Wall Climbing Robot: Mechanical Design and Implementation

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***Abstract*—A wall climbing robot is a robot with the capability of climbing vertical surfaces. This paper describes the design and fabrication of a quadruped climbing robot. We are required to design and create a wall climbing robot which uses suction as a means of sticking to the wall. The robot will be controlled using Basic Stamp and the movement of its legs will generated by two servo motors. Each servo motor will control legs which are located on the left and right side of the robot. The leg rotations mimic stepping motions through the use of a slider and crank. The suction force will be supplied by two vacuum pumps that will turn on intermittently. The main body of the robot will carry all the components except for the compressor thus making it mobile. Currently the robot is only designed for linear movement. However plans to incorporate maneuverability and other functions can be implemented after the first stage of the development achieves success.**

Keywords-component; wall robots; basic stamp; suction cups; slider-crank.

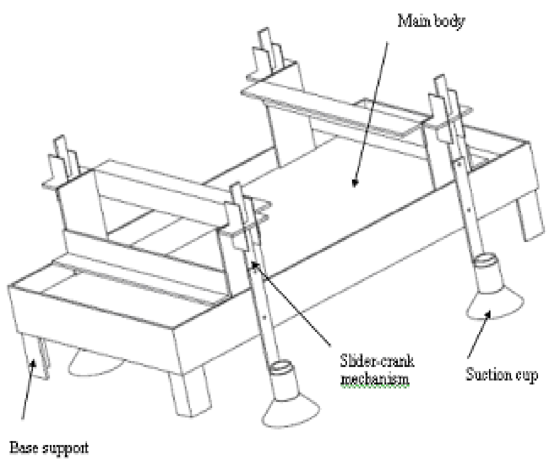
I. INTRODUCTION

Robots have been created to assist or replace humans in various dangerous and difficult tasks. Robots have been used in construction, manufacturing, security and etc. This is because they are able to adapt to different environments and situations. They have conquered nearly all environments that humans have put them through. Climbing robots can be used on artificial surfaces like a wall, or on natural surfaces like trees or cave walls. They are desirable for several applications such as search and rescue. This phenomena is still a challenge to be achieved using robotic devices. Climbing robots should have some practical utility to deal with different surfaces and geometries. This can be achieved by the use of special purpose attachment devices such as magnets or suction. At the same time, the machines need to be power autonomous, to avoid the hazard and the limitations of a tether. Climbing robots need unprecedented reliability: even one misstep in a thousand can lead to a catastrophic fall. Previously designed climbing robots have successfully climbed a number of hard, real world terrains. In general however these robots have been designed with a specific subset of terrain geometries or surface types in mind. A wall climbing robot can be used for numerous functions such as surveillance, construction, maintenance, search and rescue [1, 2, 3]. In 2003 a gecko like climbing robot called Rhex was developed for Pentagon to be used as a surveillance tool in their counter-terrorism program [4]. However Rhex is still years from completion. Current existing robots are limited in their usefulness due to their design complexity. Most climbing robots are still in their prototype stage and require much more research in order to be applicable in real life. Most wall climbing robots can either climb smooth surfaces or non-smooth surfaces. Not many robots can climb both types of surfaces. The majority of the robots in existence can only climb smooth surfaces. Researchers use nature as inspiration in designing their robots. They try to mimic nature's surface climbers such as insects, reptiles and worms. Most researchers try to mimic spiders who they believe to be one of the most versatile wall climbers [5]. Six legs give great maneuvering capabilities but limit the speed of the robot and make the design very complicated. A quadruped robot though possessing less maneuvering capabilities is theoretically faster and less difficult to build. Most quadruped climbing robots mimic lizards. However we decided to make a climbing robot that is similar to walking robots. By adding suction cups to the end of the legs we will make the robot literally 'walk' up a wall. After going through more than four different designs we came up with a design that is simple but efficient.

II. SYSTEM DESIGN

A. *Mechanical design*

Figure 1 shows different views of the general structure of the slider-crank mechanism of the leg. The purpose of this design to make sure that the all of sucking cups are vertical to the wall surface. By using 2 servo motors for controlling the movement of legs, each of leg will control by servo motor to generate the rotational motion. 2 of legs will be synchronized movement to generate the forward and backward movement of robot. The slider-crank mechanism, as shown in figure 2, is design to maintain the position of leg perpendicular to the surface of wall. The main body of the robot is able to carry the basic stamp controller, servo motors, pneumatic valves, and pneumatic pumps. At a certain time only 2 legs will touch the surface of wall, so a base support will support the body of robot during movement to maintain the stability of robot.



(a) 3D isometric view

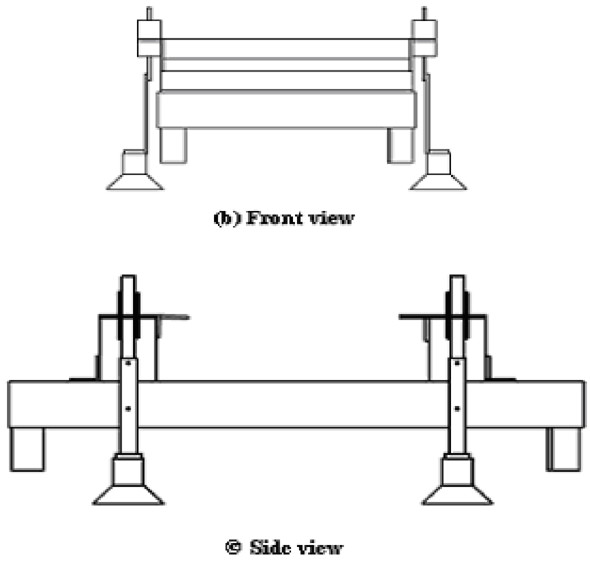


Figure 1: The lay out of the robot

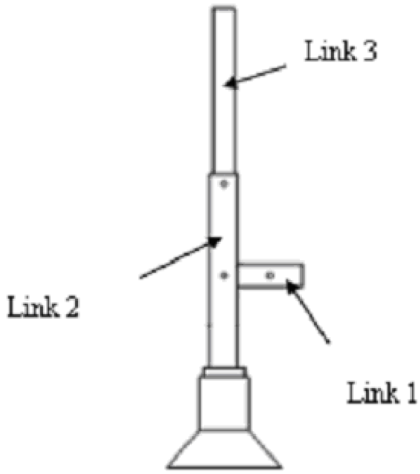


Figure 2: The slider-crank mechanism for the robot legs

B. Robot Mechanism

The mechanism of the robot includes the followings:

1. The robot consists of 2 servo motors and 4 legs, in which the functions of 2 motors are to generate rotary motion of 2 legs only (leg contains suction cup 1 & 4). These 2 legs motion will operate synchronized. The remaining 2 legs are to support a body of robot during a movement.
2. To make the body of robot move forward and backward. The slider-crank mechanism consists of the links as shown in figure 3. For the link 1 it joint with the servo motor and link 2, while for the link 2 which include with suction cup joint with the link 3, lastly the link 3 is joint with slider. A joint is a non-fixed connection between two or more links that allows certain relative motion between these links.
3. Each of the 4 cranks is connected with the slider part and sucking cup. Only the motion of the slider-crank mechanism of legs consist suction cup 1 & 4 will cause the robot to move. The remaining of legs consist suction cup 2 & 3 will be fixed at a certain position as shown in figure 3.
4. All of these position (1,2,3 & 4) will occur during rotational motion of 2 legs only. The 2 movement legs will move synchronized. These positions depend on a movement of robot whether it move forward or backward.
5. For the forward movement:
   Two rotation legs will touch the first switch at position 2 then it will stop. At this state all 4 suction cups will stick on the surface of wall. After a few seconds, the suction cups of 2 non-rotational legs will release it contact to the surface of wall.2 rotation legs will rotate until it touching to the second switch at position 4 then it will stop. At this state the suction cups of 2 rotation legs will stick on the surface of wall. At this state all 4 suction cups will stick on the surface of wall. After a few seconds, the suction cups of 2 non-rotational legs will stick to the surface of wall while the 2 legs will rotate continuously until it touching the first switch without any contact of suction cup to the surface. This process will repeat continuously to generate movement of robot.
6. For the backward movement:
   Two rotation legs will touch the first switch at position 4 then it will stop. At this state all 4 suction cups will stick on the surface of wall. After a few seconds, the suction cups of 2 non-rotational legs will release it contact to the surface of wall. Two rotation legs will rotate until it touching to the second switch at position 2 then it will stop. At this state the suction cups of 2 rotation legs will stick on the surface of wall. At this state all 4 suction cups will stick on the surface of wall. After a few seconds, the suction cups of 2 non-rotational legs will stick to the surface of wall while the 2 legs will rotate continuously until it touching the first switch without any contact of suction cup to the surface. This process will repeat continuously to generate movement of robot.

C. Degree Of Freedom (DOF) of the slider-crank mechanism

Each of the 4 cranks is connected with the slider part and sucking cup. Only 2 legs will generate motion of the slider-crank mechanism while 2 legs remain fixed at a certain position see figure 3. The numbers of DOF are the number of components of motion that are required in order to generate the motion. The formula of DOF of any planar mechanism through number of moving links (n), number and types of joints (f_1 and f_2) can be expressed as:

$$F = 3*n - 2*f_1 - f_2$$

where, f_1 is the number of one DOF joint and f_2 is the number of two DOF joint. The DOF for the slider-crank mechanism of the robot leg can be calculated.

No. of links = 3

No. of one DOF = 4 (3 joints and 1 slider)

$$F = 3*3 - 2*4 - 0$$
$$= 1$$

Therefore, the suction cups will remain vertical to the wall surface.

D. Suction Mechanism

The factors that have been considered in the development of the suction system for the robot are:

1. Make sure that all of sucking cups are vertical to the wall surface during the rotational motion of legs.
2. By using the vacuum pumps of high vacuum level application so that the suction cups adhere on the surface of ordinary wall building.

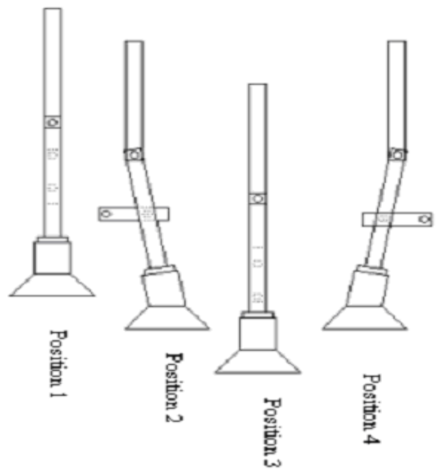


Figure 3: Legs position for different movements

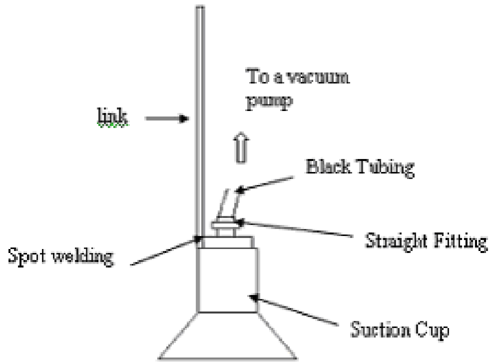


Figure 4: Suction cups mechanism

Figure 4 shows the connection mechanism of suction cup. Spot welding is used for joining the link with suction cup. For the suction process, firstly air will flow through black tubing from the compressor to the 2 valves. It operates with the ON and OFF function to control flow of air from the compressor. Each valve will connect to the vacuum pump, which 1 vacuum pump will connect to 2 suction cups. The reason using 2 valves, at a certain time all suction cups will stick on the surface of wall. When the valve turns ON, air will flow to the vacuum and suction cups. Straight fitting are used for joining the black tubing with the valves, vacuum pumps, and suction cups. Suction cup is a type of rubber elastic which can make flexible movement when touching on surface of wall. Figure 5 shows the flowchart of suction process.

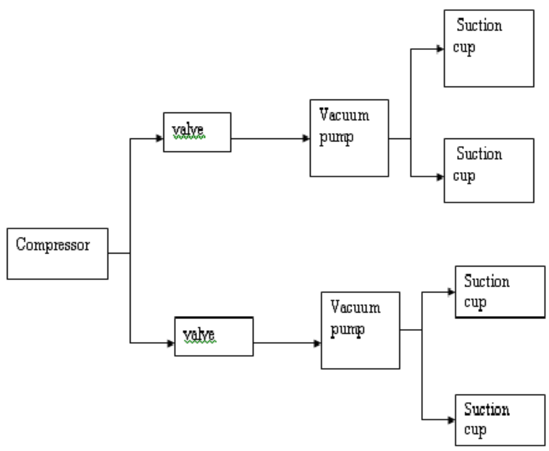


Figure 5: The flow chart of suction process

E. Electronic Designs

The electronic design of the robot consists of integrating circuits of different functions with the basic stamp. The Basic Stamp controls all of the robot's actions. The Basic Stamp BS2 module is chosen for this project. BASIC Stamp modules are microcontrollers (tiny computers) that are designed for use in a wide array of applications. Many projects that require an embedded system with some level of intelligence can use a BASIC Stamp module as the controller. Each BASIC Stamp comes with a BASIC Interpreter chip, internal memory (RAM and EEPROM), a 5-volt regulator, a number of general-purpose I/O pins (TTL-level, 0-5 volts), and a set of built-in commands for math and I/O pin operations. BASIC Stamp modules are capable of running a few thousand instructions per second and are programmed with a simplified, but customized form of the BASIC programming language, called PBASIC. The Basic Stamp BS2 modules can be connected either by using serial ports or USB. The programs are transferred through these ports and stored in the basic stamp.

III. PROGRAM FLOW AND ROBOT MOVEMENT

The program allows the robot to move forward and backward. It follows a strict sequence in order to ensure the robot's stability. The walbot program contains several sub-programs that control the overall motion of the robot. The program can be divided into two large sub-programs for controlling forward and backward movement.

a)Forward Motion

This is the main program for controlling the forward motion of the robot. The function of this program is to initialize the inputs, outputs and variables. After initializing the variables, the SEQ1 program will then turn ON both pneumatic valves thus making all four legs stick to the wall for 4 seconds. This program is responsible for controlling the first step of forward motion. The program will turn on 'OFF' one of the pneumatic valve while the other is maintained at the 'ON' state. The motors then rotate until variables representing inputs 4 and 7 are no longer 0. The program will then activate the 'CH1' sub-program. This program checks the state of the variables representing the inputs and tells the motor to stop or to continue rotating. After ensuring that each variable is equal to 1 the sub-program 'PARITY1' will then activate sub-program 'SEQ2' which will then turn both pneumatic valves 'ON' for five seconds and then the entire process is repeated with the pneumatic valve formerly 'ON' in the first process in the 'OFF' state and the pneumatic valve formerly 'OFF' in the 'ON' state. The SEQ2 sub-program is similar to the SEQ1 sub-program with a different valve 'ON'. After the second sequence is complete the sub-program called 'JCHECK' will check the state of the variable X which represents IN3. If the condition is '1' then the sub-program 'JUNCTION' will be activated. If condition is '0' then the program 'MAIN1' will be activated and the entire process is repeated from the first sequence.

b) Reverse Motion

The reverse motion main program is similar to the forward motion main program. It resets all the conditions of the variables to its initial state. It will than activate the RSEQ1 sub-program. The RSEQ1 sub-program is responsible for controlling the first step of reverse motion. The program will turn on 'OFF' one of the pneumatic valve while the other is maintained at the 'ON' state. The motors then rotate until variables representing inputs 5 and 6 are no longer 0. The program will then activate the 'RCH1' sub-program. The RCH1 program checks the state of the variables representing the inputs and tells the motor to stop or to continue rotating. After ensuring that each variable is equal to 1 the sub-program 'RPARITY1' will then activate sub-program 'RSEQ2' which will then turn both pneumatic valves 'ON' for five seconds and then the entire process is repeated with the pneumatic valve formerly 'ON' in the first process in the 'OFF' state and the pneumatic valve formerly 'OFF' in the 'ON' state.

c) *Junction Sub-program*

The JUNCTION sub-program functions as a junction between forward motion and reverse motion. Whenever the pause button is pressed the JUNCTION sub-program will be activated. This sub-program will continue looping until a selection between forward and reverse motion is selected. The flowchart of the main program is shown in figure 6.

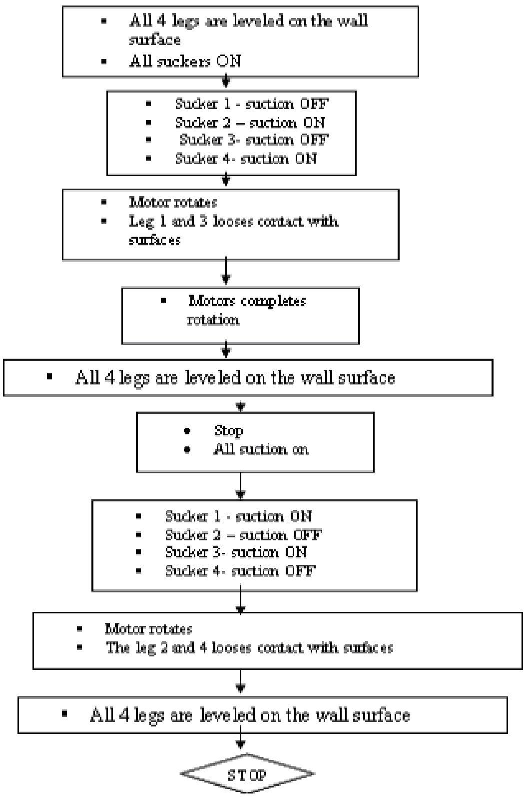


Figure 6: The flow chart of the main program.

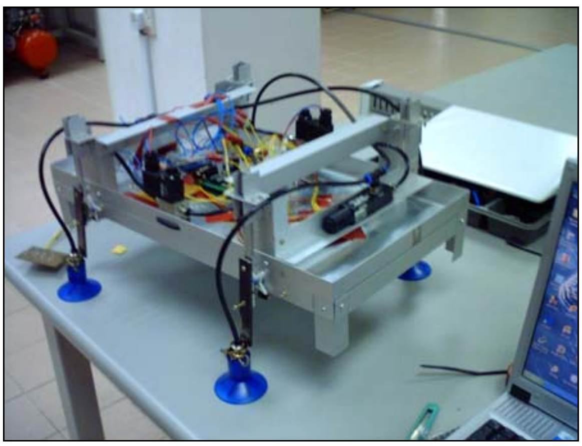


Figure 7: Wall Climbing Robot.

IV. CONCLUSIONS

The design and fabrication of the Wall Climbing Robot has been successfully achieved and is shown in figure 7. The components required are simple enough and the programming required is basic. However the material used to hold the suction cup is made out of light aluminum thus making it hard to weld the fitting together. Only by using spot welding can the fitting be attached. This is to ensure that the chasis of The power distribution of the electronic components should be planned more carefully because it is discovered that the basic stamp draws a lot of power when connected to multiple circuits. Only when using the Energizer 9V battery can the servos run. However these batteries deplete very quickly and are costly. It is recommended that another more powerful rechargeable battery be used as a supply. The battery should also be lightweight so that the torque on the servos is small. The 12V battery used for remote control aircraft has the characteristics required. However the batteries are expensive and last for a very short time. Finally, this robot should be further developed so that it can be assigned to do tasks that would be difficult for humans to do.

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