CAPABILITY STUDY OF VERTICAL MOVEMENT AND EFFICIENT ATTACHMENT AND DETACHMENT MECHANISMS IN A WALL-CLIMBING ROBOT

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INTRODUCTION

A wall climbing robot is an autonomous leg robot, which climbs vertical surfaces using suction force mechanism and the moving arm mechanism. The wall-climbing robot uses suction as a means of sticking to the wall and uses vacuum pumps to provide sufficient pressure inside the vacuum cups, which are pressed against the wall . The robot controls the movement of its legs by using four stepper motors, which are located on the left and right side of the robot. The robot can move in four directions: forward, backward, left and right. The suction force is supplied by four vacuum pumps, which will turn on intermittently. There are a variety of applications in robotics for wall climbing operations that can increase efficiency, safety and reliability. These applications include inspection of concrete walls, to access the underside of bridges, the inspection large storage tanks in nuclear power plants and cleaning tall buildings, which are usually performed by humans. Wall climbing robots have the potential to provide a revolutionary step in doing risky tasks that are usually performed by humans. Currently, there is a big demand for automatic cleaning systems for the outside surfaces of buildings, such as window glass surfaces, due to modern architecture. Some customized window cleaning machines have already been installed for practical use in the field of building maintenance. However, almost all of them are mounted on the building from the beginning and are very expensive.

The objectives of this study is to conduct a capability study of the vertical movement and efficient attachment and detachment mechanisms of wall–climbing robots.

METHODOLOGY

We selected Degree Of Freedom (DOF) 1 for each leg of the wall-climbing robot. Past literature has found that the suitable DOF is 2. However, owing to the difficulties of contracting the mechanical structure of the robot's arms, we used one DOF to achieve the optimum capability of vertical movements of autonomous robots.

For the robot suction mechanism, we designed a robot with robust and efficient attachment and detachment mechanisms. The factors that have been considered in the development of the suction system for the robot are:

1. Ensure that all suction cups are parallel to the wall surface during the rotational motion of the legs.
2. Using high-vacuum level vacuum pumps so that the suction cups adhere to the surface of a ordinary wall building.

Figure 1 depicts the overall view of the robot. The upper part of Figure 1 shows the top view, while the bottom part of Figure 1 shows the side view of the robot.

The robot works with vacuum cups. It uses the principle of pressure difference of the atmospheric pressure and the inside pressure of the vacuum cup. The pressure difference makes the force of the robot hold on to the wall. Figures 2 and 3 show the force generated in

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the vacuum cup and the vertical surface.

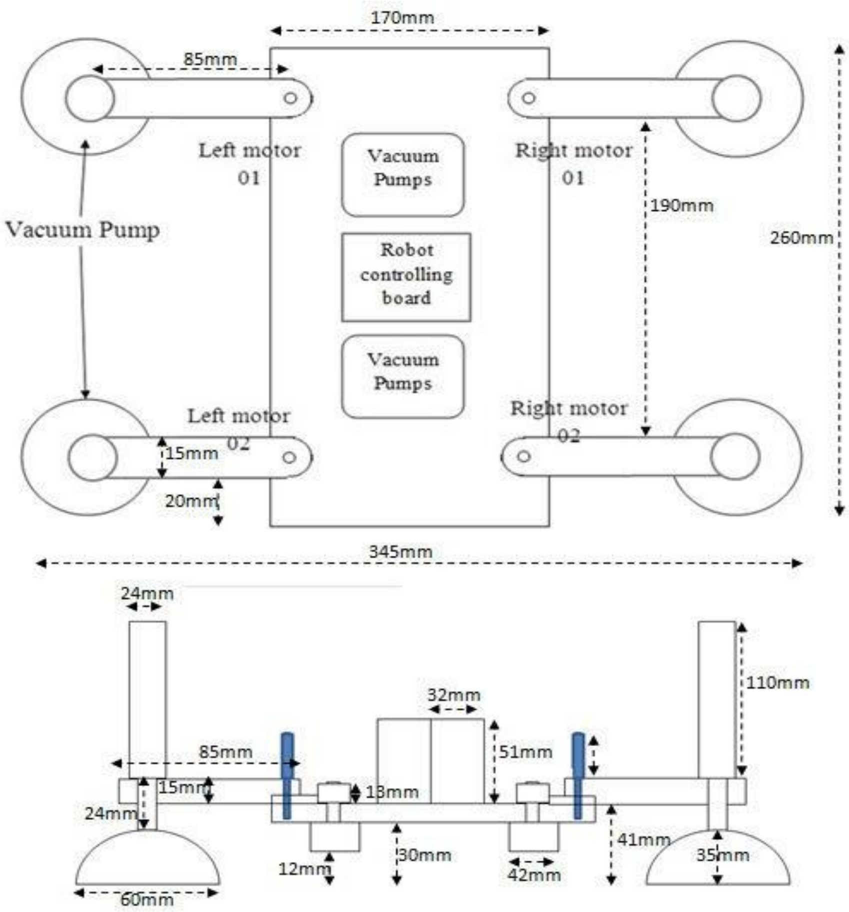


Figure 1: The overall top and side views of the system

Therefore, the force can be found as follows:

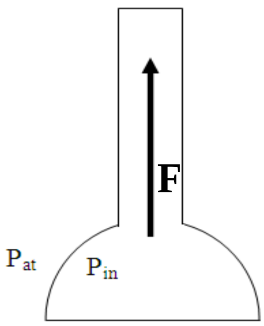


Figure 2: Force generate in Vacuum Cup

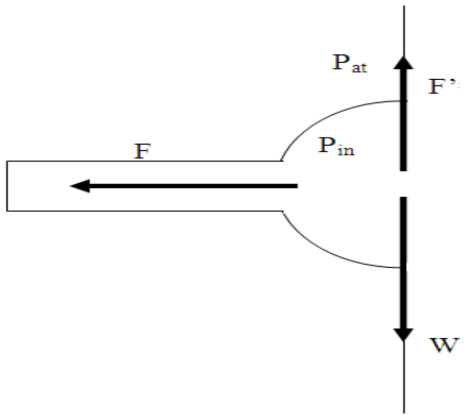


Figure 3: Force generation on vertical surfaces

$$P_{at} - P_{in} = \frac{}{A} \quad (1)$$

$$F = (P_{at} - P_{in})A \quad (2)$$

Where P_{at} =Atmospheric Pressure,
P_{in} =Pressure inside Vacuum Cup,
A =Area of Vacuum Cup

$$F = F'\mu \quad (3)$$

$$W = F \quad (4)$$

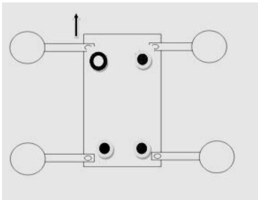
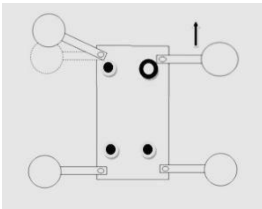
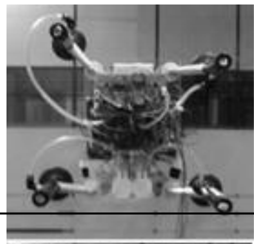
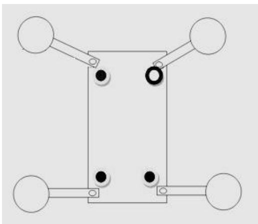
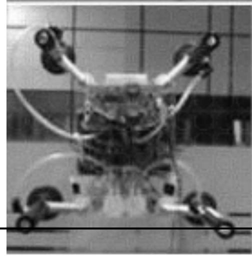
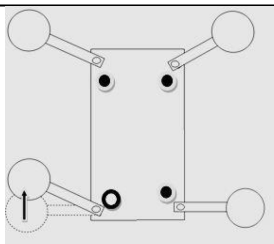
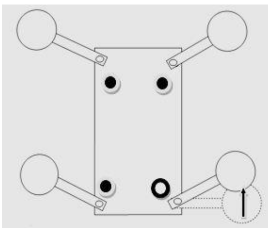
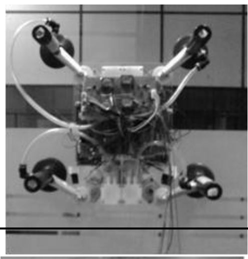
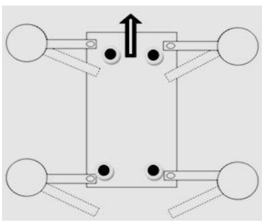
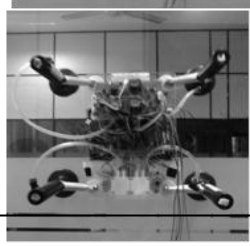
$$W = \mu(P_{at} - P_{in})A \quad (5)$$

Where F = Reaction Force, F' = Frictional Force, µ = Coefficient of Friction between Pad and Wall, it depends on the materials of Wall and pad

RESULTS AND DISCUSSION

The prototype model of the robot required 4 vacuum pumps and four stepper motors. The measured value for each stepper motor needs a 1.87A current when it is operating, and the measured value for each vacuum pump needs a 0.4A current. Therefore, the robot needs a 9.08A current. The computation showed that the maximum weight that can hold a 65k Pavacuum pump with a 60mm vacuum cup of the robot is about 40kg for $\mu = 1$. Table 1 depicts the test results of the study.

Table 1: Comparison of the results for each test case

Test Case Description	Expected results	Obtained Results	Accuracy (%)
This is the initial state of the robot. In this case, the robot obtained the expected result that was described in the methodology section.			100
First movement of the left-upper robot leg			90
Second movement of the left-upper robot leg			90
Third movement of the left-lower robot leg			90
Results of the fourth movement			90
Results of the fifth movement			95

There are six test experiments that have been successfully tested. After the fifth movement, the robot came to the initial state and moved 3cm to the front. The robot takes 4 seconds to complete a cycle (from the initial state to the initial state again). In the six test cases, as explained in Table 1, the robot achieved acceptable accuracy.

CONCLUSIONS/RECOMMENDATIONS

This study proposed and designed a wall-climbing robot for a capability study of vertical movement and efficient attachment and detachment techniques. The designed robot had one degree of freedom, so it is possible to move in a linear path, which can be considered one of the features of the system.

Suction cups and pumps operated efficiently, providing correct pressure as computed in equation 5 for the attachment and the detachment of the robot legs to the wall, while the DOF1 robot legs were controlled by the four stepper motors. It provided sufficient capability to achieve the objectives of the study with acceptable accuracy.

During the robot's movement on the wall, it was found that the robot must always retain the vacuum cups for holding. Also, this can be used only on smooth surfaces. It was unable to operate on irregular or uneven surfaces, as it was not possible to generate a suction force on irregular or uneven surfaces. This is a major disadvantage of suction force controlled robots. However, this is a better way of climbing walls when compared with existing other mechanisms.

It was found that a DOF of more than one is needed for smooth navigation, providing sufficient stability on uneven surfaces. It will also be required to consider using more than 4 legs for safety and navigation on uneven surfaces in this type of robot design.

It was observed that the vacuum pump became heated during the testinge due to the high current passing through the pumps. It is recommended that the use of a PWM pump that is controlled with a current limiting facility would increase safety and stability of wall-climbing applications.

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