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Design and Development of Semi-Autonomous Wall Climbing Robot Mechanism

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***Abstract*— The purpose of this research paper is to present a wall climbing robot mechanism which can be easily scaled up and applied in various fields like, search and rescue, surveillance etc. The objective is to make a four wheeled robot which can climb and manoeuver surfaces at any inclination be it perpendicular, acute or obtuse.**

This robot will be made by adding two upward and downward thrusters to a four wheeled robot. On approaching an inclination, the sensor mounted in the center of the robot will calculate the angle of inclination autonomously. The amount of upward thrust required to lift the front wheels of the robot is calculated and the ESCs ensures that the required thrust is generated by the propeller in the necessary angle. Thus, the front wheels have a greater area of contact on the wall and therefore can help it climb up. The motors will be connected to a beam which is connected to two servo motors on either side, thus allowing us to control the angle at which the motor is fixed, the angle is autonomously calculated by the robot, thus enabling the mechanism to manoeuver terrains with inclinations of any magnitude. This mechanism is semi-autonomous in the sense that the operator has to manually control the robots movement but the propeller set up autonomously aligns itself based on the inclination of the wall.

Keywords— autonomous, wall climbing robot, inclination, thrusters, propeller (key words**)**

I. INTRODUCTION

The versatility of Wall Climbing Robots is expanding drastically and thus a viable easily modifiable and scalable mechanism is extremely necessary. A robot with the ability to function on any structure irrespective of the surface and terrain can be valuable for several purposes like surface-based operations such as cleaning, painting, and inspection, surveillance etc. Recent research has seen the development of a wide variety of mechanisms for Wall Climbing Robots, each of which have their own advantages and limitations when it comes to scalability or functionality.

The Wall Climbing Robots developed till date use one of four basic mechanisms such as, 1. Magnetic Attraction, 2. Claws and grippers, 3. Vacuum Suction and 4. Pneumatics. This Wall Climbing Robot will use a very simple four wheel mechanism with two added motor – propeller setups on the axis perpendicular to the wheels. The axes of the propellers can be adjusted by the use of servo motors. This gets adjusted autonomously based on the inclination of the surface. The result of this is a Wall Climbing Mechanism that is extremely easy to operate, robust, scalable, cheap and practically viable. In comparison to the existing designs and mechanisms, it is much more advanced considering that it is semi-autonomous and thus, is more user friendly. The robot is designed taking into consideration the required robustness, stability, weight distribution and all other crucial design aspects.

II. LITERATURE REVIEW

The main factors to be taken into consideration while designing a wall climbing robot is, its adhesion method and locomotion mechanism. With respect to the adhesion method used, we can categorize the existing Wall Climbing Robot into 4 main types, vacuum or suction[3][7][8], magnetic[2][5], grippers[9] and electrostatic[4].

Each of the above mentioned mechanisms have their own pros and cons. Vacuum based robots[3][8] consists of suction cups which grip onto the wall, but they face a major drawback that is, they cannot be used on irregular surfaces of the wall. This sets back the practicality of the bot. Magnet based adhesion systems like the ones developed by Markus Eich And Thomas Vogele[2] and Weimin Shen And Jason Gu, Yanjun Shen [6] are heavy due to the weight of magnets and they cannot be used on non-ferromagnetic surfaces, but they are comparatively faster. These have very specialized applications unlike the robot mechanism developed by us. Gripper[9] based robots are slow and heavy yet efficient as seen in the robot developed by Jiang, Q., & Xu, F[9].

With respect to the method of locomotion used, we can classify Wall Climbing Robots into three types, they are, wheeled robots, legged robots and crawling mechanisms. Each of these have their own disadvantages and advantages. Crawlers[5] have a good speed, wheeled robots are the fastest of all but they face trouble when they have to maneuver obstacles. Legged[10] robots like the one developed by Guan, Yisheng & Zhu et al. are generally the slowest but have a better ability to tackle obstacles.

Taking Inspiration from lizards, Geckos[8] the sticking bot by F. Cepolina, R.C. Michelini, R. P. Razzoli and M. Zoppi Rmar was made with the ability to stick to the wall and move. The design consists of adhesive which was strong enough to withstand 20N force on each feet and also it is capable of sticking and detaching quickly. Thus Geckos design proved to be overcoming all the problems which were faced by mechanisms using grippers[10]. Looking at the designs using magnetic properties to climb[2][5], the major drawback is that they require a very high power source and a ferrous wall to climb which is obviously not suitable for all purpose.

The robot developed by Young Kouk Song, Chang Min Lee, Ig Mo Koo, Duc Trong Tran, Hyungpil Moon And Hyouk Ryeol Choi, called LARVA[1] is an improvised version of an vacuum suction based robot. This robot was developed with the aim to overcome some flaws of suction based

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robots like the failure caused on uneven surfaces due to concave structures on the surface like screws and bolts. However, the robot still has limitations on how uneven the surface can be.

Wall Climbing Mechanisms based on electrostatic adhesion have to be researched upon and developed further to be a practical option, as they are extremely slow as seen in the work by Akio Yamamoto, Takumi Nakashima, and Toshiro Higuchi[4].

Looking forward to solve this problem a design with an alternative method would have been a great help for the purpose of climbing inclined surfaces.

III. Design of Semi-Autonomous Wall Climbing Robot and Systems Overview

A. Design Considerations

The major factors to be taken into consideration are Position of Center of Mass of the robot, Propeller position and Wheel placement. The center of mass of the robot is to be kept as close to the surface of the wall/floor, as possible to reduce the moment due to gravity on the robot. The propellers will be positioned marginally offset from the geometric center of the robot to reduce the chances of toppling an to counter the action of gravity better. The wheels will be positioned in such a way that the area of contact on the wall is maximum and so that the initial point of contact of the robot on the wall is on the wheel rather than on the chassis.

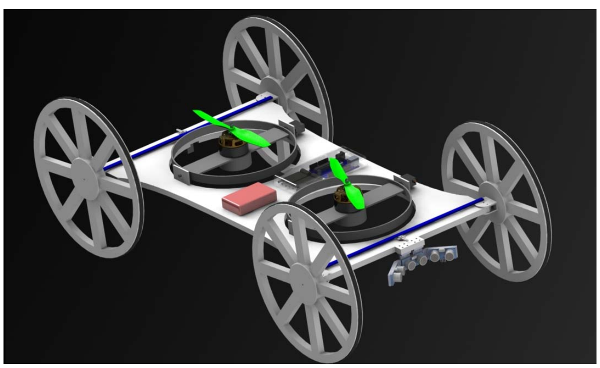

Fig 1. The isometric view of the Wall Climbing Robot is illustrated in the above figure.

Figure 1 shows a clear image of the mechanism. The mechanism has two propellers attached t servo motors on both ends to allow them to be tilted. There is an MPU6050 accelerometer , gyroscope sensor, an arduino and two ESCs placed in the space between the two propellers.

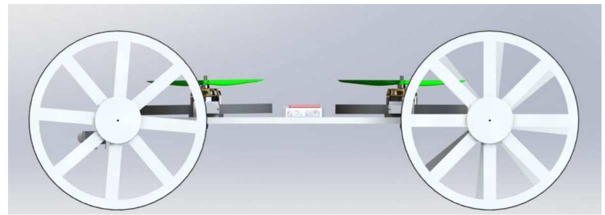

Fig 2. The above figure is of the side view of the Wall Climbing Robot Mechanism

Figure 2 shows the position of the wheels in the robot. As seen, the wheels are designed and positioned in such a way to ensure that the wheel makes the first contact with any inclination rather than the frame of the robot.

B. Propellers

The robot will be capable of traversing over indentations and uneven surfaces due to the use of propellers rather than vacuum grippers or other direct contact adhesion mechanisms. Floor-to-wall transition is made easy and smooth by using two propellers, one at the rear and one at the front. The propellers work together to keep the robot stable at all times. For an easy Floor-to-wall transition, thrust is applied in an upward direction by the front propeller and towards the wall by the rear propeller, this makes the robot flip onto the wall. The propellers will be operated using Brushless DC motors due to the high thrust requirements.

The propellers will be fitted on a housing which is further connected to two servo motors at either ends

C. Material Selection

It was taken into consideration that light weight and strong materials were required for the fabrication and the processes involved for the materials selected which were feasible according the materials properties. The Chassis Of the Wall Climber and its wheels will be fabricated using the material Polypropylene. The Chassis and the Wheels will be cut from a block of Polypropylene using CNC techniques. The Links and the Couplers and the Motor Mounts will be fabricated from 3D Printing Techniques using ABS plastic.

Polypropylene is a Strong Polymer Material with an Elastic Modulus of 8.96×10^{8} Nm^{-2} and a density of 890 Kgm^{-3} .

Various Other Properties are Listed below –

- Tensile Strength – 2.76×10^{7} Nm^{-2}
- Shear Modulus – 3.158×10^{8} Nm^{-2}
- Poisson’s Ratio – 0.4103

ABS (Acrylonitrile butadiene Styrene) is a Thermoplastic Polymer which is casted into many shapes and sizes by injection molding so it is suitable for 3D printing parts. It’s an Elastic Modulus of 2.41×10^{9} Nm^{-2} and a density of 1070 Kgm^{-3}.

Various Other Properties are Listed Below –

- Tensile Strength – 4×10^{7} Nm^{-2}

- Shear Modulus – $8.622 \times 10^{8}\ Nm^{-2}$
- Poisson's Ratio – 0.3897

D. Electronics Overview

The robot being semi-autonomous, incorporates certain electronic systems to ensure serve various purposes. The electronic systems used are the Brushless DC motors, Servo Motors, Electronic Speed Controllers, LiPo battery, an IMU sensor and ultrasonic sensors.

D1. Sensors

The robot uses the MPU6050 IMU sensor to calculate the angle of inclination. It is a 3 axis MEMS based accelerometer plus gyroscope sensor. The sensor is placed in the exact center of the robot. The sensor is capable of providing precise readings to the controller. Based on the angle of inclination, the angle at which the propellers are to be positioned is automatically adjusted by the servo motors to which the propeller housing is connected. The robot also has an array of three HC-SR04 ultrasonic sensors places in the front to detect obstacles and thus ensuring that the motor speeds are controlled in such a way that the obstacles are avoided.

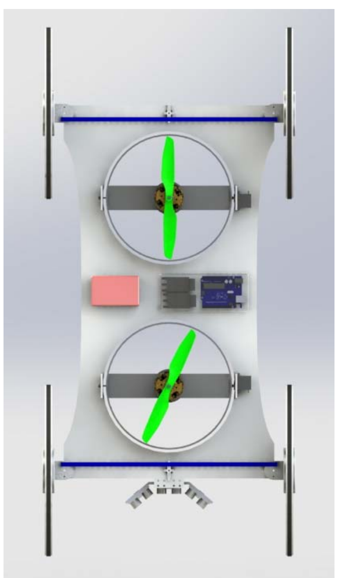

Fig 3. The above image shows the Top View of the Wall Climbing Robot Mechanism

Figure 2 clearly shows the positioning of the electronics used in the mechanism. There is an MPU6050 sensor, two Electronic Speed Controllers and an arduino uno placed between two propellers that are attached to servo motors. The front face of the robot holds the ultrasonic sensors used for obstacle avoidance.

D2. Motors and Motor Controllers

The propellers will be mounted onto Brushless motors. These motors are used due to their high rpm which is necessary to provide the necessary thrust to make the Floor-to-wall transition and to keep it on the surface of the wall. Two servo motors will be attached to each propeller housing on either sides. This will allow the propeller position to be adjusted to the necessary angle so that the direction of thrust is ideal. The rpm of the Brushless DC motor is controlled using two Electronic Speed Controllers

D3. Controllers

The robot is controlled using an Arduino Uno board. This is a board based on the Atmega 328 microcontroller based on the AVR architecture. It has an operating voltage of 5V and a clock-speed of 16Mhz. With 14 digital I/O pins, it is ideal for use with the servomotors and the ultrasonic sensors. Its easy availability and simple IDE is another benefit.

E. Calculations

m = mass
g = gravity
F_f = Frictional Force
μ = coefficient of friction
N = Normal Force
F_S = Suction Force

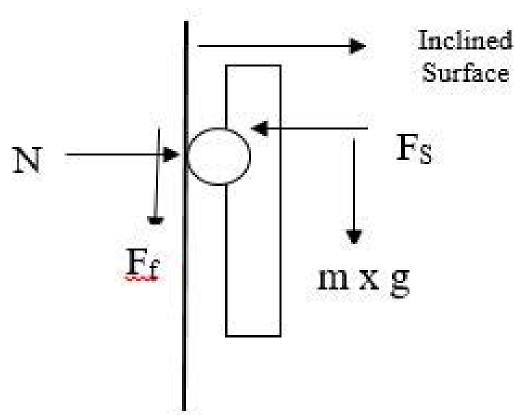

Fig 4. This figures is used to explain the calculation of thrust required to keep the robot held on to the wall and prevent it from falling.

$$F_f = \mu \times N \quad (1)$$
$$F_S = 2 \times N \quad (2)$$
$$F_S = (m \times g) / \mu \quad (3)$$

Sample Calculation –

Friction coefficient for rubber on concrete = μ = 0.6
Estimated mass of robot = m = 1 kg
Fs = (1 kg x 9.81 N/kg) / 0.6 = 16.35 N

Since the motor specifications are indicated with 'kilogram-force' or 'thrust' we will now convert the Newtons into kilogram-force.

Kilogram-force = 16.35 N / 9.81 N/kg = 1.66 kg thrust

This amount of thrust can easily be obtained easily by using a standard 1200 KV BLDC motor paired with a 10 x 4.5 spec propeller

F. Algorithm

>controller receives instantaneous inputs from MPU6050 sensor

>controller calculates velocity of the robot

> controller constantly receives inputs from the ultrasonic sensor

>controller varies the speed of the motors in order to make it turn to either right or left based on where the obstacle is detected

Situation A

>if the robot velocity is less than 15% of maximum velocity, controller checks the inclination of the robot

>if an inclination is present, the controller commands the servo motors to tilt based on the value of inclination

Situation B

>if the velocity of the robot is zero, the servo motors begin rotating slowly at step angle of 1 degree

>simultaneously, the value of angular displacement of the robot is calculate

>the servo motor constantly rotates, thus tilting the propellers, until the angular velocity becomes zero (that is, when angle of inclination of the robot and the angle of inclination of the surface is equal)

IV. Conclusion

Thus we have now designed a semi-autonomous wall climbing robot mechanism which can easily be scaled to meet the needs of the wide array of applications it is suited for, ranging from surveillance and monitoring to Area mapping and all terrain mobility. This mechanism is faster, more stable, easier to operate and much more practical than the existing designs and concepts. Its simplicity in design and intelligent electronics and controls setup allow it to be easily operated on any sort of surface or terrain

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