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Design and Analysis of Multi- Terrain Rover

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Abstract— One of the less explored fields of engineering would be rovers for off-roading terrains for military, mining and various other applications. And when a rover is built keeping such a terrain into consideration the stability and the maneuverability of the rover and the material subjected to various physical and technical paraments are the key results to look up to. The shift of center of gravity is an evolution of newtons second law of motion. Designing a rover with power and torque standards pre-defined and incorporating the core mechanism into it plays hierarchal roles. Hence the project involves developing a mechanism around the same and helping them with maneuverability opening various realms of possibilities and applications.

Index Terms— Al6092/SiC material, Shift of center of gravity, Stress analysis

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I. INTRODUCTION

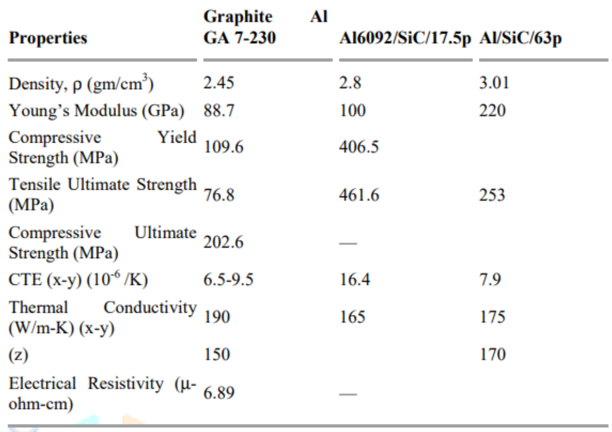
Multi-terrain rover is one kind of multi-functional special mobile rover, because the work space of this kind of rover is often on the terrain, no rover needs to have the same loco motion mechanism as mobile robots. Therefore, it is more challenging to develop a rover than a mobile rover. Its design helps it to go through irregular surface with ease, it can be equipped with thermal cameras, IR sensors and used during emergencies like search and rescue to reach out to places where it is impossible or time consuming to reach for a human being. It can be even used for research purposes and spy operations due to its small size, strong body and capabilities of going through any surface.

II. DESIGN SPECIFICATIONS

A. Choice of material and its perks

Al6092/SiC is been used for the fabrication of the above said rover as this particular metal matrix composite has been proven to be one of the leading choices for space explorations [1] as it has high temperature and fire resistance, Higher transverse stiffness and strength, no moisture absorption, higher thermal and electrical resistance etc as shown in table I.

Table I: Properties of Al6092/SiC compared to graphite and AlSiC



Properties	Graphite Al GA 7-230	Al6092/SiC/17.5p	Al/SiC/63p
Density, ρ (gm/cm³)	2.45	2.8	3.01
Young's Modulus (GPa)	88.7	100	220
Compressive Yield Strength (MPa)	109.6	406.5	
Tensile Ultimate Strength (MPa)	76.8	461.6	253
Compressive Ultimate Strength (MPa)	202.6	—	
CTE (x-y) (10^{-6} /K)	6.5-9.5	16.4	7.9
Thermal Conductivity (W/m-K) (x-y)	190	165	175
(z)	150		170
Electrical Resistivity (μ-ohm-cm)	6.89	—	

B. Necessity of Sensors

In "Redirection Concept of Autonomous Mobile Robot HY-SRF05 Sensor to Reduce the Number of Sensors" Nuryanto et al as specified that the ultrasonic sensor used on the robot has a straight forward position so it can detect the obstacles within a 30-degree angle in front of the robot[2],[3], which results in a blank area of the sensor between the two ultrasonic sensors. When the sensors were tilted the two sensors from a right angle so that the concept of trigonometry can be applied. This results in the distance from the object to be the hypotenuse of the right angle formed. The test results showed the optimum angle of the sensor's range from 35 to 55 degree and the redirection of the sensors will be reduced by approximately 42% to the number when the sensors are placed straight. For the different functionality of the multi-terrain rover, it must be incorporated with different sensors which are as follows:

1. Humidity and Temperature sensors
2. Pressure and altitude Sensors
3. Obstacle and Distance sensors
4. Angle or tilt sensor

C. Rover model and Dimensions

The 3D and 2D sketch of the rover was designed using AutoCAD and after testing the structures on Ansys the finalized structure is as follows:

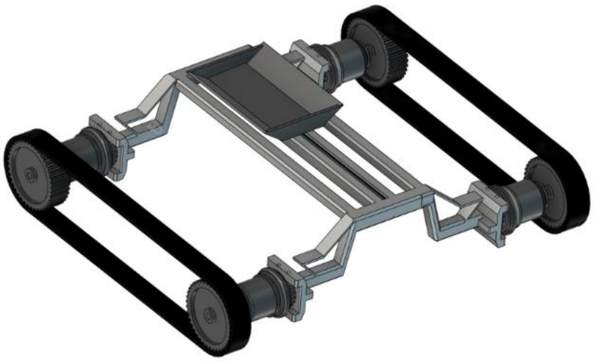


Figure 1: 3D model of rover structure with carriage and tracks for wheels.

The carriage installed on the rover and its need will be mentioned in section II.D.

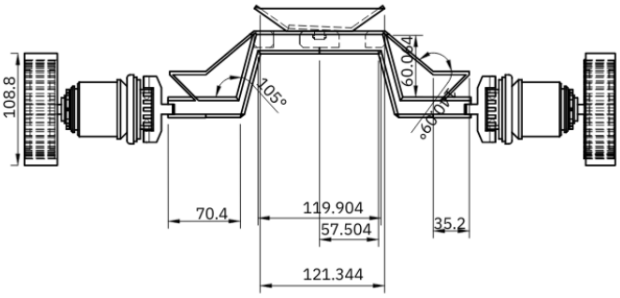


Figure 2 : front view of the rover along with its dimensions in millimeters.

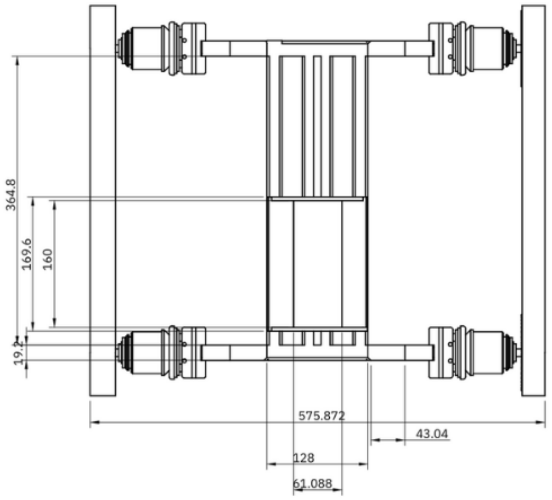


Figure 3: Top view of the rover along with its dimensions in millimeters.

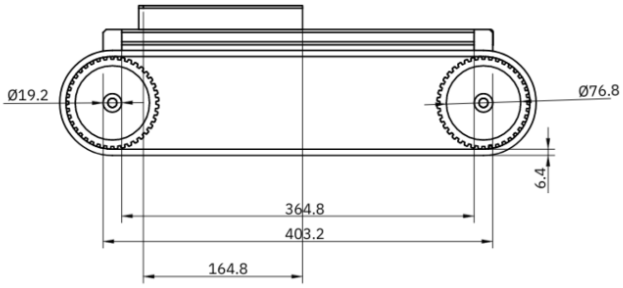
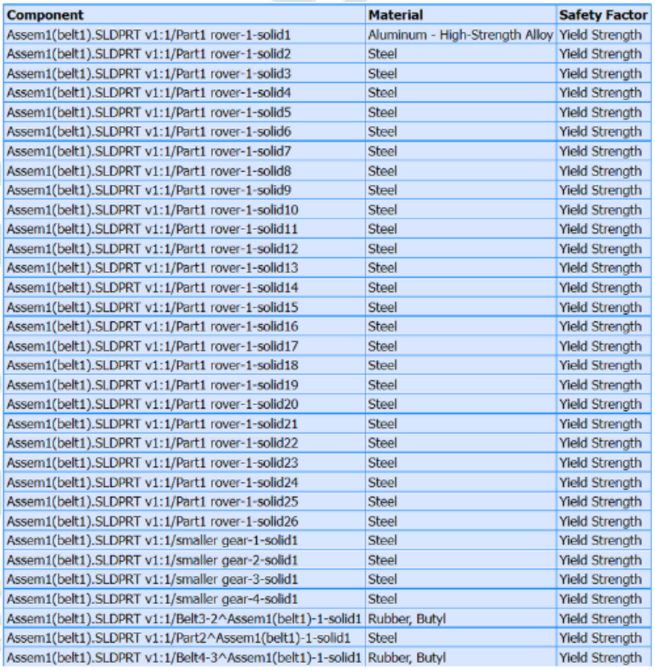


Figure 4: side view of the rover along with its dimensions in millimeters.

And materials used for each part are mentioned in table II.

Table II: Material specification of each part in the rover.



Component	Material	Safety Factor
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid1	Aluminum - High-Strength Alloy	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid2	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid3	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid4	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid5	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid6	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid7	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid8	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid9	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid10	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid11	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid12	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid13	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid14	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid15	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid16	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid17	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid18	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid19	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid20	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid21	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid22	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid23	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid24	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid25	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part1 rover-1-solid26	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/smaller gear-1-solid1	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/smaller gear-2-solid1	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/smaller gear-3-solid1	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/smaller gear-4-solid1	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Belt3-2^Assem1(belt1)-1-solid1	Rubber, Butyl	Yield Strength
Assem1(belt1).SLDPRT v1:1/Part2^Assem1(belt1)-1-solid1	Steel	Yield Strength
Assem1(belt1).SLDPRT v1:1/Belt4-3^Assem1(belt1)-1-solid1	Rubber, Butyl	Yield Strength

D. Center of gravity

Shreyas M et al in his paper on “Study on effect of center of gravity on vehicular acceleration” has mentioned that one of the most important and dynamic characteristics of a vehicle is to be stable at high speeds and have high maneuverability at different conditions. The dynamic characteristics [4].

Any force acting through the center of gravity does not hold the tendency to make the vehicle rotate. The parameters like center of mass height, relative to the track, determines the transfer of load, from side to side and causes body to lean.

The carriage carrying the payload will be placed on the top portion of the rover and this rover will be moving from and back along the median of the rover covering a total distance of 30cms. During at rest or on level plain the carriage will be at its mean position, i.e. at the geometrical center of the rover which is to be assumed as co-ordinates (0,0).

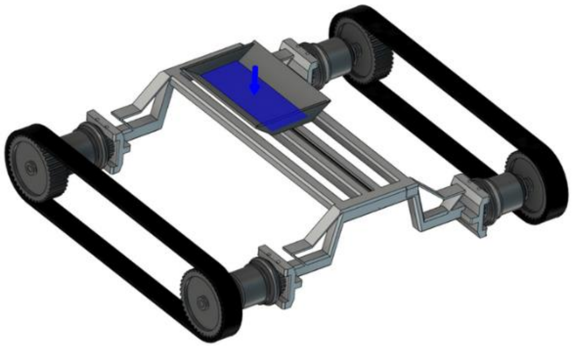


Figure 5: 3D model of the rover where an arrow is pointing towards the payload carriage.

E. Derivation and working of shift of center of gravity

The total length of the slot for payload moment is 0.3m, so the distance of extremes from its mean position is r=0.15m.

Let shift of center of gravity be S

1. For a inclination θ**:**

Let projection of the r on the inclination by r on the horizon be y.

We get $y*\cos\theta=r$

$Y=r*\sec\theta$

Since $S=y-r=r*((\sec\theta)-1)$ ……equation(1)

2. Similarly for a declination θ:

Following similar procedure, we get

$S= -r*((\sec\theta)-1)$ ……………equation(2)

Solving auxiliary formula for S from equation(1) & equation(2) we get

$S = (\theta /|"\theta"|)*(\sec \theta -1)*0.15$ ………equation(3)

By following basic trigonometric principles, we get the limits of the angle should be in $\theta \in [-\pi/3, \pi/3]$

Hence the maximum inclination or declination the rover can move in is + or – 60 degrees from horizon.

Working:

The angle or tilt sensor is fixed next to the camera infront the rover and is calibrated to standard horizon as 0 degrees, the angle calculated by the said sensor will be reported to Arduino set connected to it and that Arduino will use formula in equation(3) to get the distance to where the payload must be shifted as shown in Table III.

Table III: Distance moved by the payload from mean position for different angle of inclination.

ASCEND / DESCEND ANGLE	CENTRE OF GRAVITY SHIFT (cm)
0	0
10	0.231
15	0.529
20	0.962
25	1.550
30	2.320
35	3.311
40	4.581
45	6.213
50	8.335
55	11.151
60	15
-10	-0.231
-15	-0.529
-20	-0.962
-25	-1.550
-30	-2.320
-35	-3.311
-40	-4.581
-45	-6.213
-50	-8.335
-55	-11.151
-60	-15

A servo motor is mounted on both sides of the slot with pulley system which spin to certain angle to pull the payload based on the signal received by the servo motor from the connected Arduino set.

F. Rover Motor controls

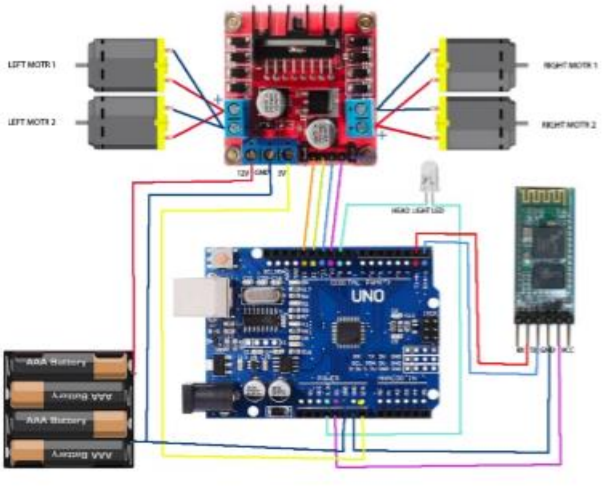


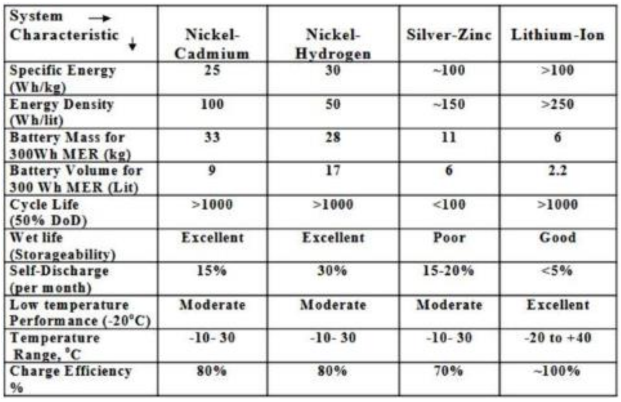
Figure 6: TinkerCAD design showing motor control connections.

As shown in Fig 6 the DC motors are connected to stepper motor driver board which receives signals from the Arduino set regarding which motor should move and in which directions. This Arduino board is connected to a wireless Bluetooth module which receives signals from a remote regarding how the rover should move.

III. ANALYSIS

Currently 4 types of batteries are used majorly out of which only Lithium ion batteries has the highest battery efficiency while having good cycle life and low discharge rate, even at high temperature[5] as shown in Table IV.

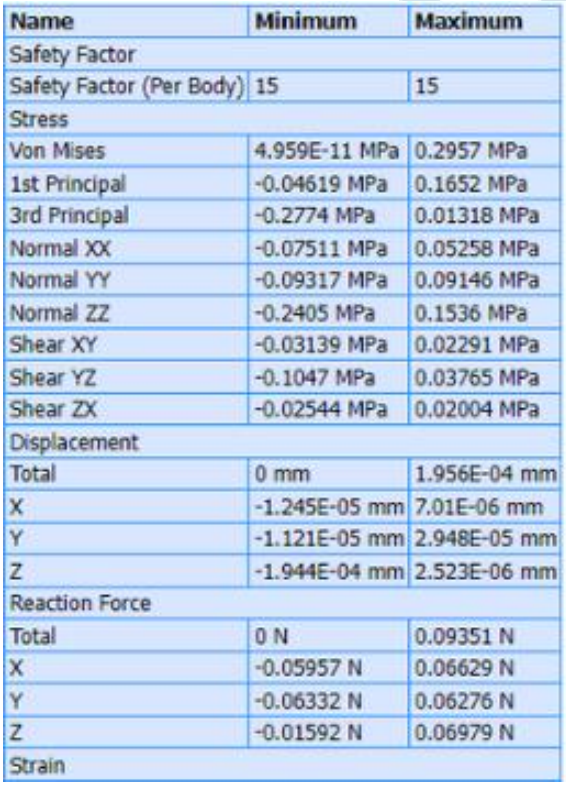
Table IV: Comparison between leading battery types[5].



System → Characteristic ↓	Nickel-Cadmium	Nickel-Hydrogen	Silver-Zinc	Lithium-Ion
Specific Energy (Wh/kg)	25	30	~100	>100
Energy Density (Wh/lit)	100	50	~150	>250
Battery Mass for 300Wh MER (kg)	33	28	11	6
Battery Volume for 300 Wh MER (Lit)	9	17	6	2.2
Cycle Life (50% DoD)	>1000	>1000	<100	>1000
Wet life (Storageability)	Excellent	Excellent	Poor	Good
Self-Discharge (per month)	15%	30%	15-20%	<5%
Low temperature Performance (-20°C)	Moderate	Moderate	Moderate	Excellent
Temperature Range, °C	-10- 30	-10- 30	-10- 30	-20 to +40
Charge Efficiency %	80%	80%	70%	~100%

The rover model was tested using ANSYS software with various quantity of load applied on the carriage and other regions, the rover was tested to obtain its safety factor, von mises stress as well as 1st and 3rd principal stress.

Table IV: Results obtained for various tests performed on the rover model.



Name	Minimum	Maximum
Safety Factor		
Safety Factor (Per Body)	15	15
Stress		
Von Mises	4.959E-11 MPa	0.2957 MPa
1st Principal	-0.04619 MPa	0.1652 MPa
3rd Principal	-0.2774 MPa	0.01318 MPa
Normal XX	-0.07511 MPa	0.05258 MPa
Normal YY	-0.09317 MPa	0.09146 MPa
Normal ZZ	-0.2405 MPa	0.1536 MPa
Shear XY	-0.03139 MPa	0.02291 MPa
Shear YZ	-0.1047 MPa	0.03765 MPa
Shear ZX	-0.02544 MPa	0.02004 MPa
Displacement		
Total	0 mm	1.956E-04 mm
X	-1.245E-05 mm	7.01E-06 mm
Y	-1.121E-05 mm	2.948E-05 mm
Z	-1.944E-04 mm	2.523E-06 mm
Reaction Force		
Total	0 N	0.09351 N
X	-0.05957 N	0.06629 N
Y	-0.06332 N	0.06276 N
Z	-0.01592 N	0.06979 N
Strain		
Equivalent	6.022E-14	1.825E-06
1st Principal	-2.537E-10	1.586E-06
3rd Principal	-1.792E-06	-2.79E-15
Normal XX	-3.458E-07	7.103E-07
Normal YY	-1.168E-06	7.293E-07
Normal ZZ	-1.072E-06	6.894E-07
Shear XY	-8.617E-07	6.359E-07
Shear YZ	-1.297E-06	1.371E-06
Shear ZX	-6.688E-07	7.295E-07
Contact Pressure		
Total	0 MPa	0.1815 MPa
X	-0.01596 MPa	0.02375 MPa
Y	-0.02923 MPa	0.08686 MPa
Z	-0.1275 MPa	0.1589 MPa
Contact Force		
Total	0 N	0.1379 N
X	-0.04287 N	0.04351 N
Y	-0.04724 N	0.1044 N
Z	-0.08948 N	0.04381 N

IV. CONCLUSION

The Multi-Terrain Rover is designed based on dynamics and kinematics of motion which enables it to tackle different kinds of surfaces with ease. Its unique mechanism enables it to balance its inertial forces which tends to pass through the point of center of gravity which improves its maneuverability and imporves reachability and hence imporves its applications. It can be used in various fields for a wide variety of applications. The materials used for the fabrication of the rover, Al6092/SiC, being ideal in nature for the rover's application. The analysis and simulation reports depict the extremities of various paramenters which shows a brief idea of the load capacity and limitations of the rover.

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