Autonomous staircase climbing robot for rescue application

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Abstract: This paper discusses the construction and application of an autonomous staircase climbing robot. Such a robot has several applications in real life. It can be used in dangerous regions for surveillance, rescue, and exploration with the help of a camera placed on it or by carrying resources. After going through various research papers a concept of such a robot was visioned. Following which design was formulated and simulations were carried out. A prototype was fabricated with mechanical and electrical parts. It is a simple climbing robot with two rods as support at the front. A simple rack and pinion gear are used to lift the robot while climbing. An ultrasonic sensor is placed at the front to sense the width and height of the stairs. Various testing and analysis have been done on the prototype to eliminate all drawbacks. The robot has shown to successfully climb the stairs.

1. Introduction

Robots are made to provide comfort to human life. They are a culmination of electrical and mechanical parts that have the ability to work semi or fully autonomously. They help in a range of activities from day to day life to complex tasks. [1]This paper presents the improvement of surveillance robots with respect to staircase climbing capacity. The robot is designed to overcome a daily life obstacle i.e. stairs. Stairs are used to cover vertical distances. Various mechanisms can be used to overcome these obstacles. After doing careful analyses of numerous mechanisms, we have decided to use a rack and pinion gear for the vertical movement of the robot. Despite numerous disadvantages of such mechanisms, it is robust and cheaper compared to others. Most of the research on autonomous climbing robots is done either on legged mechanism [2] or tracked mechanism [3]. A hybrid concept of using both has also been studied [4-5]. The fundamental detriment of the legged robot is that on level surfaces the robot speed is delayed as a contrast with the tracked robot. Moreover, the strolling and climbing arrangements are progressively intricate to create. With respect to the tracked robot, the size of the robot is quite large and it is not flexible enough to defeat obstructions. In the interim, living animals, including for instance, minor bugs, use bouncing or jumping for quick travel, just as for deterrent shirking. Accordingly, a few kinds of hopping mechanisms [6] for portable robots have additionally been proposed and created. However, there is some considerable amount of energy loss due to friction between the parts.

After studying various mechanisms in detail [7-10] we propose a type of robot which eliminates the factors of complexity and cost with a simpler mechanism. This novel technique makes use of wheels and a rack and pinion mechanism to scale up and downstairs and survive obstructions.
2. Methodology

2.1. Mechanical Calculations
The focus of calculation, of any sort, for this robot will be on the rack and pinion mechanism and it is purely simple Kinematics. The basic idea is that in order to lift the robot vertically upwards, the Torque (τ) provided by the motor attached to the pinion (spur gear) should be more than the Torque (τ) experienced on the pinion due to the weight and the upward motion of the robot.

Tangential force on the rack due to robot’s weight and motion:

\[ F_r = m (g + a) \]  

\( F_r = \) force on rack (N)  
\( m = \) moved mass; includes the application load, plus any system components that are being moved, such as the pinion, gearbox, motor, etc. (kg)  
\( g = \) gravitational constant = 9.81 m/s²  
\( a = \) maximum acceleration the robot will experience (m/s²)

\[ s = ut + \left( \frac{1}{2} \right) at^2 \]  

\( s = \) height of one step = 6in or 152.4mm  
\( u = \) initial velocity = 0 ms⁻¹  
\( a = \) maximum acceleration the robot will experience (m/s²)  
\( t = \) time taken by robot to climb one step= 6s

From (2)

\[ 152.4 \times 10^{-3} = 0 \times t + \frac{1}{2}(a \times 6^2) \]  
\[ 16a = 0.1524 \]  
\[ a = 0.0078 \text{ m/s}^2 \]

From (1)

\[ F_r = 2 \times (9.8 + 0.0078) (\text{kgms}^2) \]  
\[ = 19.62 \text{ N} \]

Torque on the pinion due to robot weight and movement

\( T_p = \) torque on pinion (Nm)  
\( r_p = \) radius of pinion (m)

\[ T_p = F_r \times r_p \]  
\[ T_p = 19.6 \times 37.5/1000 \]  
\[ T_p = 0.735 \text{ Nm} \]

Torque provided by the DC motor

Rated Torque (kg-cm): 10kg-cm or 0.98Nm  
Stall Torque (kg-cm): 28kg-cm or 2.75Nm

2.2. Components Required
Acrylic Sheets of 3mm thickness are used to make the body the robot. Two wheels of size 100mm are installed ahead. Two DC motors of 60rpm are used to power the wheels. One DC motor of 10rpm is used to power the Double sided rack and pinion for it’s up and down movement. Arduino Uno microcontroller board is used. Ultrasonic Sensors send the signal to Arduino to stop when it comes
close with the stairs. Jumper wires are used to connect components with each other. Two L298n drivers are installed. The Ilam sheet is being used in front to provide forward support and is also used to make the supportive structure at the rear. Step down DC supply module gives output in different voltages. A false shaft is used to provide support to rack and pinion. 12V Battery gives power to the robot.

2.3. Design
In the wake of considering various viewpoints which are significant for a portable robot that must be proceeded onward to climb a staircase, a CAD model was planned. Figure 1 shows the CAD model developed using SolidWorks. After careful considerations a fabricated model was produced as shown in Figure 2 and Figure 3.

![Figure 1. Designed Solidworks model.](image_url)
Figure 2. Fabricated model (rear view).

Figure 3. Fabricated Model (top view).
2.4. Sequence

The approach of the production of this robot has been grouped predominantly into three sections which incorporate design, manufacture of the proposed model and trial examination which is explained in Figure 4. The basic working sequence of the robot is shown in Figure 5.

![Methodology Sequence Diagram](image1)

**Figure 4. Methodology Sequence.**

![Working Sequence Diagram](image2)

**Figure 5. Working Sequence.**
1. The robot is placed at the bottom on the staircase and is connected to the battery. An ultrasonic sensor placed in the front measures the distance to the stair and the height of the stairs. If the distance is less than or equal to what is predetermined (see figure 6A) the robot stops.

![Figure 6(A). Sequential Climbing of Robot.](image)

2. Double-sided rack and pinion is installed which facilitates the up and down movement. In addition to the upward movement, it also needs to move forward. To achieve that as shown in figure 6B the front side is attached with two beams attached at an angle. When the robot comes in contact with the stair, the ultrasonic sensor sends a signal to the Arduino which in turn actuates the upward motion. It gets inclined to some extent and hence moves forward too.

![Figure 6(B). Sequential Climbing of Robot.](image)
3. The front wheels are specifically chosen of the size, so that they protrude beyond the front face of the robot as shown in figure 6C. As the robot climbs up and moves forward, the front wheels are made to rotate and finally they touch the nose (front edge) of the stairs and the robot is pushed upwards.

![Figure 6(C). Sequential Climbing of Robot.](image)

4. Then on reaching the stair platform robot moves forward and the rack and pinion are retracted (see figure 6D). The same process happens until the time it reaches the top of the staircase. Delay is added so lifting is done till the time it reaches the next stair.

![Figure 6(D). Sequential Climbing of Robot.](image)

5. To climb down, ultrasonic sensors are installed at the back. When there is no surface, rack and pinion will extend and the robot is pushed. The tilted beams in front of the robot, made from an ilam
sheet again provides support so that it doesn't fall down. The processes 1 to 4 are done exactly the same ways but in reverse order, for the climbing down of the stairs.

2.5. Software Used
ARDUINO IDE (Integrated Development Environment) was used to write the codes for the robot and dump it on the Arduino Uno board that controls the sensor work and therefore, the vertical and horizontal movements.
SOLIDWORKS is a solid modelling Computer Aided Design (CAD) and Computer Aided Engineering (CAE) software that was used to formulate the design of the robot along with the mechanism to aid in the designing process.

3. Experimental Trial

3.1. Testing
The prototype was tested for a long time to incorporate all the new ideas. After the initial fabrication of the model, the robot faced a number of challenges. One of the main hurdles was the distribution of weight and its self-balancing mechanism. We used a number of techniques and reevaluated our calculations to overcome these problems. The next problem we faced was the slippage of the rack and pinion gear due to which it failed to rise. After a number of trials using various screws and tightening methods, we were able to successfully fix it. There was another problem encountered during the many trial runs. It was a small but significant problem. The T-shaped structure made by the rack and small wheels at the back was slipping due to which the rack failed to align with the pinions. We had to use different materials from rubbers to leathers to increase the friction provided by it to prevent it from slipping. Finally, we were successful in using ilam sheets that held it together in place. The coding was changed from time to time in accordance with the delays and distances through trial and error methods. The overall outcome is accepted as it meets the objective of the project.

3.2. Results
After doing many test runs and making adjustments to our program, we noticed that our robot was climbing the staircase. Since the measurement was taken in accordance with the stairs and the robot, climbing was in sync with program. However it was not always climbing due to certain problems encountered such as unequal height of stairs, faulty components and slippage of rack and pinion.

3.3. Analysis
Our robot of the dimension 200x200x80mm was well placed on the stairs. The two 60rpm motors were driving the wheels and a 10rpm motor was running the rack and pinion. Arduino Uno is used for coding. Ultrasonic sensors were used for sending signals. L298n drivers were attached.

3.4. Novelty
There are many staircase climbing robots that already exist such as the four wheeled robots, track robots, legged robots, and robots that use lead screw for upward and downward movement. However, in our robot we are using a single double sided rack and pinion which is placed at the middle supported by 2 gears on each side. Our motive was to design a robot which was feasible and economic. With a single double sided rack and pinion it was stable while climbing. We faced some drawbacks like slippage which were eventually fixed.

4. Conclusion
This paper discusses the conceptualization, design, specifications and working of a staircase climbing robot by using a rack-and-pinion mechanism. The project involves fabrication of a robot that can replace humans in many fields like offices, homes, military, industry automation, hospital operations and hazardous environments among many more. Based on the testing and optimization, the robot was
made to climb the stairs with ease by the proposed mechanism. The performance was satisfactory and met the basic requirements for a staircase climbing robot.

The simplicity and small size of the robot are its advantages and it can be further modified to incorporate many other features such as a camera. The research on the topic of robots and specifically staircase climbing robots are endless and ongoing. The improvements can be done by using other mechanisms or this mechanism can be improved too by adding different design calculations, in order to lift heavy weights. This model cannot be identified as the final product as improvements can be done by incorporating Machine Learning and Machine Vision to help in better mobility and efficacy.

5. REFERENCES

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