cost of increased complexity, size and weight. Therefore, when size and efficiency are critical, a structure with minimum weight and complexity is more adequate. For these reasons the biped structure is an excellent candidate. Presently there are many biped robots with the ability to climb in surfaces with different slopes.^{1,10,18,21-26} When there is the need for increased safety or payload capability are adopted quadrupeds^{7,10,20,27} and robots with a larger number of legs.^{10,11} The control of these, typically, very large robots, is more complicated in the perspective of the leg coordination.

4. Technologies for Adhering to Surfaces

4.1. *Suction Force*

The most frequent approach to guarantee the robot adhesion to a surface is to use the suction force. The vacuum type principle is light and easy to control. This operating principle allows to climb over arbitrarily surfaces, made of distinct types of materials, and can be implemented by using different strategies. Usually, more than one vacuum cup is used in each feet in order to prevent loss of pressure (and adhesion force) due to surface irregularities.²⁰

This type of attachment has some major drawbacks associated with it. The suction adhesion mechanism requires time to develop enough vacuum to generate sufficient adhesion force. This delay may reduce the speed at which the robot can locomote. Another issue associated with suction adhesion is that any gap in the seal can cause the robot to fall. This drawback limits the suction cup adhesion mechanism to relatively smooth, nonporous, non-cracked surfaces. Lastly, the suction adhesion mechanism relies on the ambient pressure to stick to a wall and, therefore, is not useful in space applications, because the ambient pressure in space is essentially zero.²⁸ Another drawback is the problem of supplying compressed air. The vacuum can be generated through the Venturi Principle^{2,3,6,12,15} or through a vacuum pump, either on-board the robot^{7,11,14,16,18} or external to the robot.¹³

When the vacuum is generated through the Venturi Principle or through vacuum pumps, this makes climbing robots noisy (a solution for this problem has been proposed¹¹). Vacuum pumps on-board the robot increase the weight and the costs of a robot, also due to additional vacuum tubes, mufflers, valves, and so forth. This solution also causes a more or less steady and not negligible energy consumption. Vacuum pumps external to the robot imply the need to a tether cable. Hence, it is desirable to avoid an active vacuum generation and a separate installation for vacuum transportation.

Bearing these ideas in mind, Brockmann proposes the use of passive suction cups because they are low cost, simple and robust and allow a light-weight construction of climbing robots. However, although a promising approach, in order to construct a proper system, several aspects related to the behavior of passive suction cups have to be better understood.²⁵

Another way to create the adhesion is to adopt air aspiration on a sliding chamber and then to move the robot through wheels.^{5,29}

Recently, a third technology, named Vortex Regenerative Air Movement

(VRAM), has been patented. This adhesion system adopts vortex to generate high adhesion forces with a low power.

4.2. *Magnetic Force*

Another principle adopted for creating the adhesion force, in specific cases where the surface allows it, is magnetic adhesion. Magnetic attachment can be highly desirable due to its inherent reliability; furthermore, the method is fast but it implies the adoption of heavy actuators. Despite that, magnetic attachment is useful only in specific environments where the surface is ferromagnetic and, therefore, for most applications it is an unsuitable choice.²⁸

The most frequent solution is the use of electromagnets.^{10,24} Another possibility is the use of permanent magnets to adhere to the surface, combined with wheels or tracks to move along it. The advantage of this last solution is that there is not the need to spend energy for the adhesion process.¹⁹ A third solution is to use magnetic wheels that allow to implement the locomotion and the adhesion at the same time.⁴

4.3. *Gripping to the Surface*

Some developed robots climb through man made structures or through natural environments by gripping themselves to the surface where they are moving. These robots typically exhibit grippers or other gripping system at the extremity of their limbs.

Examples of this kind of robots, are the ROMA 1 robot, that has two legs with grippers at their ends to travel into complex metallic-based environment,² the ASIBOT robot able to move between different points (Docking Stations) of the rooms through an innovative grasping method based on special connectors and a bayonet fitting,² the Lemur IIb, intended for space exploration³⁰ and the ASTERISK robot.³¹

4.4. *Other Adhesion Principles*

In spite of all the developments made up to this point, the technologies presented are still being improved and no definite and stable solution has yet been found. Therefore, development is expected to continue in this research area.

Recently, new methods for assuring the adhesion, based in biological findings, have been proposed.^{28,32-34}

5. New Architectures for Climbing Robots

New architectures have also been proposed for climbing robots in order to allow them to surpass different specific problems and applications, such as to clean the inner side of atriums and glass roofs,¹² hybrid locomotion (combining the benefits of rolling, walking, and climbing locomotion)²⁴ or climbing the wet surface of the hull of ships.¹⁰

Degani et al. introduce a climbing robot mechanism, which uses dynamic movements to climb between two parallel vertical walls. This robot relies on its own internal dynamic motions to gain height. One benefit of dynamics is that it allows climbing with only a single actuated degree of freedom³⁵

6. Conclusions

During the last years the interest in climbing robotic systems has grown steadily. This paper has presented a survey of several robots, adopting different technologies for locomotion and for adhesion to surfaces, and intended for distinct applications.

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