Team 2025109

General Championship 2025

HARDWARE MODELLING

INDEX

Problem Statement

1

Everyday Challenge: Stairs for People with Mobility Impairments

- Stairs, a normal part of daily life, become major barriers for wheelchair users.
- Many buildings lack ramps or lifts, limiting access to education, work, and social events.

2

The Gap in Accessibility

- Traditional wheelchairs can't handle stairs, causing dependence on others.
- Mobility-impaired people often miss out on daily experiences due to poor infrastructure.

3

Economic Barriers to Existing Solutions

- Powered stair-lifting devices are costly and unaffordable for most Indian families.
- Many available options are bulky, complex, and require external help to operate.

The Vision: Restoring Access, Confidence, and Independence

We aim to build an affordable, compact, and user-friendly stair-climbing wheelchair.

Statistics

12 Million

people in India have mobility-related disabilities.

70%

of public buildings in urban areas are not wheelchair accessible.

92%

of existing ramps do not meet accessibility standards due to improper slopes.

Solution

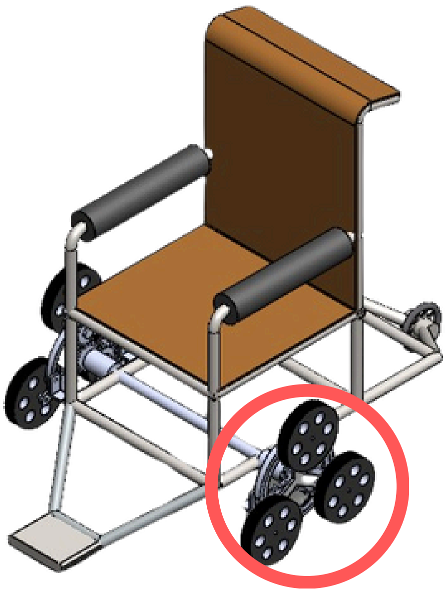
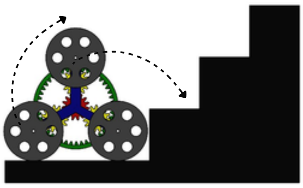


Fig-1. Wheel Chair attached to a 'Tri- Wheel Planetary Mechanism'

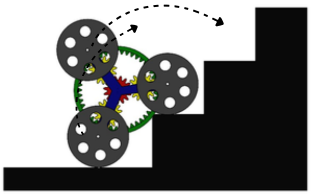
The proposed solution is a 'Tri- Wheel Planetary Mechanism' mounted on either side of the wheelchair. Each tri-wheel system comprises three wheels attached to a gear box with gears at 120-degree intervals.

How does it work?

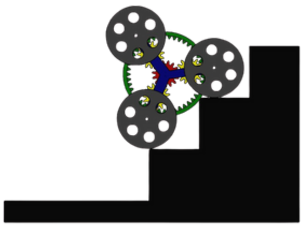
When the wheelchair encounters a step:



The tri-wheel rotates about its central arrangement, causing one of the wheels to 'topple' over the stair edge.



As the rotated wheel makes contact with the next stair tread, the system stabilizes and transfers the load onto that wheel. The cycle continues as the third wheel prepares for the next lift.



This continuous rotation of the tri-wheel hub allows the wheelchair to climb stairs step-by-step, maintaining balance and contact at all times.

Solution

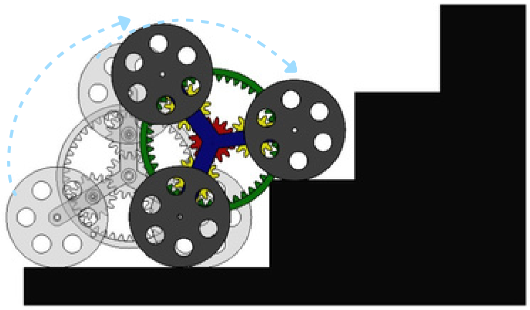


Fig-2. Animation of the Toppling Motion over a stair step

To validate our concept and showcase the working principle of the Tri-Wheel Planetary Mechanism, we have developed a scaled-down prototype using SolidWorks.

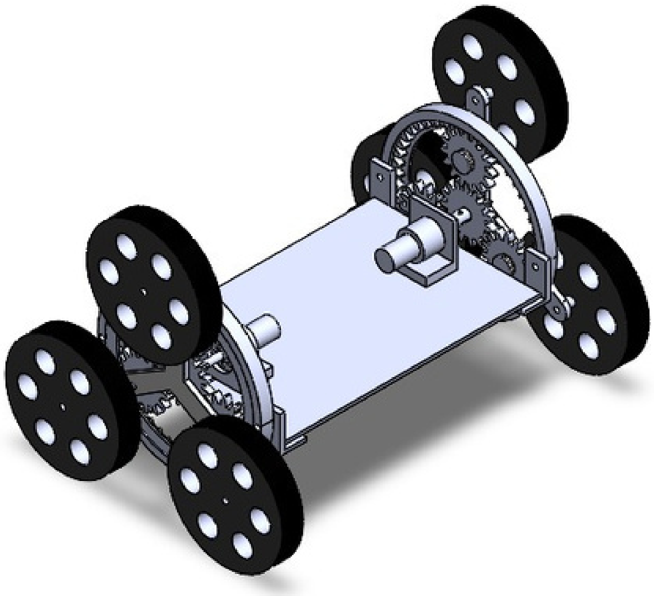


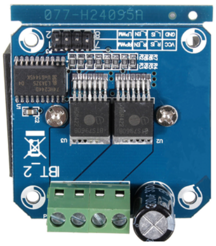
Fig-3. CAD Assembly of the scaled down Tri-Wheel Stair-Climbing Model

This physical model serves as a proof of concept, demonstrating how the tri-wheel system rotates and adapts to stair-like obstacles. While this prototype is not built to full scale, it effectively highlights the core mechanical behavior- the toppling action, wheel transition, and continuous stair climbing motion.

The model has been designed to simulate real-world usage conditions, and it helps in identifying potential improvements in balance, weight distribution, and wheel placement before building a full-scale version. This hands-on approach has allowed us to move from a theoretical design to a tangible, testable mechanism.

Components Used 03

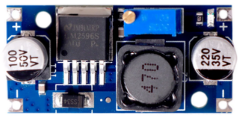
Electrical Components



BTS7960 MOTOR DRIVER

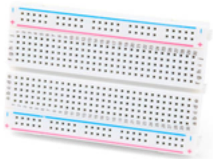
100RPM DC MOTOR

ULTRA SONIC SENSOR



LM2596 DC-DC BUCK CONVERTER

JUMPER WIRES



BREAD BOARD

ARDUINO NANO

12V BATTERY

Mechanical Components

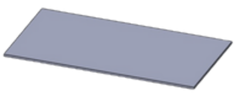
SUN GEAR

PLANETARY GEAR

RING GEAR

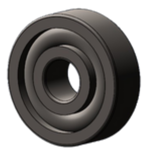
NUTS AND BOLTS

CARRIER



BASE

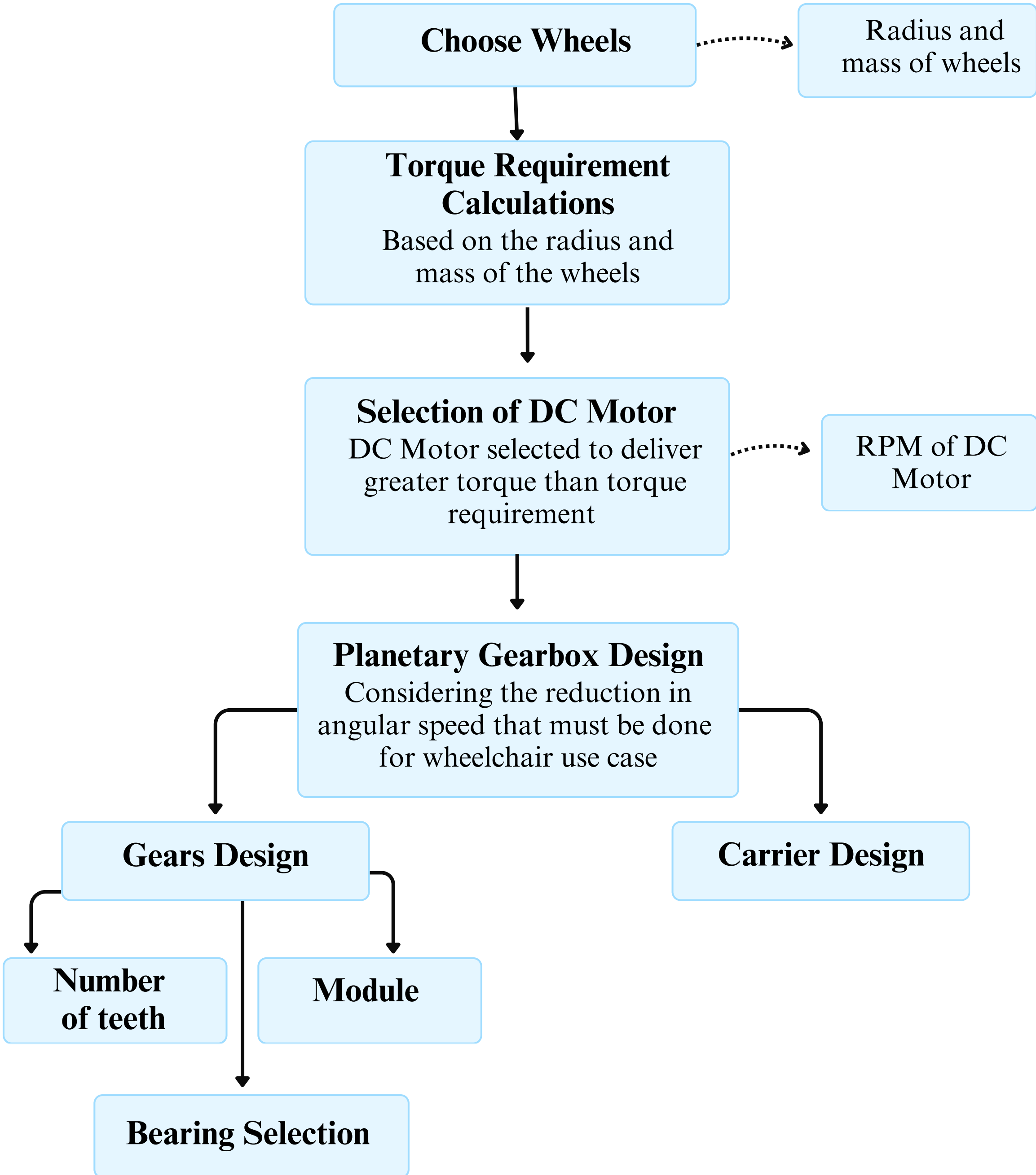
WHEEL



RADIAL BALL BEARING

Mechanical Design

Overview of Mechanical Design Process

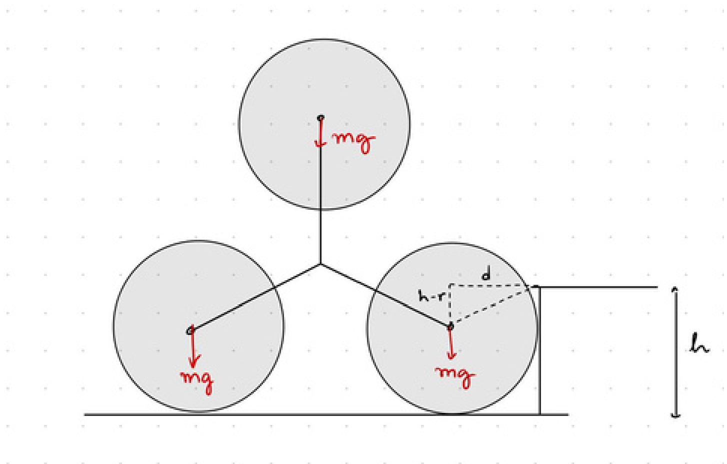


Mechanical Design 04

Torque Requirement Calculations

Wheel specifications:
The following wheel parameters have been selected for our design:
Mass of each wheel: m_{wheel}= 0.2 kg
Wheel radius: r_{wheel}= 11 / 2 mm= 0.055 m
In order for the system to drive with the given wheel specifications, the following torque calculations were performed:

Torque calculations: By looking at the free-body diagram as follows,



We define the relation between parameters shown in the free-body diagram as follows:

$$d = \sqrt{r^2 - (r - h)^2}$$

Using this to find the torque using the formula :

$$\tau = m.g.d + m.g.(l * sin\theta + d) + m.g.(2lsin\theta + d)$$

$$\Rightarrow \tau_{carrier} = 3 * m * g * (l * sin(60^o) + \sqrt{r^2 - (r - h)^2})$$

We have plotted torque variation with carrier length in MATLAB.

Torque Requirement Calculations

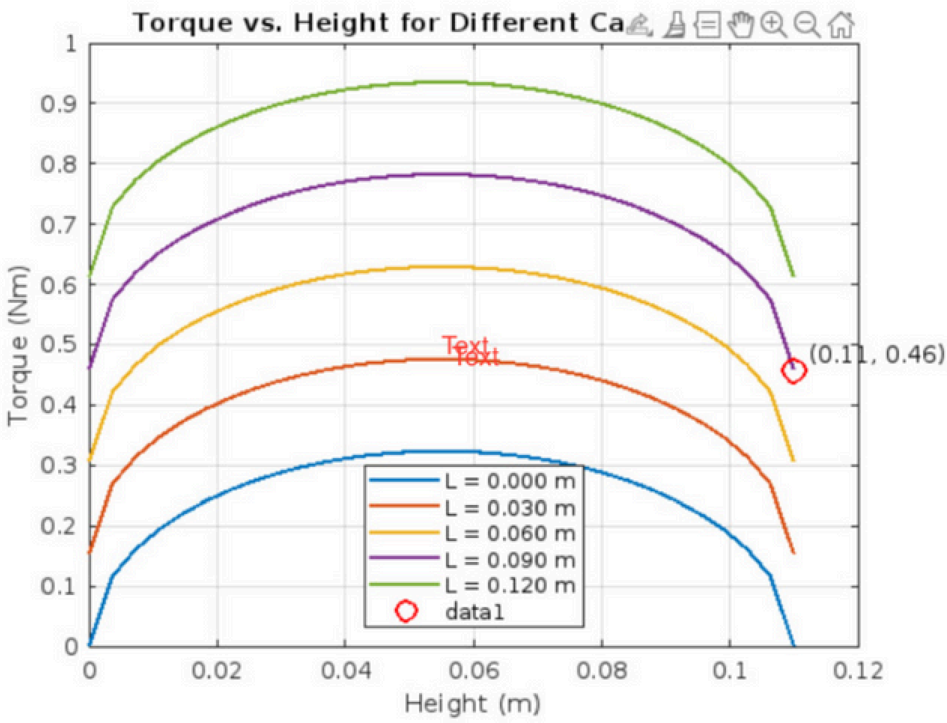


Fig-4. Plot showing torque variation (in Nm) vs height of steps (in m) for different carrier lengths

Selection of DC Motor

The required torque for our module was calculated to be 0.46 Nm. To meet this requirement with an adequate safety margin, we selected a DC motor capable of delivering a maximum torque of 1.03 Nm at 100 RPM. So we have our driving angular velocity at the sun gear attached to the motor as 100 RPM, we now can start working on the gear reduction ratios to design the planetary gearbox.

Planetary Gearbox Design

We have chosen a planetary design for our model as it offers high torque-to-diameter ratio alongside even load distribution across multiple planet gears. At any point during climbing, at least one wheel is in contact with the ground or stair, ensuring stability and balance for the module.

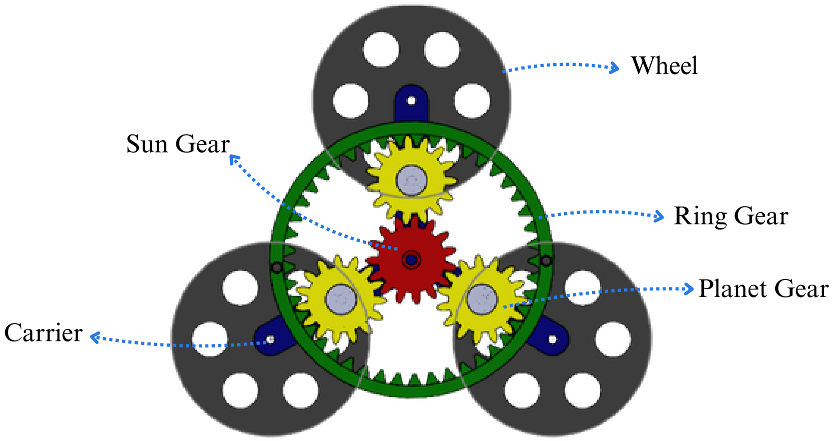


Fig-5. CAD of planetary gearbox arrangement

We have used the following formulae for our calculations:

$$N_{ring} = 2 * N_{planet} + N_{sun}$$

$$\omega_{sun} = \omega_{carrier}\left(1 + \frac{N_{ring}}{N_{sun}}\right)$$

$$\tau_{carrier} = \tau_{sun} + \tau_{ring}$$

$$\tau_{motor} = \tau_{sun} = \frac{N_{ring}}{N_{sun}} \times \tau_{ring} = \tau_{carrier}\left(\frac{N_{ring}}{N_{ring}+N_{sun}}\right)$$

$$\tau_{ring} = \frac{N_{sun}}{N_{ring}} \times \tau_{sun} = \tau_{carrier}\left(\frac{N_{sun}}{N_{ring}+N_{sun}}\right)$$

The sun gear is driven by 100 RPM motor. For it to topple we assumed that 30 RPM was a good enough speed. The nearest value of speed which is a multiple of 100 was 25. So our reduction ratio turned out to be 4:1. Thus, we have the following parameters of our planetary gearbox design:

Module: $\text{Gear Ratio} = 1 + \frac{N_{ring}}{N_{sun}} = 4 \Rightarrow N_{ring} = N_{sun} \times 3$

We chose the gear module to be 3 because 3D printing guidelines recommend using a module greater than 2 to ensure reliable tooth resolution, and increasing the module results in more defined teeth with fewer teeth for a given pitch diameter, enhancing printability, strength, and gear meshing accuracy in the planetary setup.

Number of teeth:

We have set the number of teeth in the sun gear to be 15, looking at the module and minimum requirements of the 3D printable sun gear. So our ring gear has 45 teeth.

To conclude the planetary gearbox has been designed as follows:
Wheel mount distance from carrier center:
$l = 0.090$ m (from the plot)
Number of wheels in the tri-wheel system:
$n_{wheels} = 3$
Planetary Gearbox Reduction Ratio:
$r = 4:1$
Number of teeth in sun gear = 15
Number of teeth in planet gears = 15
Number of teeth in ring gear = 45

Bearing Selection

A deep groove radial ball bearing (625 ZZ) was used with an inner diameter of 5 mm, outer diameter of 16 mm and width of 5 mm. The planet gears have been designed accordingly. The ball bearing was chosen for its **compact size and low-friction rotation** making it ideal for smooth, load-bearing rotation of the planet gears in the gearbox.

3D Printing

All gears in the prototype planetary gearbox were fabricated using **PLA**, selected for its **printability, accuracy, and structural stiffness**. While not intended for high-torque or long-term load-bearing, PLA was ideal for validating the gear ratio, meshing, and structural layout of the system. PLA has a relatively low printing temperature of around 180°C, meaning it is less likely to warp and clog the nozzle during the printing process. All the gears were made with 100% infill for best durability and strength.

Additional Design Considerations

Motor Shaft

We designed the sun gear with a with a extrusion in the center so that the motor shaft can fit directly into it. A screw is used to fasten the motor shaft firmly within the extrusion, enabling effective torque transmission and preventing slippage or wobbling during operation. This makes sure the motor can turn the sun gear without slipping. It also helps keep the gear straight and properly lined up with the motor. Since the sun gear is the first to receive the motor's speed and power, a strong connection is very important. A loose fit could cause the gear system to move unevenly or become unstable.

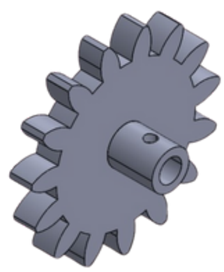


Fig-6. Sun Gear with coupler

Motor mount

The motor mount was designed to fix the motor to the base according to it's specifications, and prevent it from itself spinning in the counter direction.

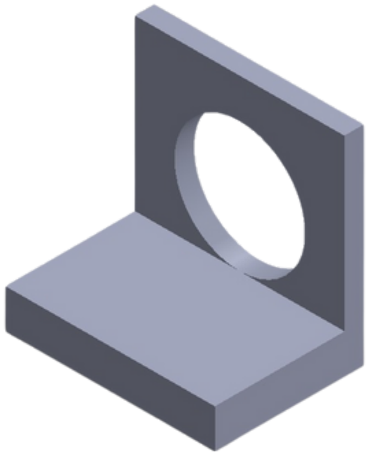


Fig-7. Motor mount

Assembly of manufactured module

Attaching the planets to carrier

- Bearings press fitted into the planet gears, since design dimensions were chosen for the same.
- Planets attached to carrier using 3D printed pins, which hold them in plane of rotation.

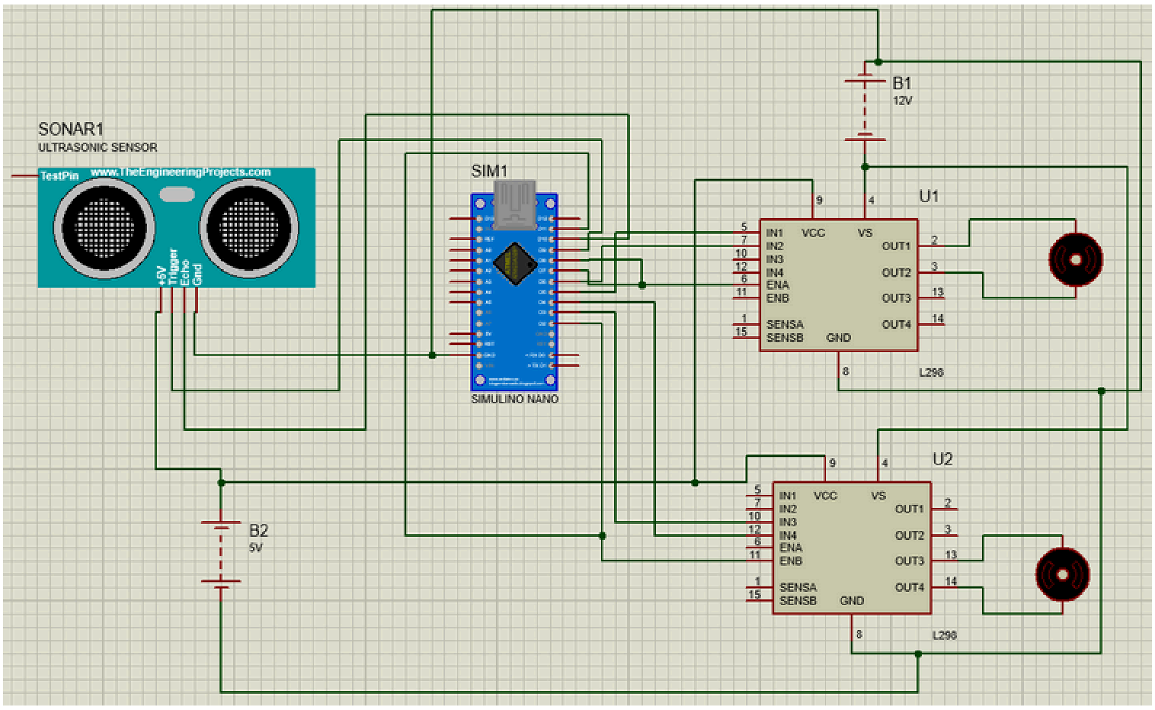
Fixing the ring gear to the base

to make sure that all the torque is directed towards rotating the carrier output and makes sure the ring gear doesn't rotate opposite to the sun gear, the base is bolted to the base.

Fixing the motor

- Motor is screwed onto the motor mount to prevent rotation against its own provided torque
- Motor mount bolted to the base plate, such that the sun gear is meshed with the planets and is in the same plane as them

Schematic Diagram



This circuit diagram gives a basic idea of the wheelchair climbing module envisioned. It detects obstacles with the help of an ultrasonic sensor (HC-SR04) and controls the two motors (which are connected to the left and right wheels) using two motor drivers. The BTS7960 motor drivers are used in the hardware implementation, but in this schematic, the L298 motor drivers have been used as a substitute. Each L298 motor driver controls each DC motor (Pro-Range 12V 100 RPM Johnson Geared DC Motor used in the hardware implementation).

The overall functionality of the Arduino code is that it measures the distance of the obstacle in front of it, and if the measured distance is less than 7 cm, both motors move forward.

In the schematic, the Vcc pins of the motor drivers and the ultrasonic sensor are powered directly by a 5V battery but in the hardware implementation, we have used a 12V battery and stepped down the voltage to 5V using a buck converter.

Working

Each BTS7960 motor driver uses Enable and PWM pins to control the speed and direction of the 12V DC geared motors.

Enable Pins (R_EN, L_EN):
Activate the corresponding side of the H-bridge. Both must be set HIGH to allow motor movement. If disabled, the motor won't respond even if PWM is given.

PWM Pins (RPWM, LPWM):
Control motor speed and direction using Pulse Width Modulation.

- To move forward, RPWM receives a PWM signal, and LPWM stays LOW.
- To move backward, LPWM receives PWM, and RPWM stays LOW.
- The duty cycle of the PWM (0–255) determines how fast the motor spins.

Enable + PWM pins allow precise control over each motor, enabling smooth starts, stops, speed variation, and directional changes.

For the Ultrasonic sensor, Vcc pins and Enable pins of the motor drivers, a stable 5V logic is required. While the option of drawing power from the working Arduino Nano remains, 5V drawn from Nano's onboard regulator is low current (typically max ~500mA, sometimes less).
Using that 5V rail to power HC-SR04, Vcc, and EN pins of two BTS7960 motor drivers is not advisable as the Nano's 5V pin can't handle high current (usually <500mA as mentioned above). Reasons are attributed to:

- It's regulated from USB or VIN via a tiny onboard regulator.
- When trying to power both BTS7960 logic circuits, sensors, etc., from Nano's 5V, it overheats or resets.

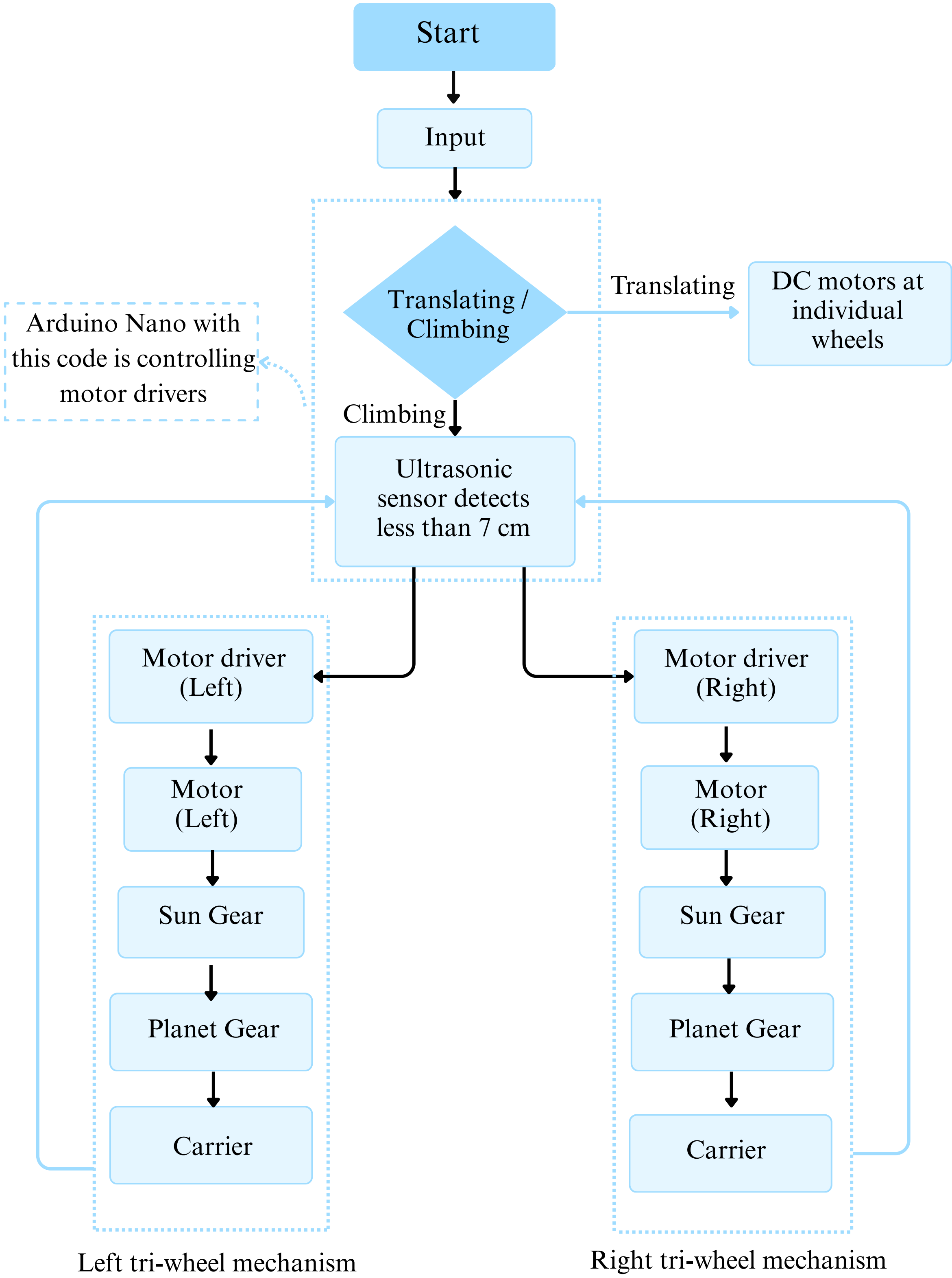
Instead, using LM2596 DC-DC Buck Converter:

- Efficiently steps down the 12V battery to 5V.
- Can supply up to 2A or more, which is plenty for:
  - 2× BTS7960 logic Vcc
  - 2× BTS7960 logic EN
  - HC-SR04

At the end, using a separate 5V buck converter for logic level power (not Arduino's 5V pin) ensures enough current supply for both motors.

Electronics and Controls

Control Flow



Cost Breakup

Components	Quantity	Total Cost(in INR)
BTS7960 Motor Driver	2	500
100RPM DC Motor	2	1780
LM2596 DC-DC Buck Converter	1	32
Ultra Sonic Sensor	1	110
Jumper Wires	20	40
Breadboard	1	60
Arduino NANO	1	2400
12V Battery	1	260
3D Printed Materials		7096
Miscellaneous Items		100

The entire prototype was built with a budget of just **₹12,328**, successfully giving a proof-of-concept for the entire mechanical and electronic architecture that can be scaled up in the future.

Future Improvements

1 Joystick Control

- Joystick detects directional movement and sends signals to control motion in machines or electronics.
- The joystick can be mounted on the armrest and connected to motors via a microcontroller to control the wheelchair's movement.

2 Shock Absorption

- By introducing small damper systems to absorb shocks while climbing or descending stairs for smoother rides.
- We can fix the tri-wheel on a spring loaded pivot arm allowing vertical motion for shock absorption.

3 Incline Assist Bar

- Prevents the wheelchair from rolling backward on ramps or stairs if motors fail or stop.
- By fixing a leg with adjustable length based on slope that locks with a pin or screw.

4 PWM Speed Control

- Implement variable speed to handle different ramp angles smoothly.
- PWM speed control helps conserve battery power by delivering only the required voltage to the motors, improving efficiency during operation.

5 Stair Detection

- We can mount a 2D LiDAR like RPLiDAR A1 or A2 low at the front, tilted slightly downward at an angle (not flat).
- This way, it scans the profile of the floor ahead, including edges and stair risers

References

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REFERENCE 2 : IEEE Access, et al. "Design of Stair-Climbing Electric Wheelchair with Tri-Spoke Wheel and
Supporting Leg." Design of Stair-Climbing Electric Wheelchair with Tri-Spoke Wheel and Supporting Leg, Digital Object Identifier 10.1109/ACCESS.2024.3371017, 30 Jan. 2024, acrobat.adobe.com/id/urn:aaid:sc:AP:56f7617c-587f-40ba-98ed-869dbaa6dfc0. Accessed 17 Feb. 2024.
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under Project NK244F.