RESEARCH PAPER | Engineering | Volume : 4 | Issue : 11 | November 2014 | ISSN - 2249-555X

Hybrid All-Terrain Defence Vehicle

KEYWORDS: defense vehicle; microcontroller; mechatronics; hybrid; all-terrain vehicle

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ABSTRACT *This paper deals with the designing and manufacturing of a vehicle, which can climb stair or move on a rough terrain. For spying and rescue operations as well as for military applications, it is helpful sensors and cameras are used in dangerous or inaccessible areas to get better situation awareness for the rescue personnel, before they enter a possibly hostile environment. The technical issues in designing of this vehicle are the stability and speed of the vehicle while climbing stairs. They should be quick and agile and, at the same time, be able to deal with rough terrain and even to climb stairs or move over obstacles. This paper presents the design and implementation of a remotely controlled mechanical system for a stair climbing robot. The basic robot parameters (track configuration, track angle of movement, mass center variation) were determined using trial and error methods, based on basic principles of physics and we propose a different approach which controls the adaptation of the robot to the ground during the climbing and descending*

INTRODUCTION

One of the important applications of robots is for surveillance and to secure locations. There are several broad applications that such robots could be used in. These robots could be deployed to perform site surveillance prior to sending humans into potentially dangerous situations. More sophisticated robots could completely eliminate the need to send people into hazardous locations by performing the work that a human would otherwise need to do. By adding image processing capabilities, a robot could recognize critical situations that a human might miss.

Most of the current robots are remotely controlled by humans, rather than being able to operate autonomously. This simplifies their design, but requires that at least one human be employed to monitor and control their operation. This system has a limited degree of autonomous operation, but is controlled by human monitors via the wireless network, which also sends the video collected by the robots back to the monitoring station. The usefulness of mobile robots has made this field a very active area of paper.

The details presented in this paper shows the use of robots that can perform security duties in a building, disaster struck areas, hostile areas etc. Robots that are used for surveillance must be capable of climbing stairs that are inside the area. The main emphasis of this paper was to find the best robot locomotion method for climbing stairs. An important step in this process was to specify the stair parameters. The most important parameters are the stair height and width. These two variables set the stair angle, which is another important variable. A stair climbing robot must be capable of climbing and descending the stairs in its deployment location efficiently and with minimal or no slippage. If the location contains more than one set of stairs, these stairs may have different heights and/or widths, and the robot must be able to climb all sets of stairs. For this paper, we have designed a set of stairs with particular dimensions.

Other important aspects of this paper included studying the best track angle of attack to reduce the repulsive force at the first stair step, and analyzing the needed minimum length of stair contact for climbing. The relation of the grouser pitch to the maximum yaw angle while the tracked robot is climbing stairs was examined. The approach taken in this paper results in a set of guidelines that can be used to find an optimal design for a tracked robot that is stable for climbing and descending stairs, and efficiently uses its available energy source. This includes the types of DC motors required for this task. Determining the torque required for climbing the first step is also important; to make sure the selected motor can supply the required amount.

The remainder of this paper is devoted to the systematic development of a stair climbing robot. This includes the mechanical design of the robot, including discussions of the selections of the major mechanical components. The total design is then summarized, and future paper aspects are briefly discussed in conclusion.

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DESIGN OF ROBOT:

The Robot will be operated in a fairly rough terrain where small steps and small obstacles are a common feature. The fundamental criteria of the robot have been laid out right from the beginning. Below are the objectives the robot is supposed to fulfil:

- The robot's footprint must be no bigger than 50cm x 30cm x 15cm in storage.

- The robot shall come with a wireless remote controller and optionally a wireless video and remote display system.

- The robot must overcome a gap of 24cm. i.e. 60% of its length.

- The robot must overcome a vertical obstacle of 10cm i.e. 100% of its height.

- The use of a flipper design is prohibited.

The robot will be designed and fabricated according to these criterions. General Performance will also be measured and tested using these criterions as the minimal guideline.

Project Requirements	Interpreted Needs
Design and manufacture a stair-climbing robot	1. Mechanisms that provides forces for horizontal and vertical displacements 2. Robust design
Construction of a solid base to ensure the robot works properly when climbing the stairs	1. A sheet-metal base onto which important components can mount 2. A casing that protects important components of the robot
Strength and toughness of the robot	1. Appropriate materials must be selected as the raw materials for manufacturing the components. 2. Important components should be designed with strength and minimum weight
Use of battery power	1. The number of batteries to generate adequate electricity for driving the mechanical power producers 2. The space for storing the dry cells
A maximum number of 6 motors to drive all the motions.	Just required to perform variety of motions by the stair-climber
A switch to control the power on and off	The route of the electrical power transmission must involve a single on/off switch.
Commission tests to ensure the robot is properly designed	1. Since there are no specified stairs the stair-climber must be able to climb, the specifications of the stairs must be decided to verify that the robot can properly climb the stairs with specified range of dimensions. 2. Construction of an artefact that imitates the stairs with suitable specifications to assist the robot in demonstrating its abilities.

HARDWARE

- **8051 Microcontroller**
- General Features of the microcontroller are:
- Compatible with MCS-51® Products
- 8K Bytes of In-System Programmable (ISP) Flash Memory– Endurance: 1000
- Write/Erase Cycles
- 4.0V to 5.5V Operating Range
- Fully Static Operation: 0 Hz to 33 MHz
- Three-level Program Memory Lock
- 256 x 8-bit Internal RAM
- 32 Programmable I/O Lines
- Three 16-bit Timer/Counters
- Eight Interrupt Sources
- Full Duplex UART Serial Channel
- Low-power Idle and Power-down Modes
- Interrupt Recovery from Power-down Mode
- Watchdog Timer
- Dual Data Pointer
- Power-off Flag.

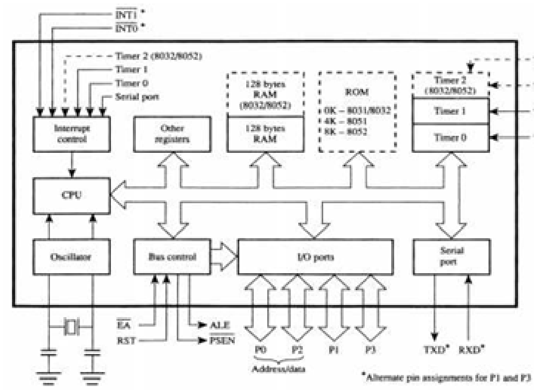

Figure 1: Block Diagram of 8051 microcontroller

- **DC Motors**

Figure 2: High Torque DC motor used. (8kg-cm torque)

Specifications:
- 60 RPM 12V DC Motor with Gear Box.
- 18000 RPM base motor.
- Shaft: 6mm.
- Gearbox diameter: 37 mm.
- Gear: metal spur gear assembly.
- Motor Diameter: 28.5 mm.
- Length: 63 mm without shaft.
- Shaft length: 15mm.

- Weight: 165 gm.
- Torque: 8-12 kg cm.
- No-load current = 800 mA (Max), Load current = up to 9.5 A (Max).

Wheels and Gripper Belt

Figure 3: The grouser belt and wheel used in the model

- The vehicle has 8 wheels among which 4 wheels are driven by high torque motors, two wheels are driven by low torque motors and 2 wheels are idle. All the wheels are moved in a synchronized manner using a gripper belt, among the 4 wheels which are connected to high torque motors 2 wheels are at front top position and the remaining 2 are at rear bottom, the 2 wheels which are connected to low torque motors are at rear bottom position as shown in the figure. Each wheel has a circumferential v-groove which helps in the meshing of belt with wheel and avoids slipping of belt. The wheels are mounted coaxially with the motor shafts and dead axle to prevent whirling. Corresponding wheels on left and right portion of the vehicle are coplanar. Two gripper belts are used to move the wheels synchronously; the belts are made from rubber and have external grousers. V groove helps to mesh the belt with wheels.

- **Other Hardware**

Apart from these main components, we have also made use of various sensors. Like infrared sensors, temperature sensor, and metal detector. With the help of these sensors, we can determine the situation of the surrounding of the robot.

Also we have made use of solar panel which can be used as a supplementary power source for the robot thus making it a hybrid one and also a wireless camera is used to wirelessly control the robot and get real time situation updates.

DESIGN PARAMETERS

In the present study, effect of crumb rubber as fine aggregate replacement on the compressive strength of concrete having mix proportions of 1:1.31:1.14 was investigated. The percentages of replacements were 0%, 10 %, 20% and30%by weight of fine aggregate. Tests were performed for compressive strength or all replacement levels of crumb rubber at different curing periods (7-days & 28-days).

- **Calculation of Coefficient of Friction between floor and grouser belt.**

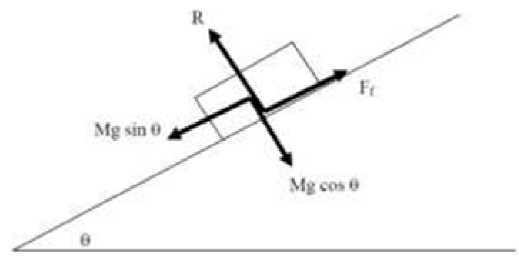

Figure 4: Resolution of forces between belt and surface.

The static coefficient of friction between the rubber grouser belt and the floor is obtained by the following methodology.

Let the static coefficient be μ. and the block is at rest

$$Mg\sin\theta = Ff = \mu R \quad (1)$$

$$Mg\cos\theta = R \quad (2)$$

The static coefficient of friction can be obtained when the block starts to move backwards down the slope when θ is increased to a certain value. Substituting (2) into (1)

$$Mg \sin\theta = \mu\, Mg \cos\theta$$

$$\mu = \tan\theta \quad (3)$$

From this result, we can obtain the value of coefficient of friction by finding the angle at which the block just starts to move down the slope.

Experimental Results

Using the above methodology, the polyurethane tracks were tested on a concrete slab and the angle of the slab measured when the polyurethane tracks just start to slide down. θ was obtained Several times and the average obtained was used to calculate the coefficient of static friction.

Attempt 1	Attempt 2	Attempt 3	Average
37°	35°	36°	36°

$\mu = \tan\theta$

$\mu = \tan 36$

= <u>0.7265</u>

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- **Calculations of Required Torque for Driving Motors**

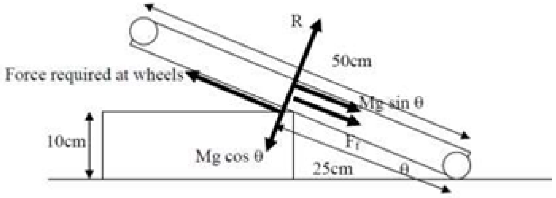

Figure 5: Resolution of forces for torque calculation.

Estimated maximum mass of EMR = 4kg

Diameter of drive wheels = 6.5cm

Coefficient of static friction of tracks = 0.7625

$Mg \sin\theta = 4 \times 9.81 \times 10/25$
$= 15.69$ N
$Ff = \mu R$
$= 0.7625 \times 4 \times 9.81 \times \cos\theta$
$= 18.7$ N

Force required at wheels = 18.7 + 15.69
= 34.39 N

Torque at wheels = 34.39 x 6.5/2 /100
= 1.117 Nm

Torque required per motor = 1.117 / 2
= 0.5588 Nm

Torque required/motor (S.F. =1.5) = 0.5588 x 1.5
= 0.8382 Nm
= <u>8.22 kg cm</u>

- **Chassis design considerations**
- The robot is constructed keeping in mind that it is equally capable of ascending and descending the staircase.
- This is made possible by making the initial contact of the robot with the force acting at an inclined angle of 50° with the stairs.
- The design also enables the robot to pass over small obstacles.
- The two resolved components of the force vectors enable the robot to climb stairs and to thrust forward.

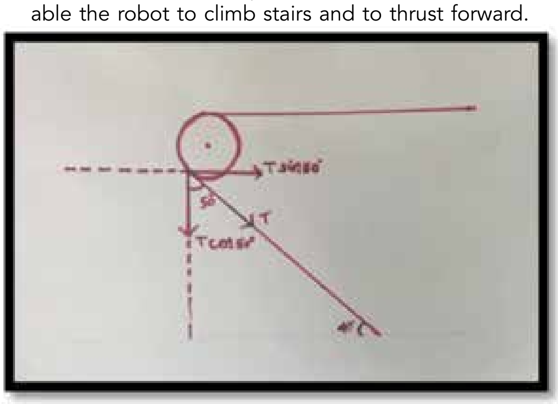

Figure 6: Resolution of forces when the vehicle contacts the stairs.

Coming to the actual design of the chassis:

- The robot is symmetric in design, such that it can ascend or descend in either direction.
- The slant portion of the robot enables itself to maintain its center of mass in such a way that it balances itself while climbing and descending without toppling.

EXPERIMENTATION

- The robot from its initial position starts moving forward and comes in contact with the raiser part of the stair case, such that the prime mover wheel just touches the edge of the stair.
- When the wheel is in contact with the stair, due to the motor's rotation the tension carried by the belt inclined to the raiser at certain angle, results in two vector components. The vertical component enables the robot to lift up and the horizontal component enables the robot to thrust forward.
- In the next step, the second set of wheels comes in contact with the raiser edge. Here when the forward part of the robot is raised upwards, the rear portion of the robot completely comes in contact with the floor. Hence it provides a forward thrust to further move the robot upwards.
- This mechanism continues and the robot climbs the completely climbs the stairs. Stairs with the help of gripper belt.

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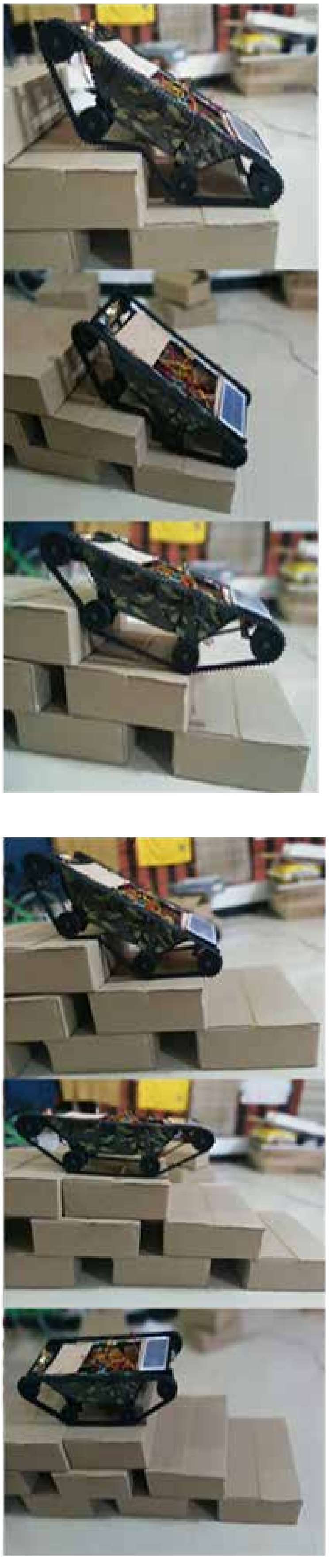

Figure 7: Shows the robot climbing stairs. (Clockwise)

Figure 8: Shows the robot crossing a gap. (Clockwise)

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RESULTS AND ANALYSIS

- **Analysis of Tracked Robot When Climbing Stairs**

This section introduces the analysis of the motion of the tracked robot while climbing stairs. When the robot encounters the stair riser, its motors apply torque to the tracks to start the robot climbing the stair riser. The most difficult part of climbing is when the angle between the robot's center of mass and the riser, θ, are between zero and 50 degrees. As θ increases, both the coefficient of friction between the track and the ground and the driving moment increase. The robot's velocity and acceleration also increase. The best arrangement of mass distribution for optimum stair climbing is when the robot's center of mass is located close to its rear wheel [1].

It is impossible to climb stairs with this configuration (Figure 9). Furthermore, finding the best location of the center of mass requires analyzing the different phases of the tracked robot during climbing and descending.

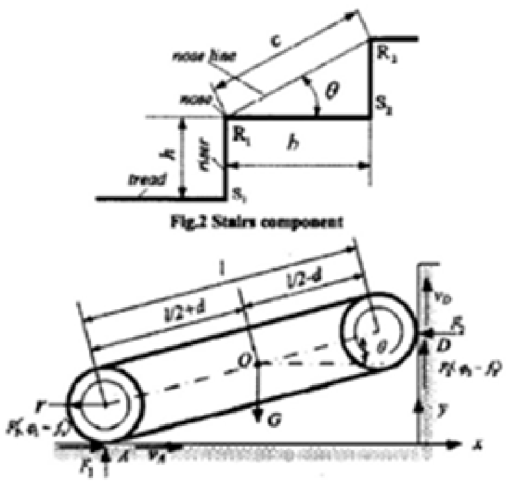

Figure 9: Climbing the wall and repulsive forces [1].

The Repulsive forces applied to the robot from the stairs as the robot climbs the stairs makes climbing difficult. These forces can be reduced by configuring the track with a front angle of attack as shown in Figure 10 [2]. This makes it easier for the robot to climb the obstacle. The angle of attack is the angle between the front parts of the tracked robot with the stair raiser or an obstacle. The height of the front part of the tracked robot must be taller or at least equal to the obstacle.

One of the most challenging subjects of study on mobile robots is the analysis of descending from objects. Figure 11 [3]. Illustrates the situation of a robot descending from a single obstacle. When a tracked robot is in forward motion and encounters the topmost step of a staircase to begin its descent, the robot keeps traveling until its center of gravity extends past the nose of the step (Point O). At this time, a rotational torque begins to develop.

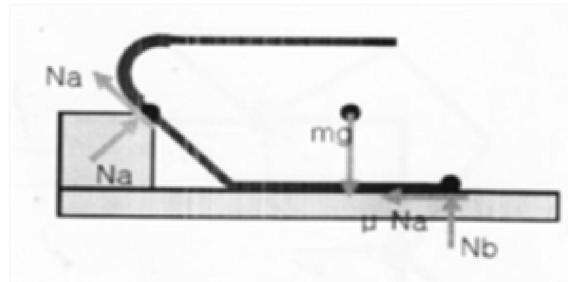

Figure 10: Designing an angle of attack for overcoming the repulsive forces [2]

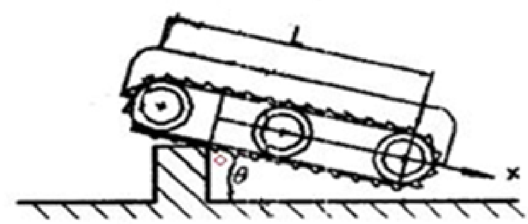

Figure 11: Descending of tracked robot as its center of mass

While the robot continues moving forward, the magnitude of the torque increases. This causes the angular acceleration of the robot to rapidly increase about its (moving) pivot point. The combination of the linear downhill momentum and the additional angular momentum results in a harder collision when the front of the robot hits the ground or another stair step. As shown in Figure 12, under certain conditions, the pivot point can shift from the first step nose to a lower stair tread or nose (Point A of the third step in this example) [3]. If the rotational momentum is large enough, the robot could topple over.

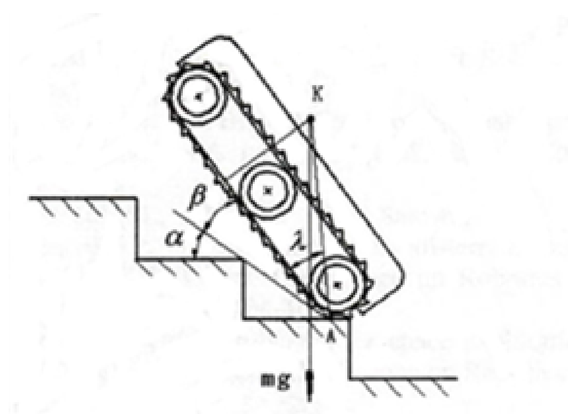

Figure 12: Tracked robot descending a stair [3]

- **Tracked Robot Turning Analysis**

The area of contact between the tracks and the ground is much larger than that of the wheels of an equivalent wheeled robot. Hence, with reference to Figure 13, when skid steering is used for turning, tracked robots require more torque than that required for a wheeled robot. The difference in speed between the two tracks imposes a very large torque on the slower track. It is estimated that the energy required by a tracked robot for turning on a flat surface is greater than that required at the start of climbing a 40° degree slope with a 0.8 coefficient of friction [4].

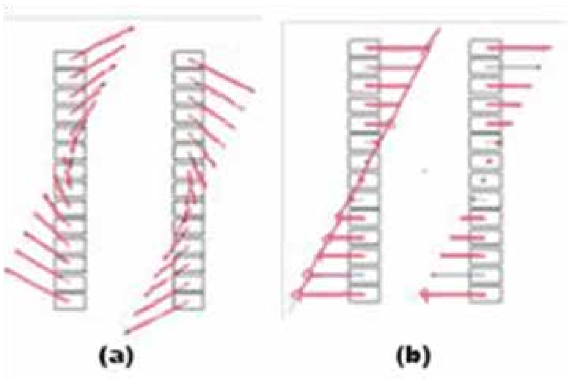

Figure 13: Skid steering turning on a stationary spot. (a) Track segment movement direction. (b) Relative friction forces between track and ground [5]

- **Other Considerations**

Other design subjects that must be considered are the tracks, timing belts, and, especially, grousers. The grousers can significantly reduce the track robot's energy consumption in all situations. They can act as a grip for climbing obstacles, as shown in Figure 14 (center and right). Only one article was found in the literature that analyses the effects of grousers, and it was written in the Korean language [2]. The authors of this article, Park Nam-Eun, Park Dong-Il and Kwak Yoon-Keeum analyzed the forces acting on the grousers while the tracked robot climbs stairs.

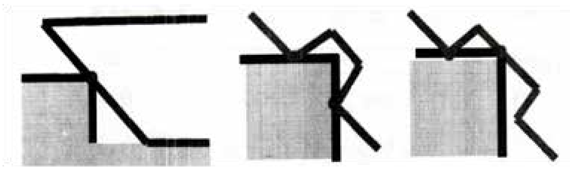

Figure 14: (a): Track robot without grouser. (b): Track with small pitch grouser. (c): Track with large pitch grouser [2]

They also analyzed the effects of the grousers' pitch. They used static rather than dynamic analysis, which is the main disadvantage of their project.

The grousers' pitch can play a very important role in the efficiency of track robots. A very small or very large pitch does not have the best efficiency. A small pitch cannot act as a grip and the track can slip. A large pitch can have slippage until the grouser reaches one of the stair noses. The grouser pitch can be an important subject of studies.

CONCLUSION

The main purpose of this project was to define the best geometry and mechanical design of a stair climbing robot to optimize its efficiency and effectiveness.

This set the main task of this project to be the design of a non-variable configuration tracked robot and analyses the behaviors of the robot during the different stair ascending and descending phases. This paper is not only useful for non-variable tracked robots, but can also be a base for analyzing any other types of robots that have stair climbing tasks.

After selecting the tracked robot as the most reliable type for climbing stairs, the factors that must be considered for the robot design must be determined. The first of these constraints is to know the geometries of the stairs that are to be climbed. In the general case, a robot will be required to climb and descend several sets of stairs, each of which may have a different geometry. Thus, the stair dimensions might vary within a set range of values provided the staircases adhere to the requirements of the building code.

The stair specifications were then used to constrain the robot design. The minimum length of the robot was determined, based on the distance between two adjacent stair noses. This analysis revealed that the bottom length of the tracked robot must contact a minimum of two stairs at all times during the stair climb.

The time when the robot first contacts the stairs and starts climbing them is very critical and is one of the most difficult situations in the stair climbing situation. This makes it important to devote a significant amount of time to designing the robot in order to minimize the power consumption and maximize the stability during this phase. The shape of the front of the robot has a significant effect on the ease of the initial climbing operation.

The grousers allow the robot to get a better grip on the stair noses during climbing. The robot with grousered tracks consumes less energy when climbing, due to the better stair grip. The larger maximum allowed angle of attack allows the robot to be smaller and thus weigh less than the smooth belt robot. These comparisons lead to the selection of a robot with a front angle of attack and tracks with grousers as the best configuration for the stair climbing functionality.

The next task of this study was to determine the location of the robot's center of mass. Static analysis showed that the center of mass must be above the nose of the first step when the tip of the flat bottom contacts the second step. The dynamic analysis imposed additional constraints; namely, that the location of the center of mass cannot be too far to the front otherwise the robot may tip over during descent. Additionally, the center of mass cannot be too far to the back otherwise it could create a strong impact when the rear of the robot falls to the ground after leaving the final step during descent. This set of constraints limits the possible location of the center of mass.

The shape and dimensions of the track were also studied to determine the best grouser pitch. The range of allowable pitch values is constrained by possible slippage or falling when the robot is climbing or descending stairs. The pitch must also be selected to minimize the possible angle on the stairs.

The results of the studies reported in this paper give a good foundation for the design of a stair climbing robot. The robot design is much simpler than most existing stair climbing robots, due to the elimination of the variable configuration arms. This robot is smaller and weighs less than existing designs, and can thus run for a longer period of time with the same set of batteries.

FUTURE SCOPE

- A combination of the tracked robot and the wheeled robot could be a better choice for building surveillance.

- This design could be modified for tracked robots so that when the robot is on level ground, wheels are lowered to contact the level ground and lift the tracks off of the ground.

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- This would result in a huge decrease in energy consumption on a flat surface compared to a pure tracked robot, even with the additional weight of the track mechanisms.

- This would allow either the run time to be increased or the battery weight to be decreased, or a combination of the two.

- The tracked/wheel robot combination could also be implemented by using a different configuration. The front wheels could be attached to an arm mechanism that can rotate 135 degrees about the Z axis (perpendicular to the X axis of forward motion and the vertical Y axis).

- Finally, studies could be performed to replace much of the robot's steel structures with composite materials. This could reduce the robot's weight and potentially strengthen its structural integrity, if the composites are deployed correctly. This could be a fruitful approach to consider.

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