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Control of Dynamics and Development of a Wall Climbing Robot

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Abstract—*Wall climbing robots are intended for smooth maneuverability over walls, glass and other vertical surfaces. Manual labor is still used in developing countries to carry out tasks like painting and cleaning of tall buildings. Robots are used to reduce human efforts and automatically carry out tasks which would otherwise require tedious efforts. To overcome the difficulties and risks that entail in manual labor a wall climbing robot can be used to carry out these tasks. Wall- climbing robot can also be used in surveillance applications like in military and security by mounting a high resolution camera. Hikers use their hands to grip the wall tightly to climb and the legs are used for support. A pneumatic mechanism inspired by this motion was derived to help climb the vertical wall surface. The capability of the robot to grip the wall firmly is the main aspect of this robot. This can be achieved by attaching vacuum suction pads which create the required suction and stick firmly against the wall surface and the robot can carry out the various tasks required. Weight of the robot is the main criterion to carry out all the calculations. The weight of robot is kept as minimum as possible so that the robot can move swiftly. This paper presents a proposed design and analysis of a wall climbing robot using pneumatic suction mechanism.*

1. INTRODUCTION

In recent decades, robotic elements have become effective tool to solve many real time issues which humans fail to do. This domain has endless opportunities as well as applications. Fields like medicine, military, automotive engineering, etc. are main domains of robotic applications. Robots for applications like surveillance, wall climbing, cleaning, search and rescue operations, etc. are widely used [1]. There has been development of various algorithms, systems, techniques to build a well performing robot. These kinds of robots have some amount of decision making skills and intelligence.

As human work force increases risk of accidents in jobs like cleaning or painting high rise buildings and wall climbing robots are developed to reduce this risk. Robotic applications not only alleviate human efforts but also reaffirm efficiency in the desired task. An efficient wall climbing robot needs to be developed in order to maximize fault tolerance, dust removal, safety, user interaction, minimize noise, energy consumption.

2. LITERATURE REVIEW

Robots have been designed since early 90's and as per increasing demands in innovative features in robot, there has been an exponential growth in robotic devices. A wall climbing robot is one such innovation in this field. The wall climbing robots are supposed to perform dangerous operations, tasks such as spray painting, cleaning of high rise buildings, working on glass surfaces, maintenance of nuclear plants, etc. According to research carried out at University of Hamburg, Germany, Shanghai Science and Technology Museum has been taken as the operation target and a new kind of cleaning robot named 'Sky Cleaner 3', a cleaning robot on high-rise buildings has been presented [Zhang & Zhang, 2006]. Fig. 1 shows prototype of Sky Cleaner 3.

Mechanism of the robot is completely actuated by pneumatic cylinders and is attached to glass wall with vacuum suckers. It consists of two cross-connected rod less cylinders named X and Y. About 2 degree rotation takes place at every step. The X and Y cylinders are connected to four short-stroke foot cylinders named Z. Function of foot cylinders is to lift and lower the vacuum suckers in their direction. For the movement in right and left direction, ankle joint is used.

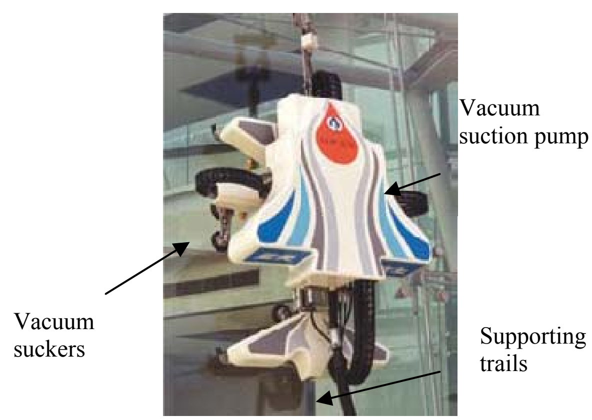

Fig. 1: A Prototype of Sky Cleaner 3, a cleaning robot used on high rise glass buildings [1].

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When the glass wall is being cleaned, used water is drained off because of gravity and collected by a supporting device placed on ground. A Programmable Logic Controller (PLC) is used as control system for the robot. In order to avoid stepping of robot on the cleaned spot, cleaning path for the wall is programmed to move from top to bottom of wall.

Advantages of this robotic system are low cost, high power-to-weight ratio and cleanliness. Use of pneumatic technology gives a great advantage to this system. PLC gives high stability and mobility to the robot. Construction is simple and efficient to achieve certain goals. Pneumatic system having characteristic of non-linearity gives a drawback such as lower stiffness, variable controller is used to implement the accurate control of position servo system. Also this system is applicable for glass surfaces only. The paper presented by Nansai &Mohan (2016) describes six distinct classes based on adhesive mechanism that they use. Authors conclude by expanding beyond adhesive mechanisms by discussing a set of design attributes of an ideal façade cleaning mechanisms. Six classes described in this paper consist of Suction Cup Adhesion, Suction Cup Crawler Adhesion, Vacuum Pump Adhesion, Magnetic Adhesion, Rope and/or Rail Gripping, Bio-Inspired Adhesion. Following subsections describe these classes in detail.

3. DESIGN OF MECHANISM

The proposed mechanism is inspired by hikers using ropes for rock climbing. The hiker uses a rope to grip and hoist himself up while his legs provide support for the upward motion. The term belaying refers to a variety of methods climbers use to reduce tension on a climbing rope so that a falling climber does not fall very far. Whenever climber is not moving, a climbing partner applies tension at the other end of the rope and removes tension from rope. Hikers use their hands to hoist themselves upwards and use their legs to support the weight of body and then climb upwards by stepping up.

The pneumatic circuit was therefore integrated with the electrical circuits as shown in Fig. 2. Then vacuum pad holds on firmly against the surface of wall then suction cups on side of the body remove its suction and allows the cylinder to retract. This extension and retraction of the cylinder is controlled by a Direction Control Valve (DCV). While current is provided to DCV, compressed air will push the cylinder and the piston will extract. The compressed air was passed through pneumatic tubes. Fittings were provided to fix the tubes to the components firmly. This algorithm was modified so that the robot can move smoothly up the wall surface.

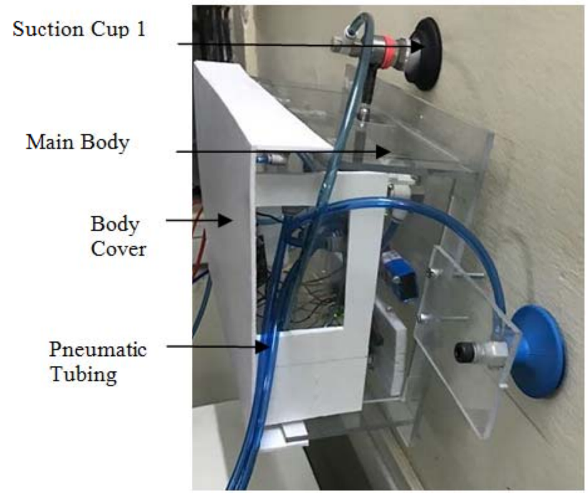

Fig. 2: Experimental setup with electrical and pneumatic connections

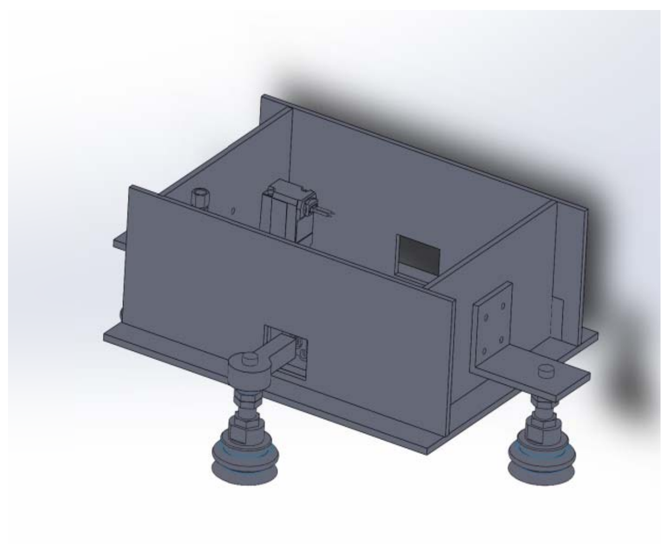

Fig. 3: Isometric view of CAD model of robot.

The cad model in Fig. 3 demonstrates the layout of the robot and its components. A rectangular body is used to hold all the components and circuits. The main body consists of components like spring return cylinder, suction cups, direction control valves and ejectors. An L shaped joint, having suction cups attached to the end, are used as arms of the robot. Robot arm at the top of rectangular body is extracted and retracted using a spring return cylinder. This arm will be the driving force of robot. Other two suction arms are used for support. These arms are activated and deactivated at certain conditions working in a loop. In all, three ejectors are used for three suction cups. Vacuum provided to these suction cups is refined using ejectors.

In the initial stages, suction is activated in all the vacuum pads. Hence, the body is firmly held against wall surface. The rope is replaced by a spring return cylinder which is in turn connected to a vacuum pad. When vacuum in vacuum pad is deactivated, cylinder shaft extends and vacuum pad creates suction and grips the wall. Then vacuum pad holds on firmly against the surface of wall while the suction cups on side of the body remove its suction and allows the cylinder to retract. This extension and retraction of the cylinder is controlled by a Direction Control Valve (DCV). While current is provided to DCV, compressed air will push the cylinder and the piston will extract.

When no current is provided to the DCV the ejector will start working. This action is continued in a loop and hence the robot propels itself upwards. The purpose of the ejector is to create enough negative pressure to in the suction cup which will grip the walls. Meanwhile, another DCV is used to control the suction cup on the lower side.

The flowchart in Fig. 4 gives the flow of process of the proposed mechanism.

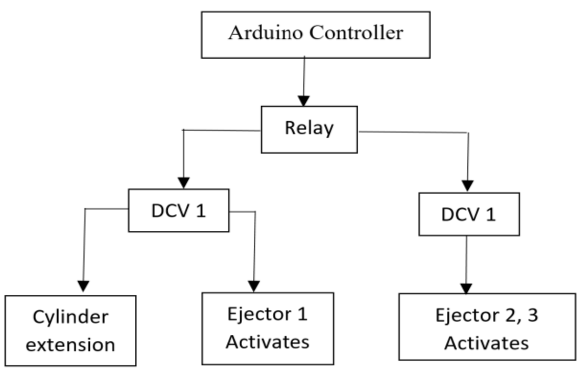

Fig. 4: Flowchart of mechanism

The suction required by the suction cup which will adhere to the wall can be calculated by,

$$P_{at} - P_{in} = F / A \tag{1}$$

where,

P_{at} → Atmospheric Pressure

P_{in} → Pressure inside Vacuum Cup

A → Area of Vacuum Cup

F → Reaction Force

The force which does not let the cup slide on wall is frictional force.

$$R = \mu F \tag{2}$$

where,

R→ Frictional Force

μ → Coefficient of Friction between Cup & wall

The Fig. 5 shows us the direction of forces that act on the suction cup. From this we can calculate the required suction from the vacuum pump that will help the suction cup to stick to the wall. An equation is derived to estimate the desired negative pressure required to adhere the suction cup against the wall.

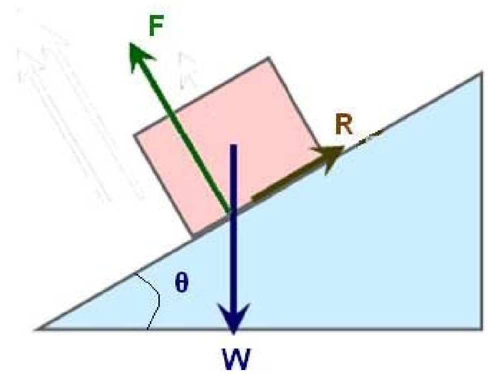

Fig. 5: Forces acting on a Suction Cup

$$R = \mu F = \mu (P_{at} - P_{in}) A \tag{3}$$

$$R = W \cos (90-\theta) \tag{4}$$

$$W \sin\theta = [\mu (P_{at} - P_{in}) A] \tag{5}$$

$$W = [(\mu (P_{at} - P_{in}) A) / (\sin\theta)] \tag{6}$$

where,

W→ Weight of Robot

θ→ Angle of Inclination w.r.t. wall

The change in volume to make necessary changes in weights can be further calculated by the following equation.

$$P_{in} V1 = P_{at} V2$$

$$P_{in} = P_{at} V2 / V1 \tag{7}$$

where,

P_{at} → Atmospheric Pressure

P_{in} → Pressure inside Vacuum Cup

V1→ Volume at t= max

V2 → Volume at t=0

Hence, using the above relation an estimated pressure of 1.05 bar is calculated, assuming the initial weight of the robot to be 3 kg. Having calculated the negative pressure, the components required to fulfil these limiting conditions were selected.

The prototype was fabricated using a polycarbonate sheet. This provided high impact strength as well as significant decrease in body weight. Vacuum ejectors were used to provide sufficient suction in the suction cups. The main suction cup at the top of the body consisted of nitrile butadiene rubber (NBR) and the suction cups on the side were made of silicon. A comparative study was carried out on the weight holding capacity of both materials, NBR and silicon. Testing of the vacuum pads was carried out against glass to check for maximum weight that could be carried at different pressures. A comparative graph of silicon and its weight holding capacity against the wall was plotted as shown in Fig. 6. It was determined that while NBR provides more suction against the wall, silicon could be used as an alternative option as it was cost feasible. As shown below, the lines of suction cups 2 and 3 overlap as they are of the same material.

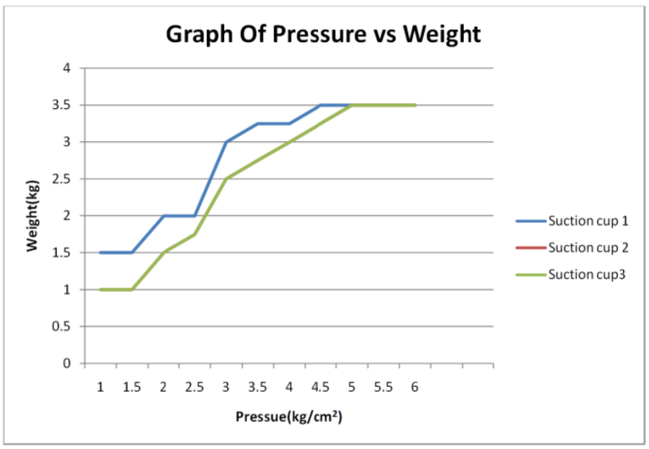

Fig. 6: Graph of weigh holding capacity and pressure

4. ELECTRICAL CIRCUIT

The wall climbing robot is intended to be full autonomous. Hence, to enable automatic motion an electrical circuit is developed to control all the components. These components are in return controlled by a controller Arduino. Arduino is an open-source electronics based on easy to use hardware and software. The Arduino board used to control the board is 8-pin. Two pins are used to control the DCVs respectively.

The Arduino board has a 5 Volt(5V) restriction. To overcome this drawback a relay is introduced such that it can be used to convert the 5V output of the Arduino to the 24V input of the components. Relays are switches that open and close circuits electronically or electromechanically. When a relay contact is Normally Open (NO), there is an open connection and no current flows in the circuit, whereas Normally Closed (NC) allows for a constant flow of power.

Hence, when electric current is provided to the relay it helps convert the 5V signal from the Arduino to a 24V output which is a requirement for the DCV. The code on the Arduino controls the electric current flow to the relay and therefore the components.

An algorithm is developed to propagate the robot in the desired steps of the mechanism as shown in Fig.7. The logic is written in such a way that DCV 1 is used to control the extension of the cylinder piston and Ejector 1. When current flows through DCV 1, cylinder will extend; when the power is cut off the ejector will start working. As current flows through DCV 2 the ejectors 2 and 3 create vacuum, hence suction cups 2, 3 create suction against the walls. Meanwhile one pin of the controller is used to regulate the speed of the motor. This motor will rotate with the desired speed and hence provide cleaning, painting action.

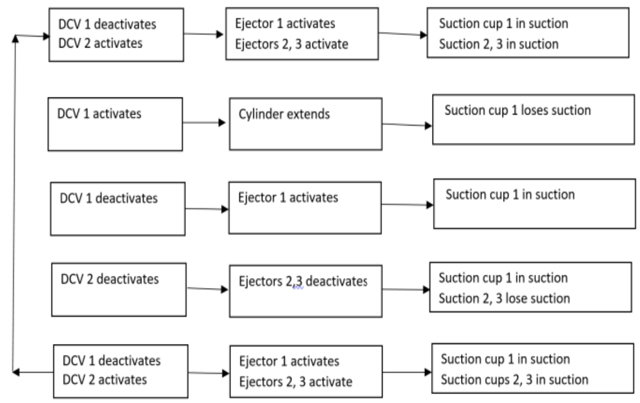

Fig. 7 Flowchart of algorithm

5. CONCLUSION

A wall climbing robot was hence designed taking into consideration its various applications. Several mechanisms were referred and a pneumatic mechanism was developed. Automation of the robot was carried by using a microcontroller. A prototype of the proposed design was fabricated and was tested on different wall surfaces. While the intended design fulfilled its objectives of climbing the wall several new ideas can be implemented for better functioning of the robot.

6. FUTURE SCOPE

The developed prototype of wall climbing robot is supposed to climb different surfaces with different roughness. The design of this robot is made particularly to climb wall having glass surface using suction cups as grippers. An alternative way to design the robot is by changing the suction cups with some others grippers such as claws, magnetic grippers, pneumatic grippers, mechanical adhesion, electromagnetic adhesions etc.

The robot can be made portable by mounting a storage cylinder on the robot body. This storage cylinder will be carrying compressed air which will be given as input to the robot to create negative pressure for suction pads. Further, for the portability, a small capacity vacuum pump can be used which will fulfill vacuum requirements for all suction cups. Negative pressure generated into suction cups will keep robot adhered to the wall surface. In case of applications like painting, a brush can be attached to the body with some minor modifications. Supply of paint can be given by tubes and capillary tubes. Another application of cleaning can be managed to develop by attaching a cleaning brush or cloth like attachment on the same body after making some changes.

7. ACKNOWLEDGEMENTS

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