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# DESIGN & DEVELOP THE PROTOTYPE OF WALL CLIMBING ROBOT

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**Abstract**—In this paper the main aim is to develop the prototype of wall climbing robot with the centrifugal impeller based adhesion system and four wheeled locomotion system which can move over the vertical wall surfaces as well as ceiling surfaces. Centrifugal impeller creates the low pressure vacuum and adhere the robot on the wall surfaces without any perfect sealing. Four wheeled locomotion system requires stability and weight distribution equally on each wheel. Equally weight distribution on each wheel gives proper traction over the vertical wall surfaces as well as ceiling surfaces. Stability of four wheeled wall climbing robot requires dynamic analysis for that reaction forces on each wheel, centrifugal forces and gyroscopic effect is analyzed. Actual prototype model is developed and tested experimentally on the wall & ceiling surfaces with the help of centrifugal impeller type adhesion system and four wheeled locomotion system.

**Keywords**-Wall Climbing Robot, Dynamic analysis, Wheeled Locomotion System, Centrifugal Impeller, Robot.

## I. INTRODUCTION

Mobile robots takes the place of human workers in many fields like surveillance and inspection of the Oil tanks and storage tank of nuclear power plants. In country like India it can possible to inspect the water tanks, flyovers, bridges and hydraulic dams. It is the difficult task to inspect the bridges, flyovers and water tanks easily by human workers and also time consuming task at very high risk. Here to solve this problem it is possible to develop the wall climbing robot which can perform these kind of task very easily and safely in less time. Now-a-days window glasses of high rise buildings are difficult to clean by the manually by human operators so for that is also possible to develop the wall climbing robot for the same application which perform glass cleaning of the high rise building very efficiently, safely in less time[9]. Wall climbing robot are also use in the surveillance, search and rescue operations, construction works and capable to carry the weight with it to transport it from one place to another place where human workers are not capable to reach. For the inspection of the construction buildings, outer surfaces of the wall are rough for that specially designed wall climbing robot with claws is developed. It has legged type locomotion system and twelve fishing hooks are attached on the each leg which can help to climb the robot on the vertical surfaces[3]. One of the most challenging task of the wall climbing robot is its self weight and adhesion system by which robot can adhere on the wall surfaces. It should capable to carry the extra weight with them for that its payload capacity should be as higher as possible. Two main functions of the wall climbing robot are its adhesion system and locomotion system. Adhesion system helps to adhere the robot on the wall or ceiling surfaces. Different types of adhesion systems are uses, like negative suction method by which robot can stick on the wall surfaces efficiently and they are used for the inspection of oil tanks and storage tanks of the nuclear power plants called as industrial wall climbing robots which has high payload capacity, Ferromagnetic surfaces are also climb by the magnetic wheeled robots of the inspection purposes[8], We can install the small bullet camera for the inspection[12]. Centrifugal impeller based wall climbing robots can generates the low pressure

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vacuum and due to continuous rotating of the impeller vanes continuous suction is created which is helpful to climb the robot on the vertical surfaces as well as ceiling surfaces[1][2]. Centrifugal impeller based wall climbing robots are also capable to transits between ground surface and vertical wall surface and between vertical wall surface and ceiling surface[2]. In some wall climbing robots series of small suction pads are attached on the tracked locomotion system and on each suction pad actuator is connected which is helpful for proper adhesion system[4].

Locomotion system of the wall climbing robot is depends on the application of work and working environment in which wall climbing robot have to work. Mostly wheeled type, tracked type locomotion systems are used in the wall climbing robot. In the wheeled type locomotion systems mostly adhesion is created by the centrifugal impeller or micro vacuum pumps which are attached on the small vacuum pumps[6]. In tracked type locomotion system, it is used where poor traction is occur due to wheeled type locomotion systems. Tracked type locomotion system gives more traction over the wall surfaces[1]. In some wall climbing robots small vacuum pads are attached over the periphery of the track which are operated by the small vacuum pumps. These small vacuum pads are engaged and disengaged simultaneously and helps to move the robot on the vertical wall surfaces[4].

This paper represent the prototype of wall climbing robot with centrifugal impeller based adhesion system and four wheeled locomotion system which can move over vertical as well as ceiling surfaces in the efficient way at low cost. Its weight is made as light as possible with more payload capacity. In the second section is discussed the prototype model of wall climbing robot. In third section, static and dynamic analysis is presented and experimental work is presented in the fourth section and conclusion is made from it.

## II. PROTOTYPE MODEL

Here prototype model of wall climbing robot is developed. It has four wheeled drive system operated by the high torque geared DC as shown in figure 1. It gives the better traction over the vertical wall surfaces and ceiling surfaces and simple to operate.

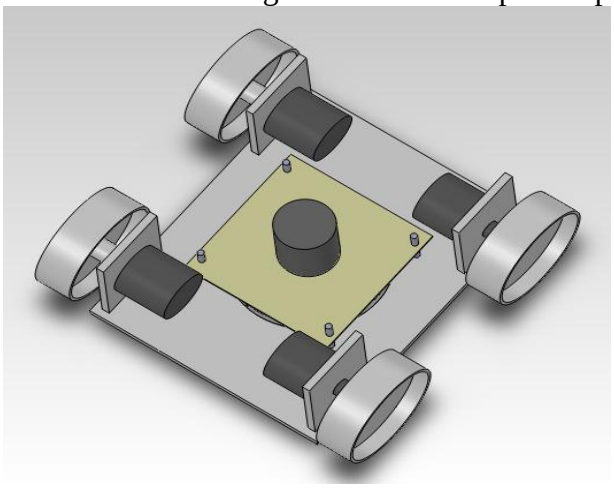

***Figure 1. Model and view of wall climbing robot Figure***

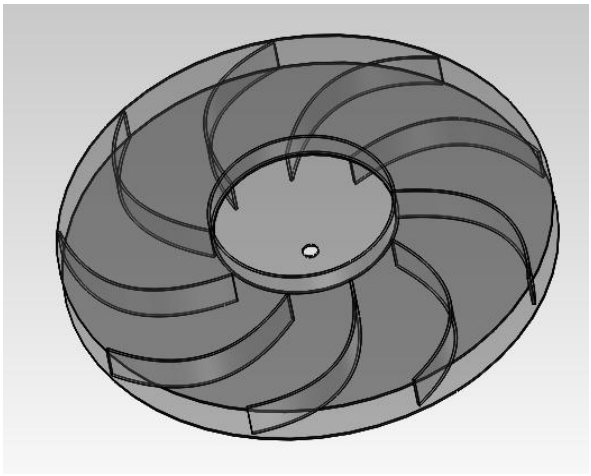

***Figure 2. Centrifugal impeller***

Adhesion system is one of the important function for climbing robot because it helps to stick the robot on the wall properly without any failure. Here centrifugal impeller with backward curve vanes are used as the adhesion system as shown in figure 2. It requires vacuum impeller and suction motor which rotates the impeller with very high speed and creates vacuum for adhesion system of the wall climbing robot. Robot weight is made very light with the help of the foam sheet material which is very light

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weight material and has excellent fabrication properties like sawing, drilling, screwing, bonding and glue bonding. It is capable to hold all the components of robot.

## III. STATIC AND DYNAMIC ANALYSIS OF THE ROBOT

Robot have to balance and no wheel is supposed to leave the wall surface while the robot takes turn. Resultant reactions by the wall surface on wheels should act in upward direction. For moving vehicle, one of the reaction is due to gyroscopic couple produced by the rotating wheels and rotating parts of the other robot components. Centrifugal force is also produced by the centrifugal force while taking the turn. As shown in figure 3 center of gravity of the robot lies vertically above the ground.

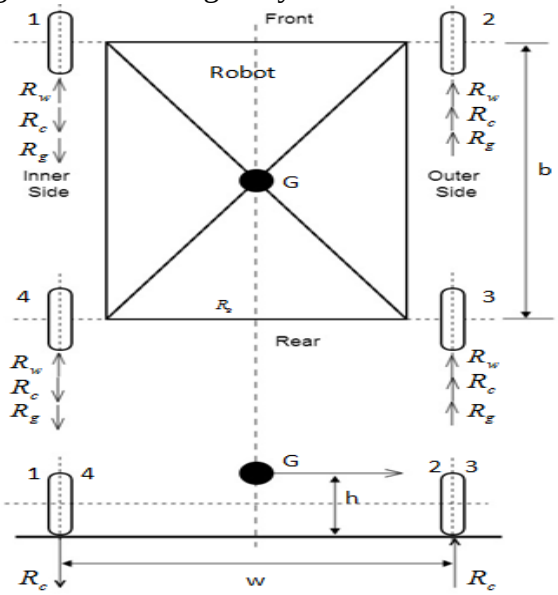


*Figure 3. Stability of four wheeled robot*

### A. Weight of the wheel

Here consider a four wheeled robot having mass m and assuming that the weight of the vehicle (m.g) is equally distributed among the four wheels. Here force acting on each wheel acting downward and reaction by the wall surface on wheel acts upward direction.

$$\text{Weight on each wheel} = \frac{W}{4} = \frac{m.g}{4} \tag{3.1}$$

$$\text{Reaction of wall surface on each wheel, } R_w = \frac{W}{4} = \frac{m.g}{4} \tag{3.2}$$

### B. Centrifugal force

As the robot moves centrifugal force also acts on the vehicle in the outward direction at the center of gravity during left turn of the robot.

$$\text{Centrifugal force, } F_c = mR\,\omega_p^2 = \frac{mv^2}{R} \tag{3.3}$$

This force generate a overturning couple will be

$$C_c = F_c \,.\, h = \frac{mv^2 h}{R} \tag{3.4}$$

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The over turning couple is balanced by vertical reaction which is upward on the outer wheels (2,3) and downward on inner wheels(1,4).

The reaction on each outer wheel (2,3), $R_c = \frac{c_c}{2w} = \frac{mv^2h}{2wR}(\uparrow)$ (3.5)

The reaction on each inner wheel (1,4), $R_c = \frac{c_c}{2w} = \frac{mv^2h}{2wR}(\downarrow)$ (3.6)

**C. Gyroscopic effect**

As a robot takes left turn, the wheel spin axis will process and rotating parts of adhesion system includes gyroscopic couple.

Gyroscopic couple due to four wheel, $C_w = 4I_w \omega_w \omega_p = \frac{4I_w v^2}{rR}$ (3.7)

Gyroscopic couple due to rotating parts of adhesion system, $C_e = I_e \omega_e \omega_p$ (3.8)

Where $G = \omega_e/\omega_w$

Therefore, the total gyroscopic couple, $C_g = C_w + C_e$ (3.9)

so, $C_g = \omega_w \omega_p (4I_w \pm I_e G)$ (3.10)

Positive sign is used because wheel and centrifugal impeller is rotates in same direction. The reaction couple is developed due to equal and opposite forces on the outer and inner wheels of the robot.

Forces on each outer wheel (2,3) = $\frac{C_g}{2w}(\downarrow)$ (3.11)

Forces on each inner wheel (1,4) = $\frac{C_g}{2w}(\uparrow)$ (3.12)

To balance this reaction couple, wall surface introduce reaction forces which act vertically upwards on the outer wheels (2,3) and vertically downward on the inner wheels (1,4).

Reaction on each outer wheel (2,3), $R_g = \frac{c_g}{2w}(\uparrow)$ (3.13)

Reaction on each outer wheel (1,4), $R_g = \frac{c_g}{2w}(\downarrow)$ (3.14)

So, the total vertical reaction on each outer wheel is $R_o = R_w + R_c + R_g$ (3.15)

So, the total vertical reaction on each inner wheel is $R_i = R_w - R_c - R_g$ (3.16)

## IV. EXPERIMENTAL WORK

Here as shown in figure actual prototype model of wall climbing robot is developed tested experimentally on the vertical wall surface as well as ceiling surface. Weight of the robot is distributed

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equally on all four wheels which helps to move the robot efficiently and increase the performance of the robot on the wall surfaces as shown in figure 4 and 5.

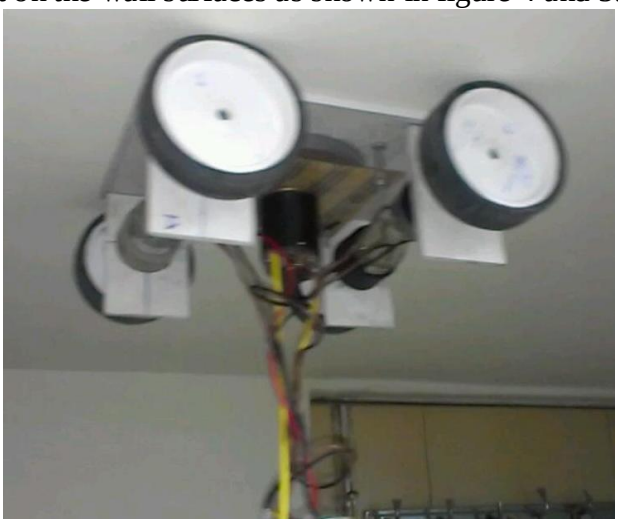

***Figure 4. Robot on vertical wall surface***

***Figure 5. Robot on wall surface***

The overall weight of the robot is approximately 980 grams with its payload capacity of 1200 grams and capable to transits between ground surface to vertical wall surface at velocity of 0.23 m/s.

## V. CONCLUSION AND FUTURE WORK

Here, wall climbing robot prototype is developed from the foam material with the centrifugal impeller based adhesion system and four wheeled locomotion system which can move over the vertical wall surface as well as ceiling surface efficiently. Four wheeled wall climbing robot, static and dynamic analysis is done for mechanical stability. No perfect sealing is required in the centrifugal impeller based wall climbing robot so the cost of the robot is low with high pay load capacity. In future work, we can use it for inspection of oil and water tanks and storage tank of nuclear power plant and also for surveillance purpose and window cleaning of high rise building.

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## NOMENCLATURE

| | |
|---|---|
| W | Weight of the robot in Newton |
| M | Mass of the vehicle in Kg |
| w | Width of track in m |
| b | Wheel base in m |
| R | Radius of curvature in m |
| h | Distance of C.G. above the road surface in m |
| $I_w$ | Mass moment of inertia of each wheel in $Kg.m^2$ |
| $I_e$ | Mass moment of inertia of rotatin parts of the robot in $Kg.m^2$ |
| $\omega_w$ | Angular velocity of wheel in rad/sec |
| $\omega_e$ | Angular velocity of rotating parts in rad/sec |
| $\omega_p$ | Angular velocity of precession in rad/sec |
| r | Radius of each wheel in m |
| G | Gear ratio |
| $C_g$ | Total gyroscopic couple in N.m |
| $C_w$ | Gyroscopic couple due to four wheels in N.m |
| $C_c$ | Gyroscopic couple due to centrifugal force in N.m |
| $\upsilon$ | Speed of vehicle in m/sec |
| $F_c$ | Centrifugal force in N |

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