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DESIGN OF ROBOTIC FRAME AND LOCOMOTION SYSTEM

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Abstract - *This project deals with the design of robotic structure and locomotion. This project is a part of a project that makes an interactive robot. There are a total of three teams other two are dealing with animatronic hand and robotic control. Our aim Is to design the locomotion and structural system. Our part include detailed CDA model, detailed development of parts, selection of material, estimation of total weight, design of gear system, selection of suitable motor and battery and design of a steering using servo motor. We design the system to climb an inclination of 30 degrees with an acceleration of 0.5 m/s. We completed the project by calculating the required parameters and designing the suitable system. After the completion of work of all the other groups the three systems are combined to form an interactive robot.*

Key Words: **Wheel base, Total Weight, Steering, Gear system, Analysis**

1. INTRODUCTION

Wheeled robots is one of the easiest ways to design a robot locomotion. We humans cannot travel in a non-habitable/hazardous environment? In this new world of advanced technological revolutions, the fast forward answer which creeps in the mind, is remote actuation.

Remote actuation is an actuation signal send by us in a safe area of habitation controlling the robot locomotion.

One of its biggest advantage, is replacing any humans working in hazard environments. The hand, fixed to a rolling base makes transportation easier while adding additional DOF.

Ever since the start of clock works in 1st century BC (relating to astronomical science), people started to think differently. Following centuries lead to mechanically programed Clocks- Automaton made of mechanical clocks. If we take a closer look these time profiles created on the Automaton is still used in cam shaft (as well as timing gears) of internal combustion engines. And after a while the first mechanical computer "Bombe" is born.

Years later, the first electronic computer ENIAC is built and this in decades, transforms to the programmable chips that we know today. The integration of these programmable chips, to mechanical parts came to be known as mechatronics. Following, mechatronics used in animal like robots is called Animatronics.

What we attempt, has been attempted, many a times before but what makes this different, is that we learn from the mistakes, to build something better. As in the words of Stephen William Hawking, "We stand on the shoulders of Giants."

2. ESTIMATION OF WHEELBASE

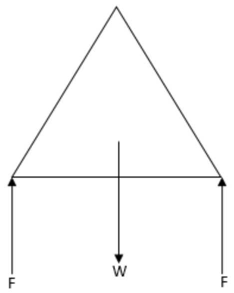
The proper wheelbase is needed for a vehicle to avoid the rollover at an inclination.

Vehicle rollovers are divided into two categories: **Tripped** and **Untripped**.

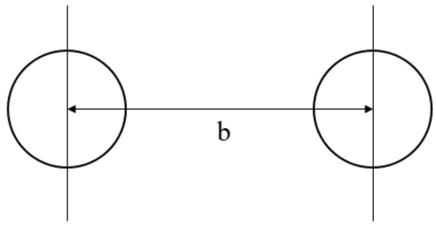
Tripped rollovers are caused by forces from an external object, such as a curb or a collision with another vehicle. The most common type of tripped rollover occurs when a vehicle is sliding sideways, and the tires strike a curb, dig into soft ground, or a similar event occurs that results in a sudden increase in lateral force. The physics are similar to cornering rollovers. In a 2003 report, this was the most common mechanism, accounting for 71% of single-vehicle rollovers. Another type of tripped rollover occurs due to a collision with another vehicle or object. These occur when the collision causes the vehicle to become unstable, such as when a narrow object causes one side of the vehicle to accelerate upwards, but not the other. Turned down guard rail end sections have been shown to do this. A side impact can accelerate a vehicle sideways. The tires resist the change, and the coupled forces rotate the vehicle. In 1983, crash tests showed that light trucks were prone to rolling over after colliding with certain early designs of guide rail.

Untripped crashes are the result of steering input, speed, and friction with the ground. Untripped rollovers occur when cornering forces destabilize the vehicle. As a vehicle rounds a corner, three forces act on it: tire forces (the centripetal force), inertial effects (the centrifugal force), and gravity. The cornering forces from the tire push the vehicle towards the center of the curve. This force acts at ground level, below the center of mass. The force of inertia acts horizontally through the vehicle's center of mass away from the center of the turn. These two forces make the vehicle roll towards the outside of the curve. The force of the vehicle's weight acts downward through the center of mass in the opposite direction. When the tire and inertial forces are enough to overcome the force of gravity, the vehicle starts to turn over.

The Wheelbase is calculated by, assuming the total weight is summarized at the bottom of the vehicle. Thus the mass distribution is taken as a triangular model.



Where,
W = Weight acting downwards
F = Reaction force



F = W/2
(W sinθ × h/3) = (F × b/2)
(W sinθ × h/3) = (W/2 × b/2)
4/3 × h Sinθ = b
b > 255.33 mm
The wheel base should be greater than 255.33mm to avoid the roll over.
For considering further wheel size and clearances the wheel base assumed to be 280mm

3. ESTIMATION OF TOTAL WEIGHT

3.1: Estimation of weight of sheet metal in frame

Outer diameter of AISI4130 pipe = 21.3 mm
Inner diameter of AISI4130 pipe = 16.7 mm
Inner diameter of frame = 222 mm
Outer diameter of frame = 224 mm
Height of frame = 386 mm
Volume of body = $\pi \times (r_1^2 - r_2^2) \times h$
=270422.01 mm^3
=2.704×10^{-4} m^3
Density of AISI4130 sheet metal =7850 kgm^{-3}
Weight of sheet metal in frame = Density × Volume = **2.14 kg**

3.2: Estimation of weight of head

Total length of 4 square tube = 800mm
Total length of square tube excluding shaft diameter = 760 mm
Volume of square tube = 760×20×20-760×18×18 = 57760 mm^3
Total height of shaft = 250 mm
Radius of shaft = 5 mm
Volume of shaft = $\pi r^2 \times h$ = 19634.9 mm^3
Total volume = 77394.9 mm^3
Density of shaft = 7850 kgm^{-3}
Mass of frame = **0.6 kg**
Volume of sheet metal = $\pi(101^2-100^2) \times 200$ = 126292mm^3
Mass of sheet metal = 0.99 ≈ **1 kg**
Total mass = **1.6 kg**

3.3: Estimation weight from CAD model

Total weight of base and skeleton=20kg

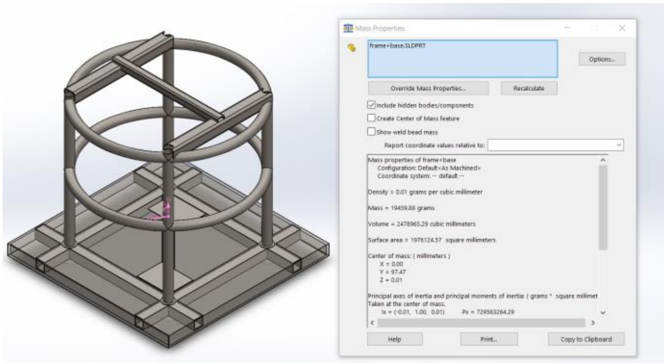


Fig – 1: Main frame and Base weight estimation

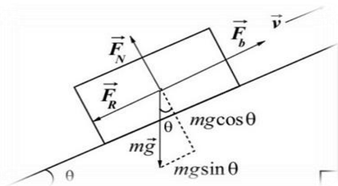
3.4: Estimated weight of arm = 14 kg

Weight of battery and motor is estimated 10 kg
Total weight is calculated as 47.74kg
Total weight is taken as 50kg

4. FORCE ANALYSIS

4.1: Force analysis assuming 1m/s acceleration

For initial calculation we are assuming an acceleration of 1m/s for climbing an inclination of 30 degrees.



For the analysis of carried out by assuming an inclination of 30 degree
Total mass = 50 kg
Coefficient of friction (μ) = 0.4
Total weight = 500N
At equilibrium
$F_b = F_R + \mu F_N$
Fb = 500 sin (30) +0.4 x 500 cos (30)

= 423.20N
Force required to stop the robot in the inclination without rolling back is 423.20 N
Diameter of wheel = 200 mm = 0.2
Perimeter of wheel = 2πr = 2*π x 0.2 = 0.628 mm
Assuming the required seed to be 20 km/hr.
i.e. = 5.56m/s
Revolution per second = 5.56 / 0.628
8.85rps
Revolution per minute = 8.85 x 60
= 532 rpm
Torque required = 423.2 x 0.1 = 42.32 Nm
Let the robot move with 1m/s^2 acceleration
Force = 50 x 1 = 50 N
Torque (T) = 50 x 0.1 = 5 N
Total torque required = 42.32 + 5 = 47.32 Nm

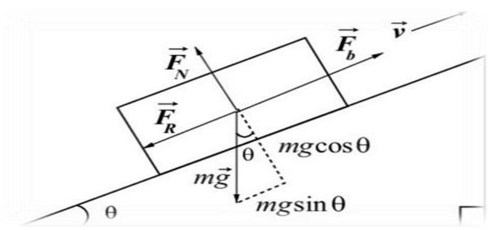
4.1.1: Calculation of gear system

We are using a compound gear system with 4 gears with has a coaxial gear system at the middle two. Gear 1 is connected to the motor while gear 4 is connected to the rear axil.
Torque required in the rear axle = 47.3N
Let the diameter of the gear is fixed as 90 mm and considering a gear reduction of 3 between gear 3 and gear 4

T4 = 47.3N T3 = 15.7
D4 = 90 mm D3 = 30mm
N4 = 532rpm N3 = 1596rpm

For coaxial gear system 2 and 3 torque and rpm are equal. And from marker analysis it is known that torque value is some were around 10 to 14 nm for DC motors.
T2 = 15.7 Nm T1 = 12 Nm
From that gear ratio is obtained as 1.3 by trial and error method and minimum gear size is taken as 25 mm
N2 = 1596rpm N1 = 2074.8 rpm
D2 = 32.5mm D2 = 25mm
By using T1 and N1 motor of 12Nm torque and suitable rpm greater than 2074.8 rpm is selected
After selecting the motor and battery weight is recalculated as 75 kg

4.2: Force analysis after the determination of total weight



Coefficient of friction, μ = 0.4
Weight W = 750 N
Gradient θ = 30°
F_R = 750Sinθ
= 375 N
F_N = 750Cosθ
= 649.51 N
At equilibrium,
F = F_R + μF_N
F = 375 + 0.4×649.15
F = 634.8 N
Thus, for equilibrium the force required = 634.8 N
Toque obtained = F × radius of the tire
Radius of tire = 0.1m
⇒ Torque = 634.8 × 0.1
= 63.48 Nm
Force due to acceleration is, F = ma
Taking acceleration 'a' = 0.5 m / s^2
We get, F = 75 × 0.5
= 37.5 Nm

Toque obtained ΔT = F × radius of tire
= 37.5 × 0.1
= 3.75 Nm
Thus total toque obtained = 63.48 + 3.75
= 67.23
= 68 Nm

4.2.1: Calculation of gear system

Let the diameter of the gear is fixed as 90 mm and considering a gear reduction of 3 between gear 3 and 4
T4 = 68 Nm T3 = 22.6 Nm
D4 = 90 mm D3 = 30 mm
N4 = 532rpm N3 = 1596rpm
From that gear ratio is obtained as 1.89 by trial and error method and minimum gear size is taken as 25 mm and motor torque is taken as 12 from motor selection
T1 = 12 Nm T2 = 22.68
D1 = 25 mm D2 = 47.25
N1 = 3016.4 rpm N2 = 1596 rpm

5. STEERING

We are applying Ackerman steering mechanism.
The Ackermann steering mechanism is a geometric arrangement of linkages in the steering of a vehicle designed to turn the inner and outer wheels at the appropriate angles. We used Ackerman steering mechanism to determine the optimum lock angles for the wheels
For turning purpose, we are using servo motors instead of rack and pinion mechanism. The servo motor is connected to the wheels by means of gears and the determined lock angles for the wheels is applied.
Calculation of determining lock angles
R = b/ Sin Φ + (a-c)/ 2
Where R = turning radius
b = wheel base
a = track width
c = rack + tie rods
Here we have a turning radius of R = 510mm

Wheel base b = 280mm
Track width a = 400mm
c = 300mm

$\Rightarrow$ 510 = 280/ sin Φ + 50/2

Φ = 35.26°

Cot Φ – Cot θ = c/b

$\Rightarrow$ θ = 71.06°

Servo motor calculation is determined by imagining a rack and pinion mechanism and finding the torque that is being generated on pinion to turn the wheels.

This torque is then considered for the servo motor to be used and thus specifications are obtained

Torque on pinion = Frack × R (radius of pinion)

Frack = 60.20 N

Radius of pinion taken = 7.5 mm

$\Rightarrow$Torque on pinion = 60.2 × 7.5
= 450 Nmm
= 4.5 kgf-cm

This torque is considered as the torque of the required motor

Table -1: Specification of the motor available on the market for the required torque is as follows

Torque	4.2 kgf-cm
Operating Voltage	4.8 - 7.2 V
Total degree of rotation	180°
Weight	55 g
Dimension	40.7 x 19.7 x 42.9

6. COMPONENTS

- AISI4130
- BLDC MOTOR
- LITHIUM-ION BATTERY
- WHEEL
- SERVO MOTOR
- BEARINGS
- GEAR SYSTEM
- AXLE

7. ANALYSIS

7.1: FORCE APPLIED ON BASE

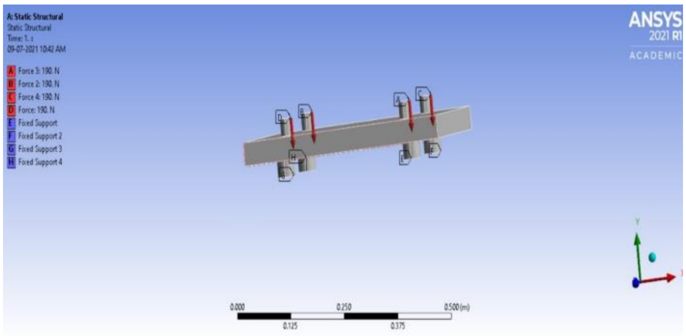


Fig-2: Forces applied

Force 190N is applied on points A, B, C, and D.
Fixed support at point E, F, G and H.

7.2: TOTAL DEFORMATION ON BASE

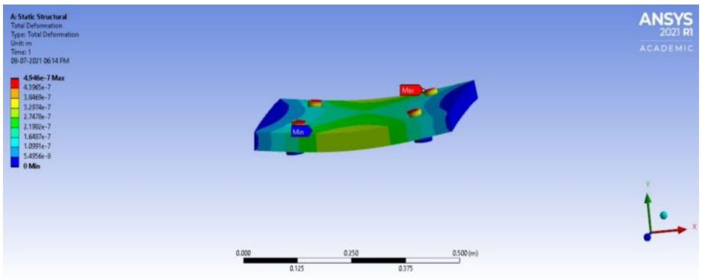


Fig-3: Total Deformation

Type: Total Deformation
Unit: m
4.946e-7 Max

7.3: FORCE APPLIED ON AXLE

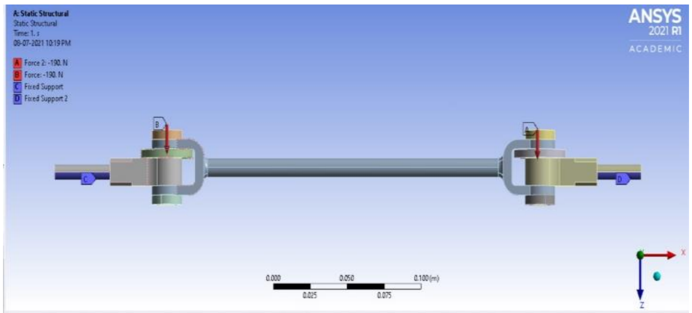


Fig-4: Force applied

Force 190N is applied on A and B
Fixed support at point C and D

7.4: TOTAL DEFORMATION

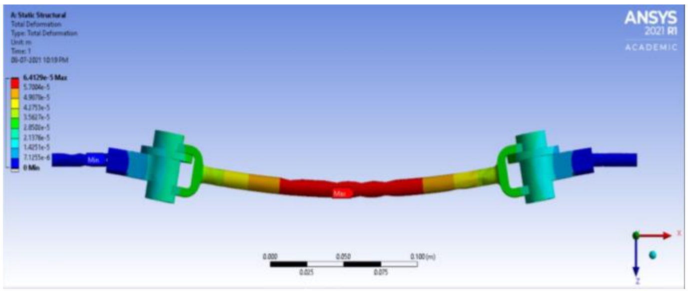


Fig-5: Total Deformation

Type: Total Deformation
Unit: m
6.4129e-5 Max

8. CONCLUSIONS

By working on this project, the frame and base of the robot is deigned. Total weight of the body is calculated. By conducting force analysis, maximum speed, maximum acceleration, required motor, battery, gear system and bearings are found out.
The head shape is designed considering constrains like drag force. Then its structure is designed using standard tubes made of AISI 4130. The weight is determined and is used for other calculation purposes.
For steering purpose, Ackerman steering mechanism is selected and hence the lock angles and turning radius is determined. By considering these, front axle is designed and proper servo motor is estimated.

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