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Design and Fabrication of Tracked Mobile Robot Prototype

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ABSTRACT

Tracked mobile robot prototype was designed and fabricated with its Rolling Resistance (RR) calculated to be 5.94N and Grade Resistance (GR) of 18.74N. The Acceleration Force (FA) was calculated to be 5.5N and the Total Tractive Force (TTF) which is the sum of RR, GR and FA was computed to be 30.18N. Motor torque obtained to ensure good vehicle performance was obtained as 2.113Nm. The fabricated robot was able to cross a ground gap of 26cm and climb a height of 13cm. Its speed was measured to be 0.418m/s.

1. INTRODUCTION

Robotics is an important field of interest in modern age of automation. Unlike human beings a computer controlled robot can work with speed and accuracy without feeling exhausted. A robot can also perform pre-assigned tasks in a hazardous environment, reducing the risks and threats of human beings. As for example a mobile robot can easily find and eliminate a variety of enemy threat activities, nuclear, biological and chemical materials. It can also traverse into inaccessible routes and terrains [1].

Unmanned Ground Vehicles (UGV's) often referred to as mobile robots by academic researchers was first deployed during World War II by the Russian military. Tracked mobile robots are typical unmanned ground vehicles with continuous tracks or treads which provides increased mobility (added traction and low ground pressure) over rough terrain environments.

The first ever unmanned ground vehicle as mentioned earlier were the Russian teletanks used during the early 1940's, followed by Goliath. Goliath is an unmanned ground vehicle designed and built by the Germans based on French prototype which was developed earlier by the French military [4]. It is a small demolition midget tank. Hence, unmanned, armed and remote controller ground vehicles can be said to be at least a sixty nine years old technology. A good number of this unmanned ground vehicles have been in deployment in Iraq and Afghanistan mainly for military usage as short range scouts robot to inspect and detect suspected bomb sites and mines [2].

Urban disaster and conflicts, hostage situations and improvised explosive device detection are extreme and unpredictably dangerous especially when entering into buildings with no prior knowledge of what is happening inside. Mobile reconnaissance robots help to greatly reduce the dangers associated with these types of missions by making available intelligence information through imagery and maps of indoor and outdoor environment before rescue personnel's are sent it. This type of missions is most practical in cases where the robot platform is small enough and deployment can be carried out by one person [3].

Unmanned ground vehicles are therefore designed for deployment on land for tasks that are difficult and impossible for human to effectively perform. In general these vehicles are used in tactical surveillance, reconnaissance, improvised explosive (mine) detection, explosive ordinance disposal, fire intervention, physical attack and destruction missions, military damage assessment in war zones, nuclear-biological-chemical research work and planetary research etc. Most importantly, the increase in the number of terrorist attacks has resulted in the increase of research conducted in the field or mobile robotics (Yagimli and Varol, 2008).

The tremendous increase in the demand to traverse environments where human beings cannot penetrate, operate safely and effectively and the urge to reduce human exposure to dangerous environment evoked my interest to design and develop a robust prototype of a tracked mobile robot.

2. METHODOLOGY

2.1. Design calculations for drive wheel motor torque

The drive wheel motor torque calculation is done after successful fabrication of the mechanical structure in other to determine the minimum torque required for the mechanical structure to start moving and based on the obtained value of torque a suitable electric motor which produces or falls in range of the required torque is selected from the market.

In choosing an electric motor this is mounted on the drive wheel of mobile vehicles, certain factors are taken into considerations so as to accurately determine the torque required by the system (tracked mobile robot).

Gross Vehicle Weight (GVW):
(11kg × 9.81m/s²) = 107.91N

Radius of wheel: = 0.14m

Desired top speed (V_{max}): = 0.5m/s

Desired acceleration time (t_a) : = 1sec

Maximum incline angle (θ): = 10°

Worst working surface (Grass): = 0.055

Having identified the vehicle's design criteria based on the fabricated mechanical structure of the tracked mobile robot, choosing a motor capable of producing enough torque for the mechanical structure is inevitable. Therefore Total Tractive Effort (TTE) is determined for the mechanical structure.

$$\text{TTE (N)} = \text{RR (N)} + \text{GR (N)} + \text{FA (N)} \qquad (1)$$

Where;

RR = Force necessary to overcome rolling resistance
GR = Force required to climb an inclined angle
FA = Force required to accelerate to final velocity
To determine the required torque, the components of the above total tractive effort equation are determine in the followings steps.

2.2. Determining the Rolling Resistance

Rolling resistance (RR) is the force necessary to propel a vehicle over a particular surface as shown in table 1. The worst possible surface type to be encountered by the vehicle is factored into modeling of the robot as shown in equation 2.

$$\text{RR (N)} = \text{GVW} \times C_{rr} \qquad (2)$$

Where:
RR = Rolling resistance
GVW = Gross Vehicle weight
Crr = Surface friction

RR = 107.91 × 0.055 (“grass”)
= 5.94 N

2.3. Determining grade resistance

Grade Resistance (GR) is the required amount of force necessary to move a vehicle up a slope. This calculation must be made using the maximum angle the vehicle will be exposed to or expected to climb in normal operation. To Convert incline angle (θ), to grade resistance, figure 1 will be used as illustration and equation 3 will be used for the conversion.

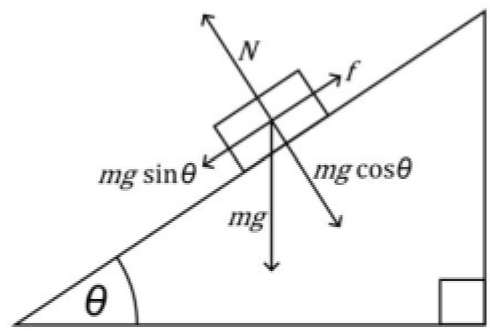

Fig. 1. Free body diagram for grade resistance

$$\text{GR (N)} = \text{GVW} \times \sin(\theta) \qquad (3)$$

Where:

GR = Grade resistance
GVW = Gross vehicle weight
θ = Maximum incline angle the vehicle climbs in normal operation.

GR = 107.91 × Sin (10)
= 18.74 N

Determining the Acceleration Force
Acceleration force (FA) is the force necessary to accelerate from a stop to maximum speed in a desired time. Equation 4 shows the formula for the acceleration force.

$$\text{FA(N)} = \frac{\text{GVW} \times \text{Vmax}}{9.81 \times t_a} \qquad (4)$$

Where:
FA = acceleration force
GVW = Gross Vehicle Weight
Vmax = maximum speed

Ta = time required to achieve maximum speed

$$\mathrm{FA(N)} = \frac{107.91 \times 0.5}{9.81 \times 1}$$

FA = 5.5 N

2.4. Determining Total Tractive Effort

The Total Tractive Effort (TTE) is the sum of forces calculated in equation 2, 3 and 4.

TTE (N) = RR (N) + GR (N) + FA (N)

$$\mathrm{TTE} = [5.94 + 18.74 + 5.5]\ \mathrm{N}$$
$$= 30.18\ \mathrm{N}$$

2.5. Determining drive wheel motor torque

In other to ensure good vehicle performance through the selection of a proper electric motor, the drive wheel torque is calculated based on the total tractive effort to obtain the minimum torque required for the mechanical structure to start moving.

Tω (Nm) = TTE (N) × Rω(m)RF (5)

Where:
Tω = Wheel torque (Nm)

TTE = Total tractive effort
Rω(m) = Radius of drive wheel
RF = Resistance factor

Tω = 30.18N × 0.14m × 0.5 = 2.113 Nm

From the drive wheel motor torque calculation performed in the steps above the obtained minimum torque is 2.113Nm.

2.6. CAD modeling mechanical components

The mechanical system for the prototype is designed using Solidworks software and are presented in figures 2 to 6.

3. RESULT AND DISCUSSION

Various experiments were performed with the prototype to check on its capability. The experiment include

- Maximum ground gap crossing
- Maximum angle of staircase it can climb
- Obstacle crossing
- Maximum speed

The prototype robot was able to cross ground gap of about 26cm as shown in figure 7. Table 3 shows measured ground gap it crossed.
The prototype was also tested with an obstacle of 13cm which it successfully climbed as shown in figure 8. Staircase climbing was another testing done with the prototype but it failed because the angle of inclination of 50^0 between the robot and the staircase was too high. This is shown in figure 9. However, a smaller staircase will not be a challenge.

The maximum speed testing was carried out on a horizontal grassy surface. Six repeated speed experiments were carried out to ascertain the time within which a distance of 3.048m will be covered by the prototype. Table 2 shows the time taken in the six different times the speed test was done.

$$\text{Average time} = \frac{43.69}{6} = 7.28\text{s}$$

$$\therefore\ Maximum\ speed = \frac{3.048}{7.28} = \frac{0.418m}{s}$$

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Table 1: Rolling Resistances of different surfaces

Contact Surface	C_{rr}
Concrete (good/fair/poor)	.010/.015/.020
Asphalt (good/fair/poor)	.012/.017/.022
Macadam (good/fair/poor)	.015/.022/.037
Snow (2 inch/4 inch)	.025/.037
Dirt (smooth/sandy)	.025/.037
Mud (firm/medium/soft)	.037/.090/.150
Grass (firm/soft)	.055/.075
Sand (firm/soft/dune)	.060/.150/.300

Table 2: Maximum Speed Experiments

Experiment	Time (sec)	Distance (m)
1	6.59	3.048
2	7.35	3.048
3	7.20	3.048
4	7.40	3.048
5	7.80	3.048
6	7.35	3.048
	Total time = 43.69s	Constant

Table 3: Measured Ground Gap Lengths

Experiment No.	Ground Gap Length (cm)	Result
1	10	Pass
2	22	Pass
3	26	Pass
4	30	Fail

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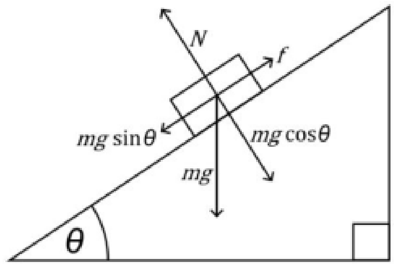

Fig. 1. Free body diagram for grade resistance

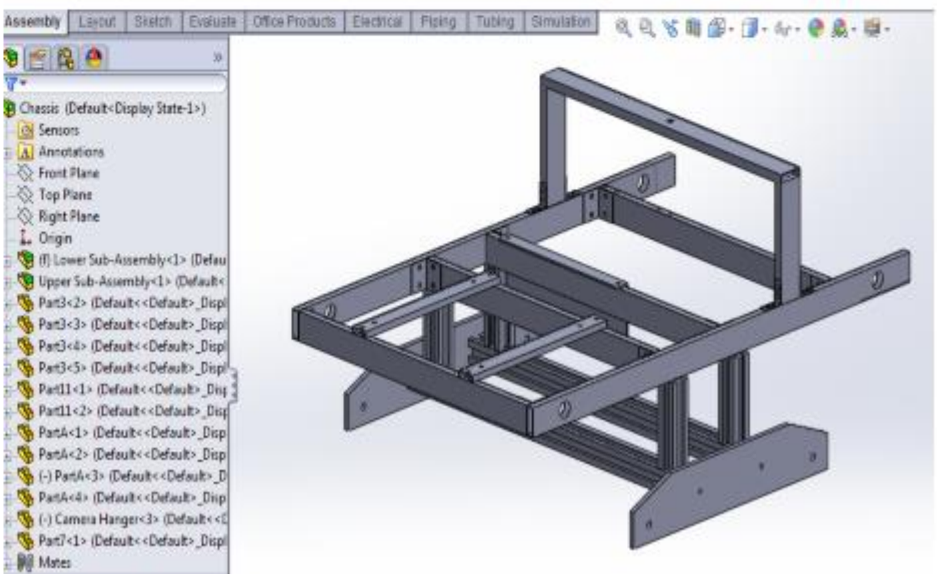

Fig. 2. Chassis design for the prototype

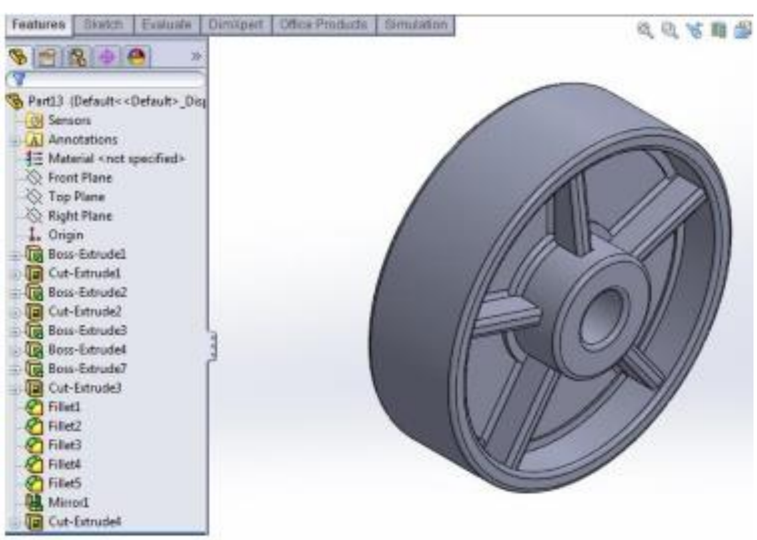

Fig. 3. Upper chassis wheel design

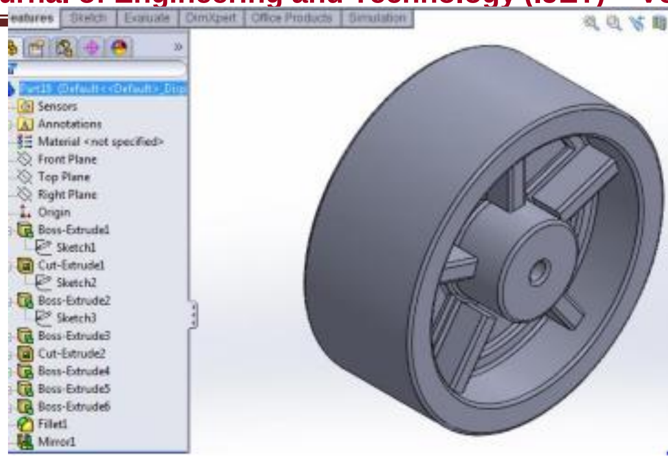

Fig. 4. Lower chassis wheel design

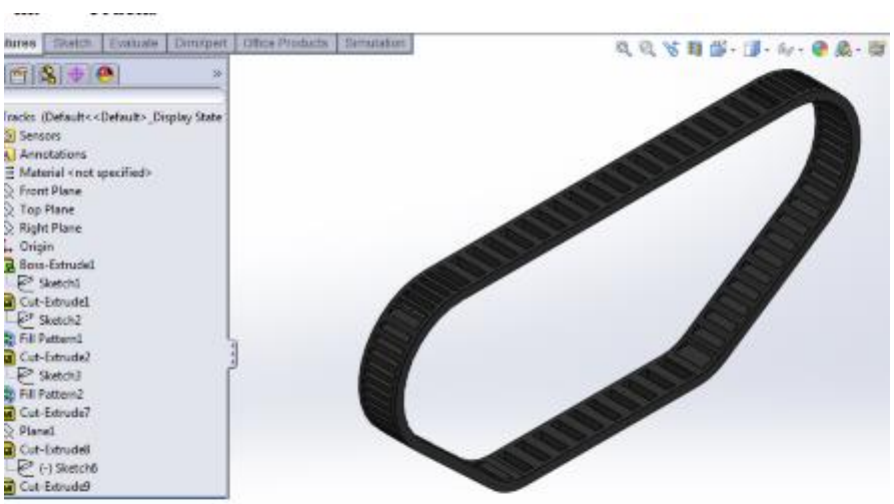

Fig. 5. Track design

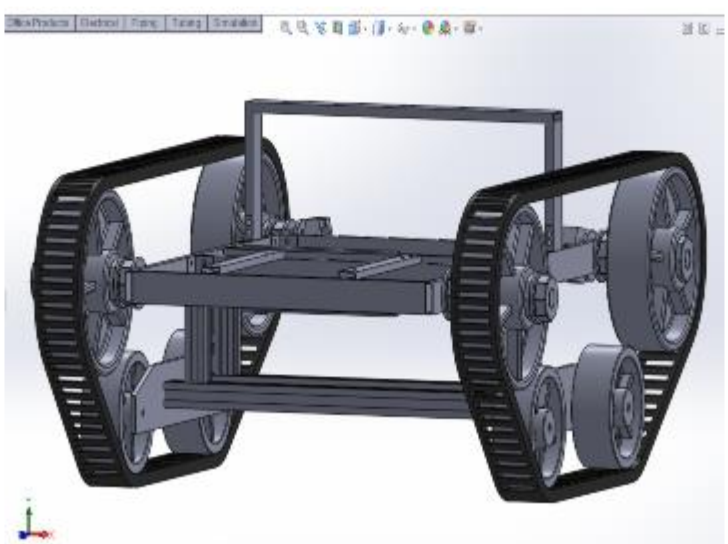

Fig. 6. Assembly of components

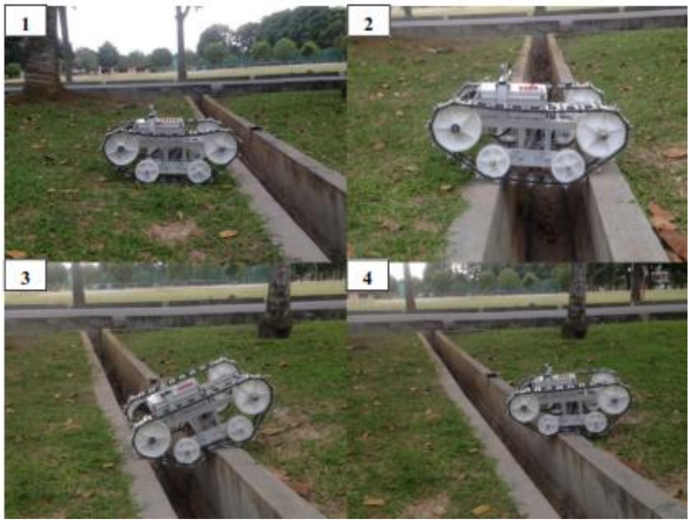

Fig. 7. Prototype robot ground gap crossing

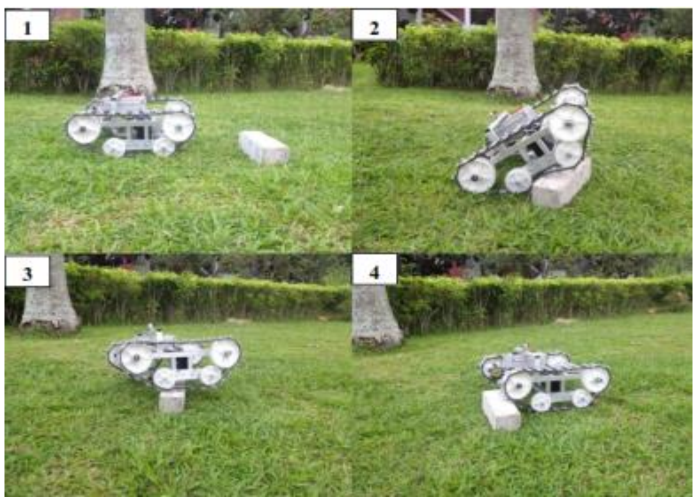

Fig 8. Prototype crossing of 13cm high obstacle.

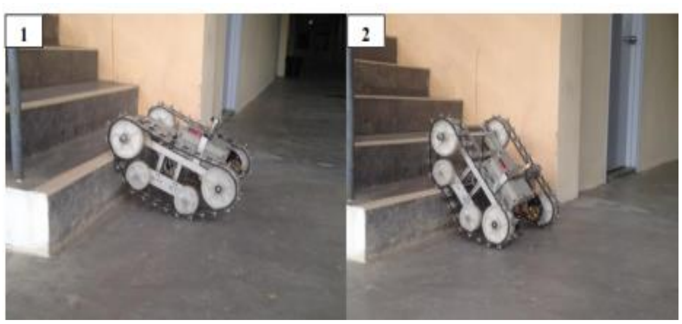

Fig.9. Staircase climbing by the prototype robot