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Design and Development of a Step Climbing Wheeled Robot

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Abstract: This paper presents a design of Step Climbing Robot that can move in uneven environment and traverse a slope or staircase. The condition imposed on this new system of robot is that it will move only in linear fashion, which will reduce the demands on the physical complexity of the robot unit. A summary of the current state of research in the field of mobile robots as it relates to robot stair climbing and moving in uneven surfaces. The architecture of the robot is developed and compared with the previous design. *Copyright © 2009 IFSA.*

Keywords: Step climbing, Slope climbing, Wheeled robot

1. Introduction

In recent years mobile robot is one of the essential parts in many areas for application in industry, hospital, home appliance, defense and in other various fields of technology. Various designs and models have been developed in this area from past few years, which can be applied in simple and uneven environments. The new type of mobile robot proposed here, is capable to climb steps or stairs (uneven surface). From the study of those systems it is observed that in each system the parameters taken are very complicated. The present paper focuses on designing a model of a mobile robot which is light weight and simple design, without compromising with the functionality.

It is observed from the research work of E. Z. Moore and M. Buehler that the stair height and stair length of their developed model was 15.9 cm and 27.9 cm respectively [1, 2, 12]. They designed the

leg size which was same of the stair height. Again Daisuke et al designed a model of step climbing robot, where they had taken the step size of 10.0 cm and 12.5 cm and 18.2 cm to test the model and designed the diameter of the wheel 13.2 cm. [4]. An innovative off-road wheeled mobile robot, named Octopus was developed which was able to deal autonomously with obstacles in rough terrain without getting stuck. For this, the robot was equipped with tilt sensors and tactile wheels. This mechanism of Octopus has 8 motorized wheels and a total of 15 degrees of freedom among them 14 are motorized. This robot was 43cm in length, 42cm in width and 23cm in height. The mass of the system without payload was about 10 kg. [3] Another type of step climbing model was introduced named Gremlin robot, which was based on the Alliance architecture, which was an effective scheme for step climbing [5]. A mobile robot architecture which was developed by James Gaston whose different parts are arranged together to climb the step [6]. Daniel M. Helmick, Stergios I. Roumeliotis, Michael C. McHenry & Larry Matthies developed a mobile robot using multi sensor which is able to climb stairs [7]. A group Solomon Steplight, Geoffrey Egnal, Sang-Hack Jung, Daniel B. Walker, Camillo J. Taylor and James P. Ostrowski from University of Pennsylvania developed mathematical model of step climbing robot [8]. Timothy Wolfe Bretl in his research at Stanford University developed a robot which can climb rocks [9]. A climbing micro-robot was discussed which is controlled by DSP based embedded controller [10]. Wall climbing micro- robot with fuzzy control was developed which consumes low power [11].

The model developed in the present paper is capable of steps or stairs height with. The developed robot is having two parts which is joined with a hinge. This hinge is used for bending the robot in to two portions of the system while climbing. The algorithm of the step climbing has been discussed. The control is shown with the help of block diagram and also with real time photographs, which have been taken during testing. It can be used in uneven environment. A simple Micro – controller based ON – OFF controller is applied in this system to control the robot. This is can be termed as a portable robot for stair climbing.

2. Hardware Design of the Robot

The Robot consists of two parts and both of them are linked with a hinge. This hinge is used during climbing on stairs. The prototype of the developed robot is shown in Fig. 1 and mechanical drawing of the robot shown in Fig. 2.

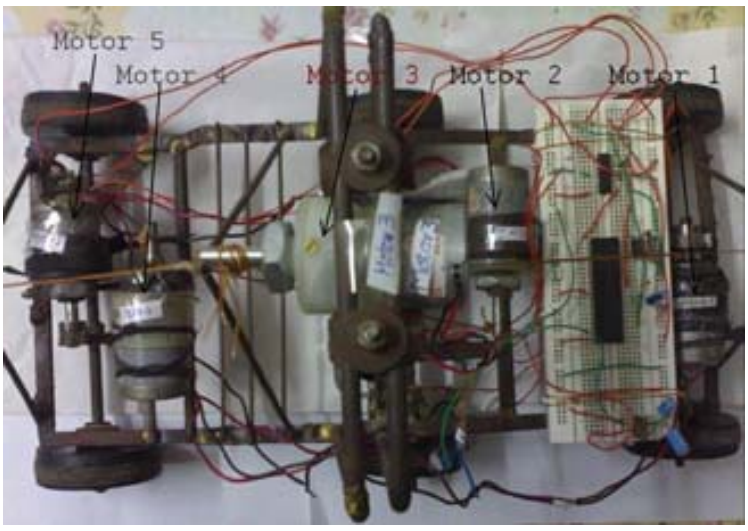

Fig. 1. Structure of the robot with motor position.

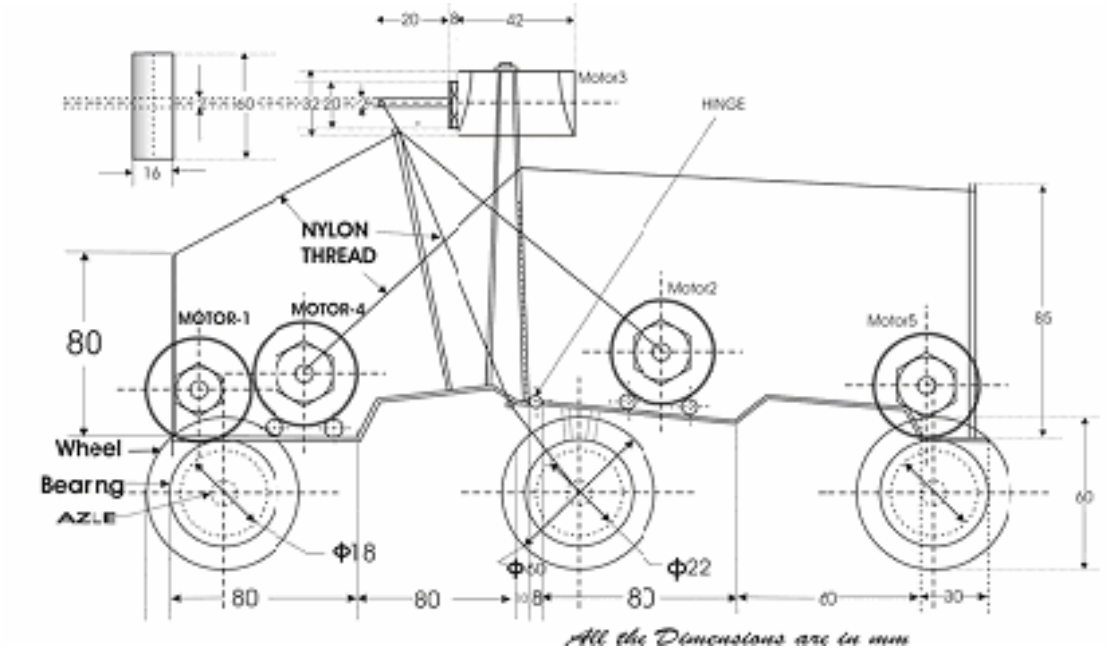

Fig. 2. Side view of the prototype model.

The present model of the robot is made of 2 mm thin iron strip and iron rod. The total structure contains 6 wheels, and 5 motors, the wheel diameter is 60 mm each. The system has three degrees of freedom .The dimension of prototype vehicle is 37.6 cm (length) x 21.5 cm (width) x 25.5 cm (height) and its weight is 2 Kg (approx). Five low cost DC Gear Motors have been used.

At the middle of its length a hinge is placed which is actually used during climbing any obstacle or step. The climbing mechanism is done with the help of three different nylon tendons and three different DC motors. One end of each tendon is attached with the shaft of the motor and the other end is attached with the rod parallel to the wheel axel. When the motor rotates in either direction, the nylon tendon is wounded up around the motor which causes movement of the axels along with the wheel pairs either in upward or in downward direction which is essential during step climbing. Motor-1 and Motor-5 jointly drive the system in forward direction. When front wheels are needed to climb, Motor-2 rotates and the nylon tendon pulls up the front wheels. When the middle wheels need to climb Motor-3 will start which is mounted at the top of the system and it will pull up the hinge that is the middle portion of the system. After covering the stair or step, Motor-3 will rotate in opposite direction to go back to its original position. Then Motor-4 which is placed in the front side of the system will start to pull up the back wheels.

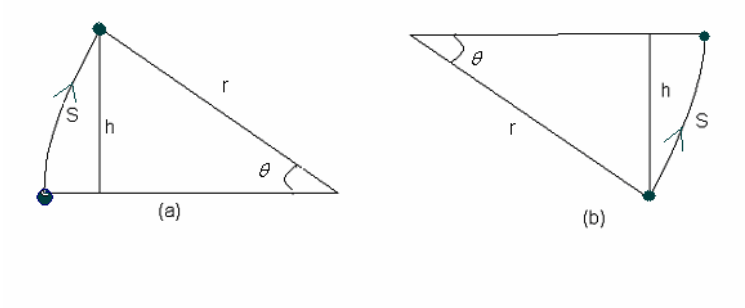

Fig. 3. View of front portion of the robot climbs (a) rear portion of the robot climbs (b).

The required time of rotation to over come height 'h' is say T_h

$$T_h = [r \sin^{-1} (h/r)] / [k_m \Pi D], \quad (1)$$

where r = length of the base of the robot, h = required height for Climbing, k_m = rpm of the motor, D = 2 r =diameter of the circle appears. With this process the system crosses the step. The photographic view of free joints or hinge is shown in Fig. 4 which is used to climb the steps or stairs.

Fig. 4. Hinge of the system.

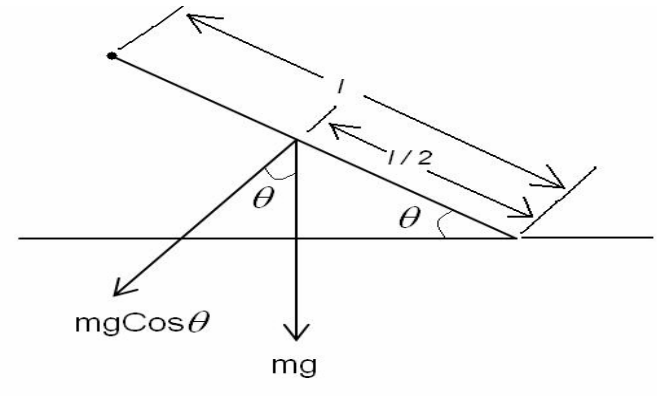

Fig. 5. Vector representation of the wheel climbing.

The energy required by the motor to lift the front and rear wheel

$$E = \frac{1}{2}\frac{ml^2}{3}(\dot{\theta})^2 + (\frac{l}{2} mg \cos\theta)\dot{\theta}, \quad (2)$$

where, m= mass of the body. l = length of the front/rear portion of the system. Θ = angle at which the front/rear wheel climbs. g = acceleration due to gravity. To lift the middle wheel the energy requiresd is double to that of expressed in Equation (2).

2.1. Testing

The step height at which the model has been tested is 97 mm. This model is able to move only linearly at steps and uneven environment. It has been observed that when the front and the back wheels are on the same plane, the middle wheels can climb up to 54 mm with the aid of the hinge. The photograph is shown in Fig. 6 and when the front wheels are at a step of 57 mm height, the middle wheels can climb up to 80 mm height and it is shown in Fig. 7.

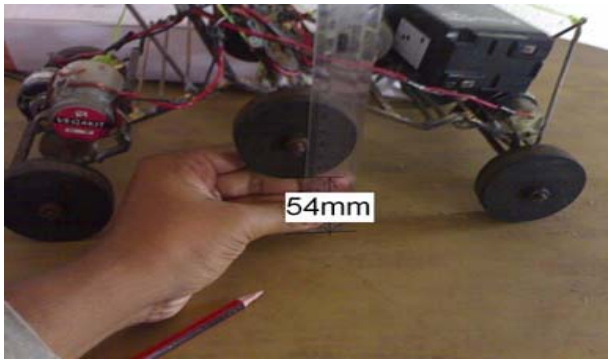

Fig. 6. Climbing of the middle wheel.

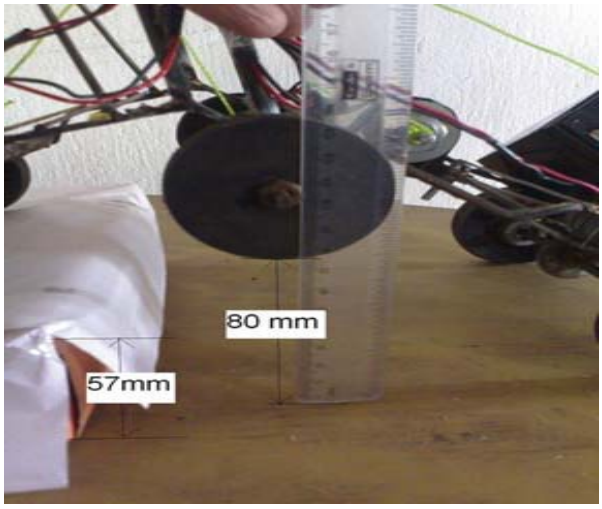

Fig. 7. Position of middle wheels while the front wheels are on the step.

Physical dimensions of the developed robot are shown in Table 1.

Table 1. Physical dimensions of the developed robot model.

Total Mass	**Less than 2.5 kg**
Length	376 mm
Width	215 mm
Height	255 mm
Wheel Diameter	60 mm

3. Block Diagram of the Present Work of One Complete Step Climbing

When power supply is given to the motor-1 and motor-5, the system starts moving in forward direction. The step or stair appears to be an obstacle in front of the system. When such an obstacle is sensed by sensor, the motor-2, motor-3 and motor-4 will start respectively, by which front, middle or back wheels will climb the step or stair. The respective motors will remain ON as long as it crosses the steps or stairs. When the robot completes crossing the obstacle, all the motors except motor-1and motor-5 will start rotating in the reverse direction to achieve its original position. The detail block diagram is shown in Fig. 8.

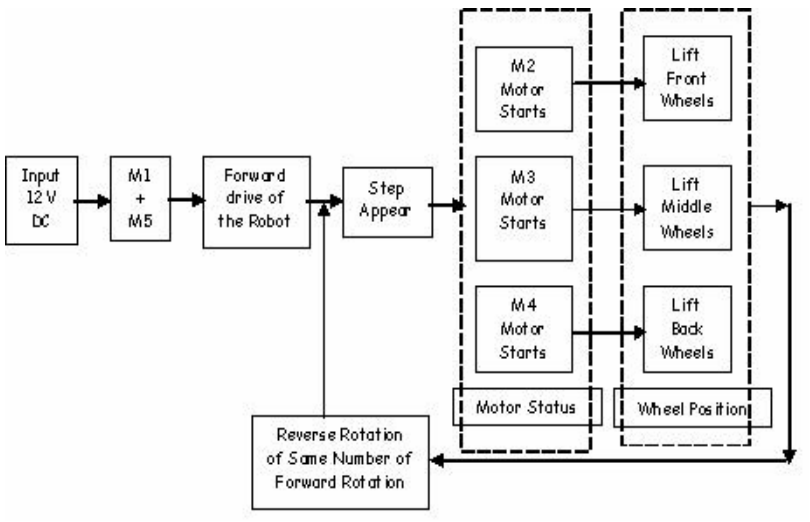

Fig. 8. Block diagram of the step climbing process.

3.1. Algorithm Used for Step Climbing

Algorithm used for the system is shown bellow. This Algorithm is for one complete cycle for the system.

Step 1 – Power supply is given to Motor 1 and Motor-5 [M1, M5] to drive the robot to move in the forward direction.

Step 2 –When the robot faces any step or stair as obstacle, Motor-2 [M2] starts running and the front wheels of the robot are lifted till those cross the obstacle.

Step 3 –After front wheels cross the step, M2 rotates in the opposite direction to achieve the previous position. Now the middle wheels will face the obstacle.

Step 4 –Motor-3 [M3] starts and the middle wheels start to be lifted till it crosses the step height. After lifting, M3 rotates in opposite direction to achieve previous position. Now the back wheels will face the obstacle.

Step 5 –Motor-4 [M4] starts and then back wheels will start to be lifted till it crosses the step. Again M4 will rotate in the opposite direction to achieve the previous position

4. Pictorial View of Step Climbing

The developed robot can climb up to 97 mm height comfortably. The photographs of those are shown in Fig. 9.

Fig. 9. Photographic view of Step Climbing.

5. Experimental Analysis

Graphical analysis of the system is shown bellow.

5.1. Front Wheel Climbing

From the Fig. 10 (b and c) it is clear that the angle produced by the system is directly proportional to the speed of the motor and on time of the motor by which the system front wheel climbs.

i.e.

$$\vartheta_1 \propto \omega t \tag{3}$$

$$\vartheta_1 = k\omega t\,, \tag{4}$$

where, ϑ_1 = angle produced by the system to climb the front wheels, k =constant, ω = angular velocity, t = time. As in the present system, the speed of motor is considered to be constant, we can say. Where, $C_1 = k\ \omega$ = Constant.

$$\vartheta_1 = C_1 t \tag{5}$$

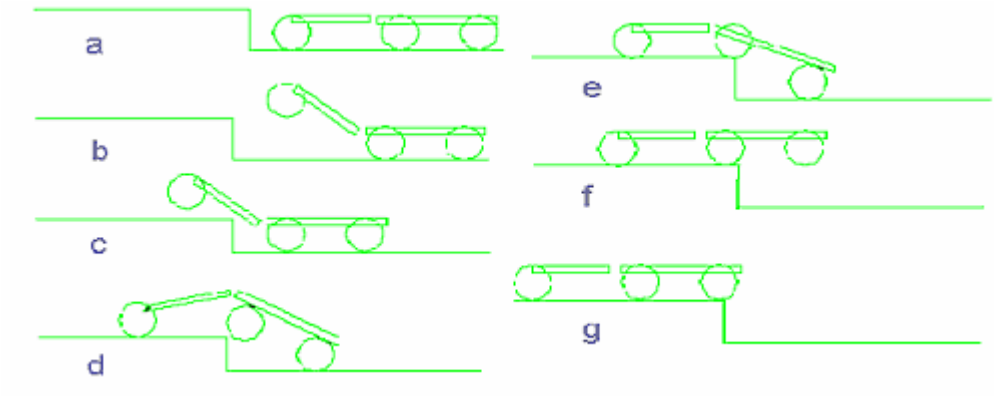

Fig. 10. The steps shown how the wheeled robot will climb the step.

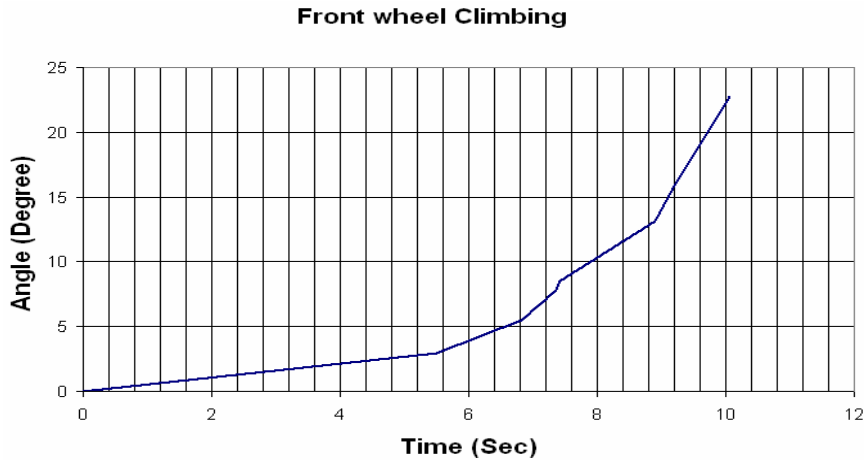

Fig. 11. Time - Angle curve.

5.2. Middle Wheel Climbing

From the Fig. 10 (d) it is clear that the height produced by the system is directly proportional to the speed of the motor and on time of the motor by which the system middle wheel climbs. i.e.

$$h \propto \omega t \tag{6}$$

$$h = k\omega t\,, \tag{7}$$

where, $h =$ height covered by the system to climb the step, $k =$Constant, $\omega =$ Angular velocity, $t =$ time. As in the present system, the speed of motor is considered to be constant, we can say Where, $C_2 = k\ \omega =$ Constant.

$$h = C_2 t \tag{8}$$

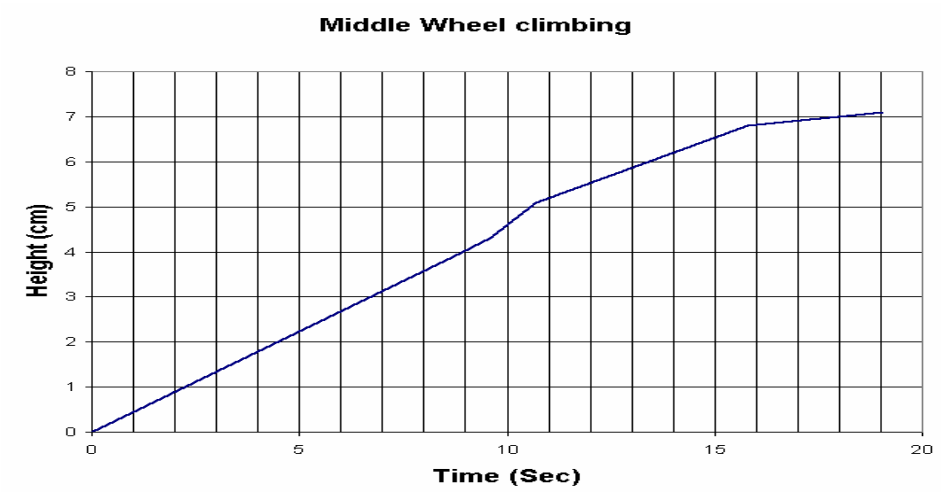

Fig. 12. Time - Height response.

5.3. Rear Wheel Climbing

From the Fig. 10 (e and f) it is clear that the angle produced by the system is directly proportional to the motor by which the system front wheel climbs.

i.e.

$$\vartheta_2 \propto \omega t \tag{9}$$

$$\vartheta_2 = k\omega t \tag{10}$$

where, ϑ_2 = angle produced by the system to climb the rear wheels, k =constant, ω = angular velocity, t = time. As in the present system, the speed of motor is considered to be constant, we can say Where, $C_3 = k\ \omega$ = Constant

$$\vartheta_2 = C_3 t \tag{11}$$

In this case the angle is produced by the system. Now with the motor actuation it comes to zero degree as shown in the Fig. 10 (e and f).

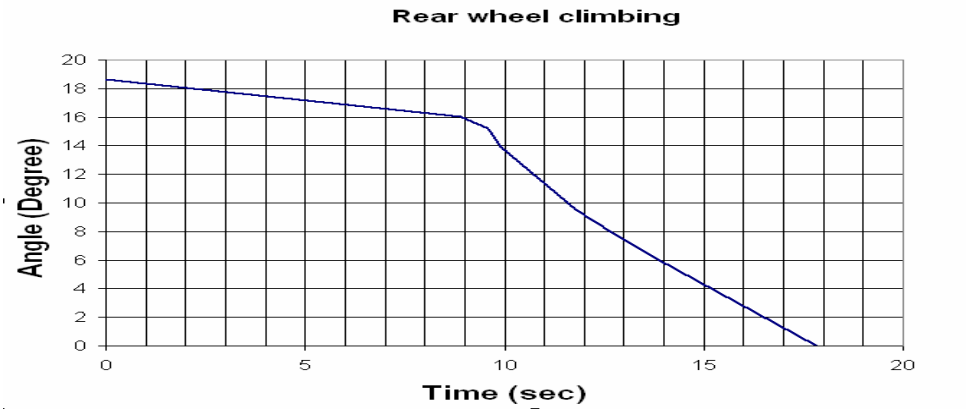

Fig. 13. Time - Angle response.

5. Comparative Study with Developed Model and Previous Models Developed for Step Climbing

The present model has been compared with the other previously developed models and the result has been shown in Table 2. It is observed that the present model is lightweight and less complex compared to others.

Table. 2. Comparative study of previously developed models and the presented model.

Model parameters and stair dimensions	R Hax By E.Z.Moore, D.Campbell, F.Grimminger & M.Buehlar (2001 & 2002)	Plural Wheel Robot By D.Chugo, H.Asama & T.Mishima (2006)	Octopus Wheeled Robot (2002)	Present Model
Mass	7.5 Kg.	21.6 Kg	10 Kg	Less then 2.5 Kg.
Length	510 mm	595 mm	420 mm	376 mm
Height	127 mm		230 mm	255 mm
Width			430 mm	215 mm
Wheel Diameter /Leg Length	(Leg) 106 mm	(Wheel) 132 mm		(Wheel) 60 mm
Stair length	160 mm			370 mm
Stair Height	280 mm	100 mm 125 mm 182 mm		97 mm

6. Conclusions

From the above discussion author wants to conclude that the model developed is unique comparing with the other models. Because using nylon thread this is the only step climbing robot model developed. The developed model also working properly in uneven environment. And it is comfortable to climb any step (less than 97 mm) height. So the idea of the model discussed is satisfactory. Step climbing or stair climbing is one of the projecting fields of research work. The system developed is limited with step climbing only. But as per its design it can be able to climb the stairs of a limited height. This model is also able to come down from any stair or steps, the design will support the operation for this purpose. In this system only simple controller i.e., ON – OFF controller is used. So for more precise control other complex controller can be design.

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