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Design & Development of Stair Climbing Robot Prototype

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Abstract - The purpose of this report is to develop a prototype stair climbing robot for climbing and descending stairs, in addition to traveling on flat surfaces.The basic robot parameters (minimum track size, track angle of attack) were determined using North American standards for the stair geometry. And for mathematical design of the robot we have calculated different aspects of the robot such as for stair geometry of rise 9.5 inches and tread of 8 inches we have track length of 39.64 inches, and will require 4 DC motor for the robot to climb the stairs with torque of 0.6936 Nm and rpm of 31.83 for the required speed of 1000 mm/sec to carry the load of 8 kg including its own at 45 degree angle of inclination. The material selected for the chassis of the robot is mild steel as it has high strength and can withstand high loads without breaking and can be welded and is cheaper than aluminum. Staircase climbing robots are a rapidly developing technology with a wide range of potential applications. Our robot can be used in future for various applications like old buildings, hospitals and rough terrains to carry load or explore ground where humans cannot reach.

Keywords— Stair climbing, Robot, Quadrobot, Belt Drive, DC motor

I. INTRODUCTION

Robots have widely been used for a wide number of tasks. But a very promising use of robotics lies in goods transport. The problem in using robot transport is that they cannot climb stairs and cannot go through rough terrains. Most robots use either a wheeled or a tracked mechanism for mobility. While wheeled mechanisms offer impressive speed and a significant advantage in steering, this often proves to be difficult to use in off road conditions and for climbing over obstacles. Stair climbing robots stand at the nexus of technology and mobility, exemplifying the intricate fusion of mechanical engineering, robotics, and artificial intelligence. These remarkable machines are designed to navigate the vertical world, surmounting one of the most ancient and challenging obstacles faced by both humans and robots alike – stairs. For decades, there have been other efforts to develop fast, reliable, and simple robotic mechanisms to overcome stairs. Commonly, modified tracked and wheeled mechanisms have been chosen for indoor service robots. There is a huge potential market for indoor service robots in various fields. However, a market-dominant solution with a high stair-climbing ability has not appeared yet. To the best of our knowledge, there has been no report to summarize fundamental studies related with stair-climbing robots.

II. PROBLEM STATEMENT

To develop a staircase climbing robot that efficiently navigates various step heights and surfaces. The design should prioritize stability, adaptability to different stair configurations, and energy efficiency. The robot must ensure user-friendly remote control and possess safety features to prevent accidents. This project aims to address the need for a versatile and reliable robot capable of ascending and descending stairs in diverse environments, making it applicable for tasks like surveillance, rescue operations, and accessibility in both indoor and outdoor settings. Load Capacity: Specify the maximum payload the robot should be able to carry while climbing stairs, as this can impact the robot's design and power requirements. Battery Life: Define the desired or minimum operating time on a single charge, as battery life is crucial for the robot's usability and efficiency. Size and Form Factor: Determine size constraints and form factor requirements, considering whether the robot needs to fit through doorways or into tight spaces. Maintenance and Repairs: Consider ease of maintenance and repairability, as these factors can affect the robot's long-term usability. Load capacity: the stair climbing robot is to be designed to carry weight upto 5kg, as it is prototype.

Power source: the robot consists a battery of 12v, 59 Watt hour lithium battery which can give upto 3 hrs backup with more than 2000 life cycles Motors: The robot will require a motor with 12 DC voltage with 40 rpm; its torque can be increased by adding gears. The 12 DC motor is selected because it is suitable for the power supply Torque: The 12 DC motor will give a torque of 1.8 N.m it is required to give maximum output as the speed is not our concern with dial to control the speed Mobility mechanism: We will use a belt drive mechanism on the robot to climb the stairs, as tracked wheels will provide good grip on every surface with less to zero slipping chances on stairs, the robot will have two tracked wheels on both sides.

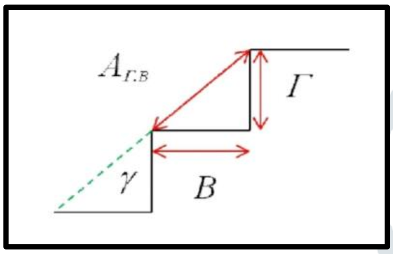
III. MATHEMATICAL DESIGN

A. BELT DESIGN

North American standards of stairs and steps			
Degree(γ)	Γ; (In)	B ; (In)	$A_{\Gamma,B} = \sqrt{\Gamma^2 + B^2}$
30 (Minimum)	6.5	11	12.78
50(Maximum)	9.5	8	12.419

Table 1: Staircase specifications table as per the building code [25]

Table also shows that the maximum difference between the noses of two steps is about 4 millimeters The stairs rise, r, , the tread, B, slope of stairs, y,, and distance between two noses, Ar,B



By pythagoras theorem
AB^2 + BC^2 = AC^2
(9.5^2) + (8^2) = 154.2
AC =12.41 inches

Fig 1: stair tread, slope and rise

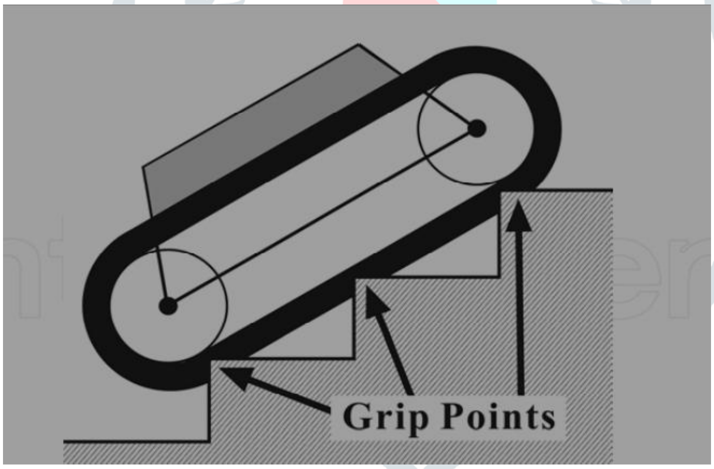


Fig2: Belt drive contact points

Therefore grouser belt should be 12.41×2 = 24.82 inches long
Circumference of wheel = π×d = 3.14× 4.72= 14.82 inches
R
Total length of belt drive = 14.82+24.82 = 39.64 inches
We will require two belt drives of 39.64 inches.

RPM required for motor

RPM = Desired Speed / (Wheel Circumference)
RPM = 1000 mm/s / (π × 100 mm) =31.83 RPM

B. ***DC Motor-Torque Calculation***

For weight 5 kg and inclination 30 degrees
F2=G×sin (α)
= (5)kg × 9.81m/s^2 × sin (30°)
=24.525 N
T=1/4×F2×r=(¼)×24.525×0.05m= 0.3065625 N*m

For weight 8 kg and inclination 45 degrees
F2=G×sin (α)
= (8)kg × 9.81m/s^2 × sin (45°)
=55.49 N
T=1/4×F2×r=(¼) × 55.49 × 0.05m= 0.6936 N*m

For weight 5 kg and inclination of 45 degrees
F2=G×sin (α)
= (5)kg × 9.81m/s^2 × sin (45°)
=34.68 N
T=1/4×F2×r=(¼) × 34.68 × 0.05m= 0.433 N*m

For weight 8 kg and inclination of 30 degrees
F2=G×sin (α)
= (8)kg × 9.81m/s^2 × sin (30°)
=39.24.N
T=1/4×F2×r=(¼) × 39.24 × 0.05m= 0.4905 N*m

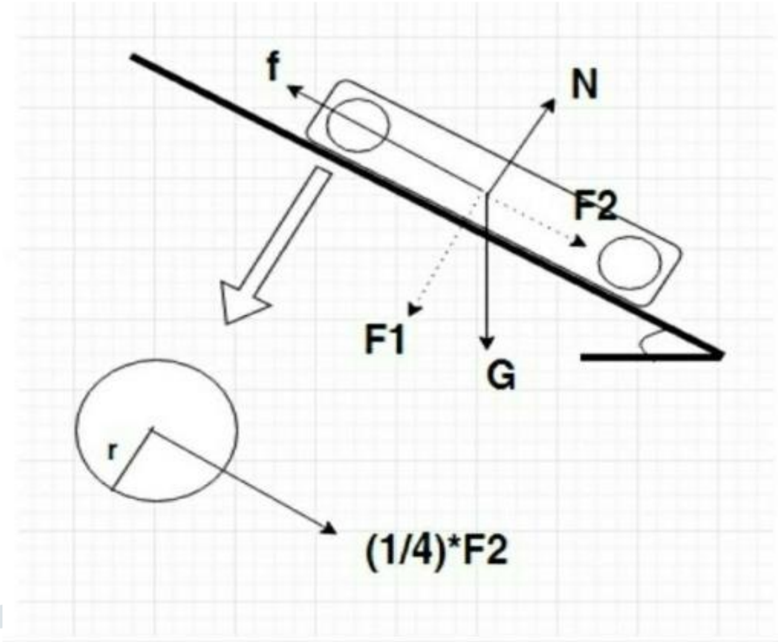


fig3: Force and Gravity on a Object on incline

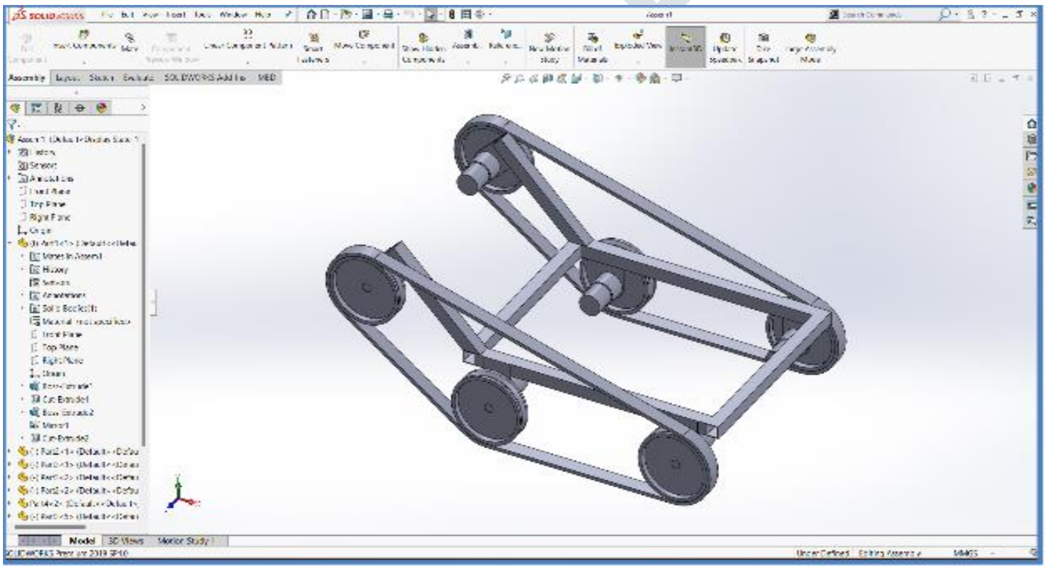
Where T is the torque needed for a single DC motor, G is the total weight of the climber machine including the weight of machine and load, α is the tilt angle of the stairs, F2 is the component force along the stairs, R is the radius of the tracked wheel.

C. Motor Selection

The motor selected for the robot is Johnson motor high torque DC geared 12V 300rpm- Grade A
Model No. RKI-1188
Rated torque- The motor has rated torque of 4.5 kg cm which is 0.44Nm which is sufficient for the robot
Stall torque- This motor has stall torque of 9.06 kg cm which is 0.88 Nm and gear ratio of 1 : 60
Weight- The weight of the motor is 200 gm
No Load speed- And no load speed of 18000RPM
Load Current- The load current of the motor is upto 7.5 Amp
This motor is selected for the robot because it is easily available and cost efficient as compared to other mtor while giving high torque of 0.44 Nm at 300 RPM with high efficiency and low weight, DC motor also works at low noise as compared to other motors.

IV. 3D DRAWING

Fig 4 : screenshot of 3d model of stair climbing robot made on solidworks



V. ANALYSIS

A. MESHING

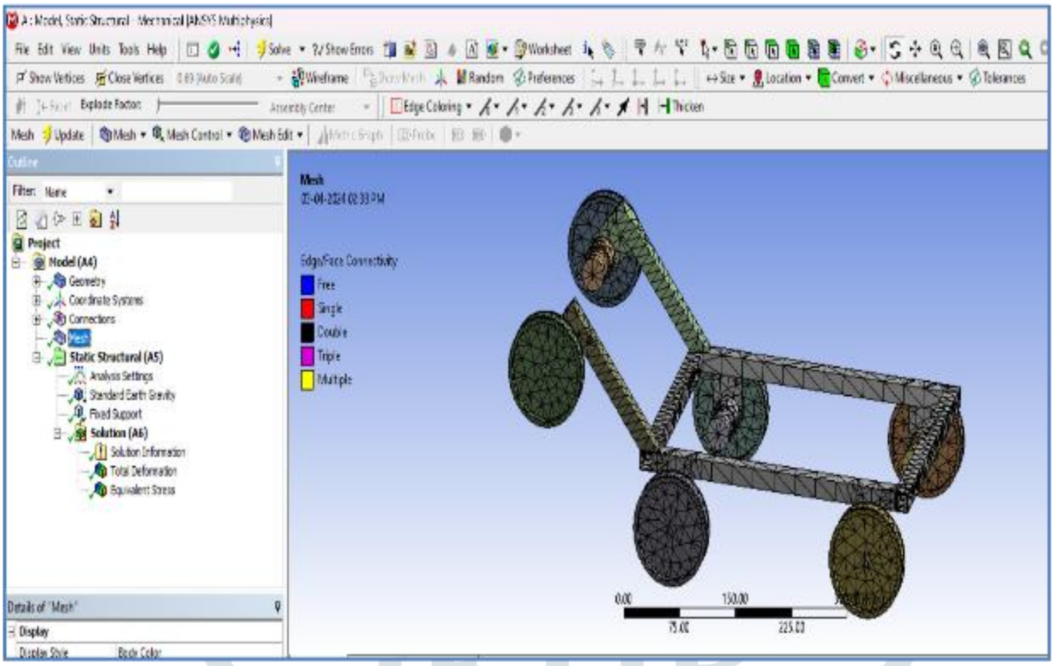


Fig 5: meshing of model

Nodes	Elements (hexa / tetra mesh)
38110	10940

B. TOTAL DEFORMATION

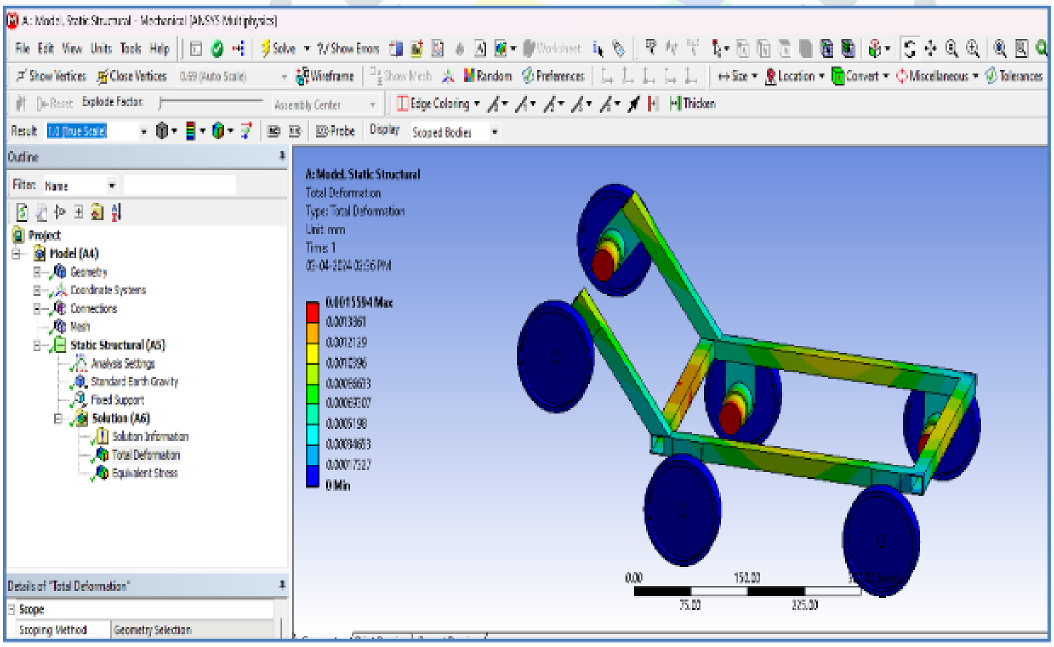


Fig6: Total deformation of model

Max Total Deformation	0.0015594 mm
Min Total Deformation	0 mm

C. EQUIVALENT STRESS

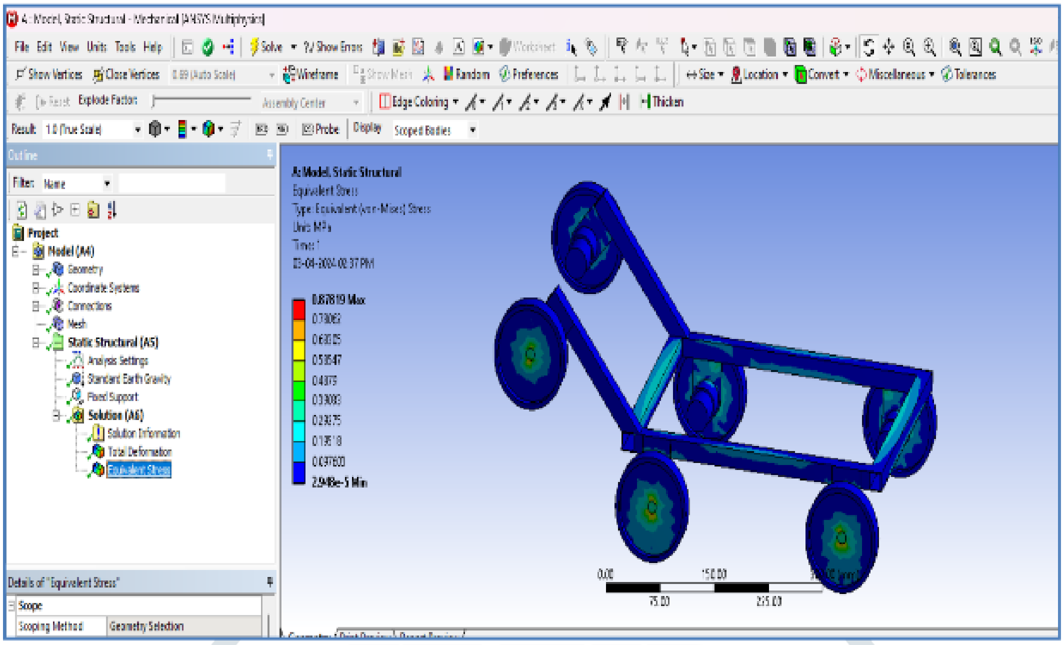
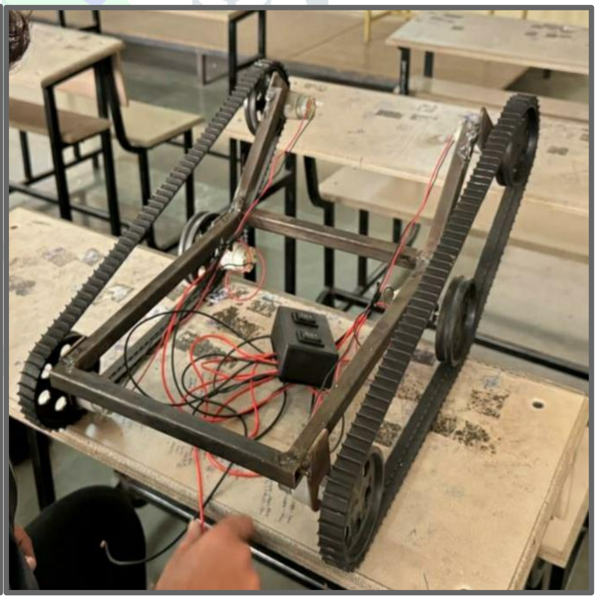


Fig7: Equivalent stress of model

Max Equivalent Stress	0.87819 Mpa
Min Equivalent Stress	2.948e^-5 Mpa

D. ACTUAL PHOTO OF MODEL



VI. RESULTS

Based on the results after performing many test runs and making adjustments the model can climb stairs and can carry weight upto 8 kg without errors or slipping and have achieved the objective of climbing stairs with accuracy, the model carried weight of 3 kg , 5 kg and 8kg. The robot can ascend and descend the stairs. It can develop an adjustable staircase climbing robot to replace the human effort to carry out difficult task in places like offices, hospitals, industrial and military automation, security systems and hazardous environments.

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