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Development of a Mini–Robot for Climbing Vertical Surfaces

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This paper describes a mini-robot for climbing on walls/vertical surfaces. Taking into consideration the size of a mini-robot, we propose the use adhesives for climbing on walls. while moving on a wall, the adhesion force of the adhesive that has been painted to the wall is used to support the mini-robot.

Keywords: Mini–robot, adhesive, adhesion, wall, leg mechanism.

1. Introduction

In recent years, many researches and developments have been done on micro robots. By definition, micro robots are robots that are smaller than 100 mm^3 in size, but it usually refers to robots which are 10 mm^3 or smaller. There exists various hidden potentials for such micro robots.

Utilizing its small size, micro robots are able to operate within spaces that are too tight for normal robots. For example, in applications such as maintenance and inspection in narrow gaps between machineries, as well as targeted treatment within the human body, there are great expectations for the role of micro robots. Also, as it is inherently lightweight, it is also suitable for applications with severe weight restrictions such as expeditions at other planets or at place Polar Regions.

Micro robots are more than simply miniaturized versions of the larger normal robots. The main reason for this is because of scale factor. For micro–sized parts, when the scale factor of the laws of physics is small, its effects on the operations of the aforesaid parts becomes big. Conversely, when the scale factor of the laws of physics is big, its effects on the operations of the micro–sized parts is small. As the dominant laws of physics being applied in it is different from those of normal robots, micro robots have fundamentally different mechanisms and constructions as compared to normal robots.

Within the category of micro robots, the authors specifically refer to robots within the size range of 10 mm^3 and 100 mm^3 as 'mini–robots'. Within this size range, because of their scale factor, the mini–robots can be constructed with the same construction as normal robots. On top of this advantage, it can also be used in small–sized applications. Also, as micro robots for expeditions have needs for long distance mobility and transportability, the mini–robot which is somewhat larger becomes necessary. With the size of the mini–robots, its maintainability and its manufacturability can be ensured.

While this enables the mini-robot to be useful in various applications, in the considerations of its usage, the biggest limitations are the avoidance of obstacles, and damages arising from it stepping on obstacles. Due to its small size, without a movement function, the mini–robot cannot be applied to works spanning large areas. That being said, even for applications such as the inspection of small parts, objects the size of small rocks would also be relatively large obstacles to the mini–robot. While there are various methods to move a robot beyond an obstacle, the most suitable method for a mini–robot would be to have it move across the surface of the obstacle. As this method is also being used in reality by smaller organisms such as insects, it proves to be a method that is sufficiently effective. Using such a method, while moving the robot across the surface of a large obstacle, that surface would also be included in the coverage of the operations of the robot, thus improving the versatility of the mini–robot.

This paper is written on the basis that the movement across the surface of a wall is the most basic and important process for the movement beyond an obstacle, and hence proposes the usage of the adhesive attachment [1] method as a suitable method for the mini–robot's attachment to a wall. At the same time, the paper gives details on the wall moving mini-robot that was developed to apply this method.

2. Wall movement by adhesive adsorption method

In order to move across the surface of a wall, there is first a need to adhere to the surface of the wall. Prior reports for wall moving robots use either vacuum suction [4][5] or magnetic methods [2][3], but such methods have restrictions in the material of the target wall surface. Moreover, the corresponding constructions tend to be complicated, and are thus difficult to be applied onto the mini–robot.

Therefore, the authors have mimicked the method which smaller organisms use to move across a wall, and thus propose the "adhesive attachment method", which uses adhesives as the wall attachment mechanism.

The main characteristics of this adhesive attachment method are detailed below:

1. There is no particular limitation on the target wall surface material. This enables it to have a wider field of application in terms of movement, as compared to the magnetic adhesion method. Furthermore, as long as there is sufficient

area of adhesion at the contact surface, the adhesives will be able to adhere to porous surfaces, to which vacuum suctions fail to adhere.

2. As the adhesive force does not require any external driving forces, even when driving forces are cut off due to circumstances such as accidents, the adhered condition can still be maintained without the need for any special mechanisms.

3. The scale factor of the attachment force is L^1. When compared to that of magnetic force, L^3 and that of vacuum suction, L^2, this value is smaller, thus enabling small machineries such as the mini–robot to generate a relatively large attachment force for its size.

4. The surface of the wall which was coated with the adhesive will also produce an adhesive effect. Because of this, it is possible to do away with structures that are dedicated to maintaining the attachment, making it an effective method for the mini–robot which is assembled simply and is without complicated structures.

While there are definite advantages as described above, the adhesive force of the adhesives cannot be controlled, and repeated adhesion and peeling off of adhesives is required for movement, thus movement forces of magnitudes corresponding to the weight of the body of the robot are required. Therefore, from this perspective, the "adhesive attachment method" would be the most suited for mini–robots which are lightweight by design.

On the other hand, the movement of micro robots, being smaller than mini–robots in size, is affected to a very large extent by the stickiness of the adhesives due to scale factor. Even if the stickiness of the adhesives is reduced, the movement of the micro robots would still be difficult. Therefore, the size of the mini–robot has the best compatibility with the usage of this method for its movement.

3. The mini–robot for experiments

In order to demonstrate the movement across walls using the adhesive attachment method, an experimental mini–robot (hereinafter referred to as "prototype") with differing leg structures was made. This prototype was constructed simply and minimally, with only the function to move on walls. Table 1 shows its specifications.

For its movement methods, legs, crawlers, wheels and such were considered, but eventually the leg mechanism was chosen, as it produces a relatively large pressing force against the surface of the wall.

In the movement of the leg mechanism on the surface of the wall, the locus of the sole is different depending on the direction of gravitational and adhesive forces, due to differences in conditions for movement on the respective surfaces. Moreover, due to the use of adhesives on the prototypes, whenever the legs contact the surface of the wall, it is necessary to generate a pressing force that is perpendicular to that surface. In this aspect, if the locus of the sole is circular, the sole of the contacting leg would be able to exert a perpendicular force on the surface of the wall during contact. Furthermore, when the lifting leg is peeled off the surface of the wall, the reaction force from the peeling motion will act as an additional pressing force onto the wall at the contacting leg (Fig. 1).

Table 1 Specification of prototype robot

	Prototype
Length	74 [mm]
Width	53 [mm]
Height	47 [mm]
Stride	6 [mm]
Weight	70 [g]
Max. speed	4.3 [mm/s]
Area of feet	200 [mm^2]
D.O.F	1

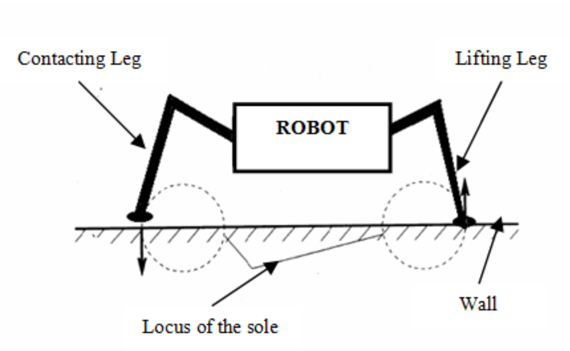

Figure 1 The forces at touching legs

The legs are separated into two groups, and set at a phase difference of 180 degrees. Although this method is structurally very simple, due to its tendency to generate vibrations, its energy efficiency is low. To overcome this, the stroke (or stride) of the legs, as well as the movement speed of the legs were minimized.

For the prototype, the output of the small DC motor placed within the body is transferred onto the contact surface through the gear mechanisms of the body and the adjoining structure of the leg. It has six legs, which are assembled into sets of three legs, and moves by static walking, in the same form as insects. At its soles, special adhesive clay moulds with circular surface areas are assembled, in order to increase the adhesive forces. These adhesive clay moulds are replaceable.

4. Wall movement experiment

The objective of the wall movement experiment is to climb up to the top of the wall. For the adhesive material that was used for the attachment to the wall, commercially available synthetic rubber adhesives were sprayed onto the surface of the wall. As for the material of the wall, readily available material like steel, plywood or plastic were used, yet there were hardly any instances of poor adhesion due to the wall surface being too smooth.

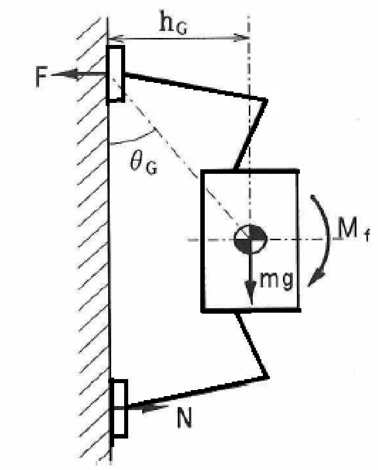

Figure 2 Forces while climbing on a wall

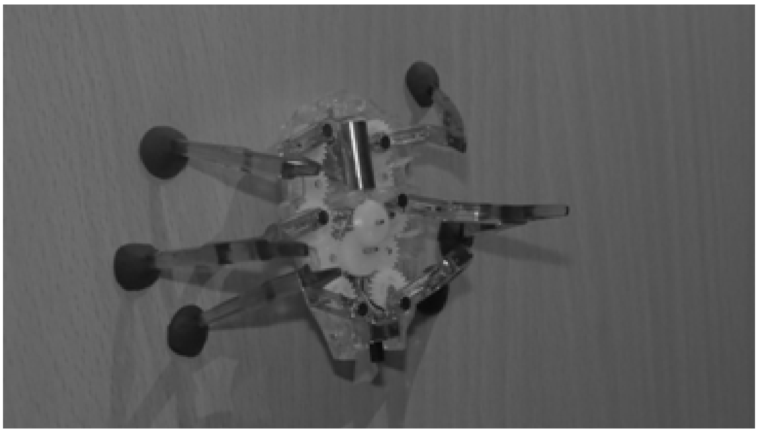

Figure 3 Prototype while climbing on a wall

It was difficult to measure the adhesive forces. This was done by placing the adhesive clay moulds of the soles (198 mm^2) flatly on top of a wall surface, then placing a 100 g weight on it for about 10 seconds, and then measuring the adhesive force by pulling the mould with a spring scale until it peeled off from the surface. There were big fluctuations in the measurement of the peeling force of the adhesive moulds, but the readings were found to be in the range of 110 gf to 200 gf. Also, the pressing force of the legs during walking could not be determined, but in the course of the experiment, there were almost no slippages of the soles, and almost no unintended peeling off of adhesives of the sole. Fig. 2 shows a diagram of the forces acting on the wall and the robot.

The wall moving experiment involving the Prototype was conducted approximately 10 minutes after the coating of adhesives were applied. During the experiment which lasted for at least 20 minutes (up to a maximum of two hours), stable wall climbing through adhesion to the wall was achieved. A picture is shown in Fig. 3.

5. Conclusion

In this report, the need for an obstacle avoidance maneuver function in mini–robots was highlighted, where a mini–robot is defined as a robot 100 mm^3 or smaller in size, which while being categorized as a micro robot, is constructed similarly to the slightly larger normal robots. Also, wall movement by the mini-robot was tested as the first stage to achieving obstacle avoidance maneuver. For the purpose of movement on walls, the "adhesive attachment method" was proposed as the mini-robot's unique method for attachment onto the wall. Through the results obtained through the experimentation of prototypes, it was confirmed that movement on walls was indeed possible. The adhesive attachment method involves the coating of the wall with adhesives, and the subsequent usage of its adhesive forces to derive the necessary forces for the mini–robot's movement on the wall. The spray–type synthetic rubber adhesive which was used in the experiments retained its adhesiveness for a while after it has dried on the coated surface, and is thus a suitable choice of adhesive for this method of adhesion to the wall.

In the aforementioned applications of mini–robots to conduct inspections in narrow gaps between machineries, or to perform investigations within confined spaces, the usage of adhesive attachment method assumes that the walls are rigid. Therefore, while it is not intended to be a method of adhesion for micro robots which enter environments such as the human body, it may be possible for far smaller mini- or micro robots to achieve sufficient adhesion by utilizing the adsorption force of water, without the use of any special adhesives that are customized to their respective scale factors.

On a final note, matters that should be addressed from this point onwards are summarized as follows:

1. Because the mini–robot itself does not have the function to coat the target surface with adhesives, a mechanism for this coating process needs to be considered. As mini–robots usually operate in groups, it is necessary to build mini–robots that specialize in coating adhesives.

2. During the overhanging wall movement experiment conducted on the prototype mini–robot, due to the limitations of the adhesive forces at each leg, its walking motion could not withstand a large overhanging angle. Thus, it is necessary to review and optimize the surface of the sole boards, so that the mini–robot will be able to operate on various wall surfaces.

3. The prototype mini-robots was only made to move up the wall in straight lines. It is necessary to experiment with movements in any given direction

on the wall, as well as with the transition to the mounting of the wall from a horizontal plane.

4. The prototype mini–robot was only capable of moving along flat wall surfaces. It is necessary to consider mechanisms that would allow it to move along uneven wall surfaces as well.

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