Autonomous Scaling Robot

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Introduction

This project aims to design and develop an autonomous vehicle capable of completing three main tasks: climbing two flights of staircases, navigating a 90- or 180-degree turn between flights, and reliably carrying a 1kg load. Significant focus was placed on stability and efficient locomotion. During initial research, I found references to the "last-mile issue," [1] which closely resembles our problem, as it refers to the final stage of delivery often presenting the most obstacles to overcome, particularly with regard to staircases.

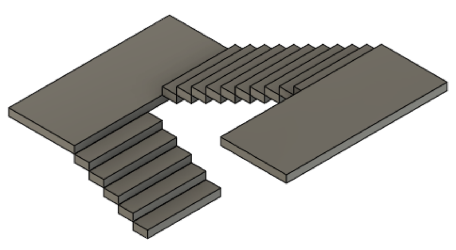

Figure 1. Navigation

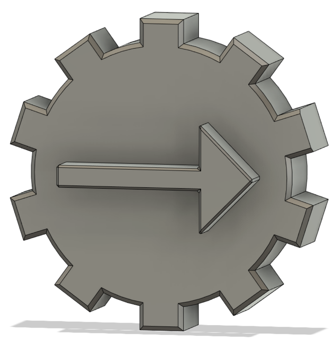

Figure 2. Locomotion

Figure 3. Load Bearing

Locomotion

The focus was on rapid prototyping, so I designed a modular 10 part frame from 6mm MDF in Fusion 360. MDF was chosen for its lightweight, sturdy nature and quick laser-cutting ability, which allowed for fast assembly compared to 3D printing. Additionally, MDF is a sustainable material made from recycled wood fibers, reducing environmental impact. The modular design made it easy to change out the wheels and arm, promoting rapid testing and iteration while minimizing waste. The general shape of the design and the hook arms were inspired by the trispoked style [2], but the design was heavily modified by adding two more wheels to enhance locomotion and positioning the tri-wheels ahead of the body to improve traction.

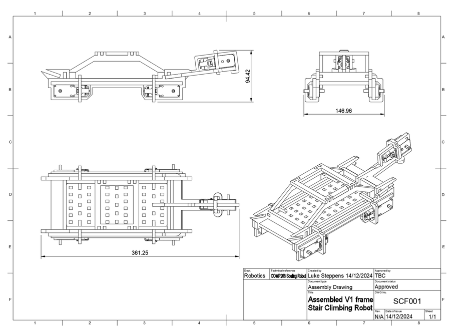

Figure 4. Prototype Test Frame Schematic

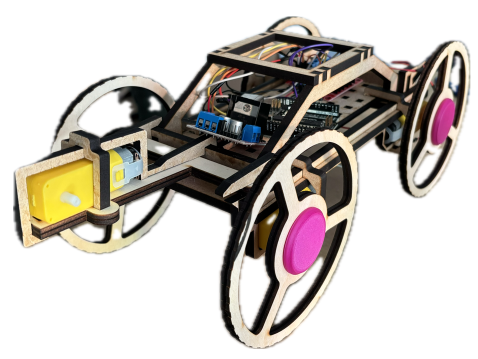

Figure 5. Frame and Wheels

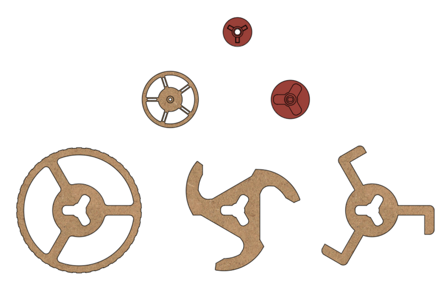

Figure 6. Hub and Wheel Designs

Initial Testing

The first prototype was successfully tested on a flat surface but failed when attempting to ascend the test stairs. The four 3-12V DC motors lacked the torque needed to climb even a single step. As a result, we decided to simplify the design by removing the arm and replacing the front wheels with tri-wheels. This shift introduced the biggest challenge for me: designing and implementing a much stronger gear system.

Gearing Design

Research led me to choose planetary gears for their efficiency, commonly used in vehicles. I first designed a test version in Fusion 360 and 3D printed it (see Figure 7), but found it too complex to implement[3]. I then created a simpler gear system (see Figure 8), which was added to the frame and connected to the front DC motors, but it failed the stair test.

Figure 7. Prototype Gear System: Planetary

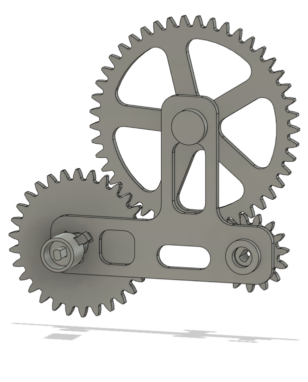

Figure 8. Prototype Gear System: Trigear

I explored the use of compound gears to increase torque and sourced JGA25-371 motors to handle the added load. I then designed a new compound gear system and a custom frame to house it. This effort resulted in a system capable of reliably operating under high-stress conditions.

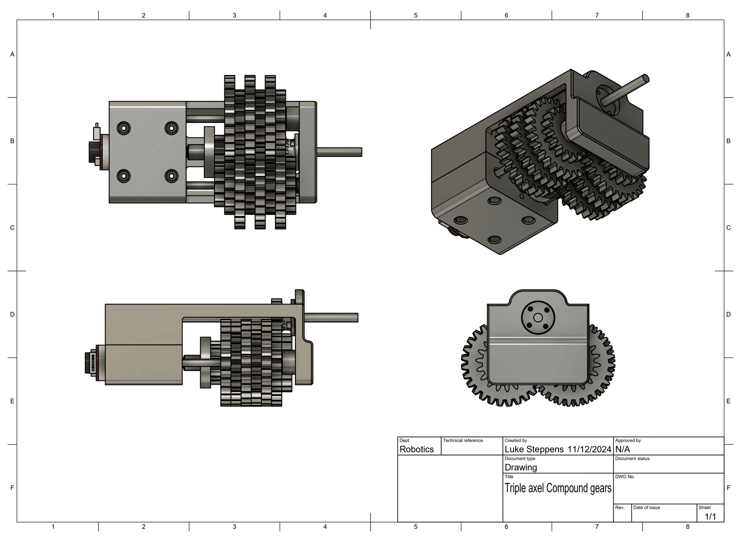

Figure 9. Gear Train Final Design.

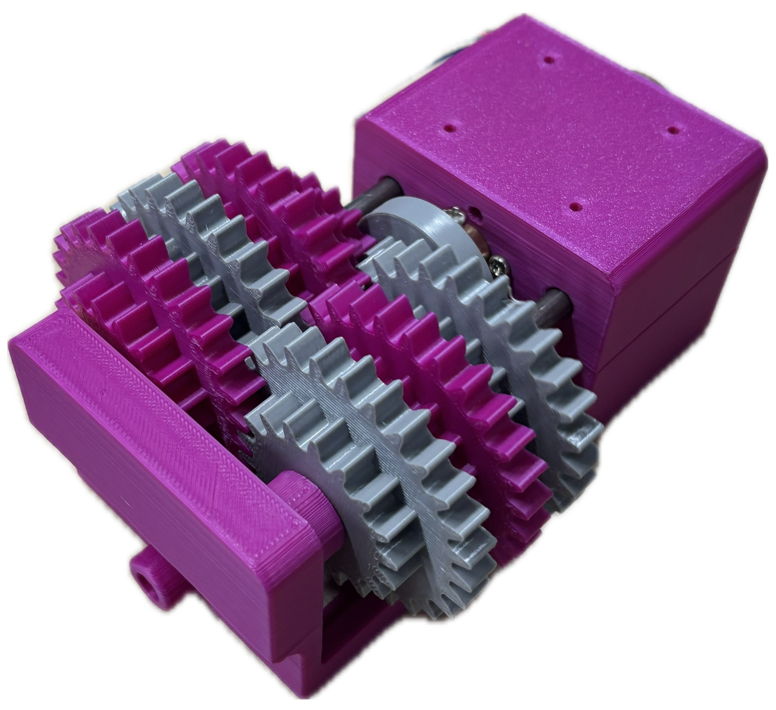

Figure 10. Final Gear Train 3D Print

Gearing System									
Amount of Gears	**Position**	**Gear Type**	**Input/Output**	**Pitch Diameter**	**Teeth**	**Module**	**Backlash**	**Root Fillet Radius**	**Thickness**
1	Motor	Single	Input	20mm	10	2	1mm	0.5	7mm
1	Rear Axle	Compound	Input	26mm	13	2	1mm	0.5	7mm
			Output	36mm	18	2	1mm	0.5	7mm
3	Front Axle	Compound	Input	56mm	28	2	1mm	0.5	7mm
			Output	36mm	18	2	1mm	0.5	7mm
3	Rear Axle	Compound	Input	56mm	28	2	1mm	0.5	7mm
			Output	36mm	18	2	1mm	0.5	7mm
1	Wheel	Single	Output	22mm	11	2	1mm	0.5	7mm

Table 1. Gearing System Specifications

Torque Calculations

The gear and torque calculations for the Gear train are as follows:

$$\text{Gear Ratio} = \frac{\text{Teeth of Output Gear}}{\text{Teeth of Input Gear}}, \quad \text{RPM Out} = \frac{\text{RPM In}}{\text{Ratio}}, \quad \text{Torque Out} = \text{Ratio} \times \text{Torque In}$$

Gear Calculations:

Gear 1-2: Ratio $= 1.3$, RPM Out $= 46.15$, Torque Out $= 1.13\,\text{Nm}$
Gear 2-3: Ratio $= 1.56$, RPM Out $= 29.8$, Torque Out $= 1.77\,\text{Nm}$
Gear 3-4: Ratio $= 1.56$, RPM Out $= 19.1$, Torque Out $= 2.76\,\text{Nm}$
Gear 4-5: Ratio $= 1.56$, RPM Out $= 12.24$, Torque Out $= 4.30\,\text{Nm}$
Gear 5-6: Ratio $= 1.56$, RPM Out $= 7.85$, Torque Out $= 6.71\,\text{Nm}$
Gear 6-7: Ratio $= 1.56$, RPM Out $= 5.00$, Torque Out $= 10.47\,\text{Nm}$
Gear 7-8: Ratio $= 1.56$, RPM Out $= 3.21$, Torque Out $= 16.34\,\text{Nm}$
Gear 8-9: Ratio $= 0.61$, RPM Out $= 5.20$, Torque Out $= 9.97\,\text{Nm}$

Overall Output:

$$\text{Times Stronger} = \frac{9.97\,\text{Nm}}{0.872\,\text{Nm}} = 11.43Nm$$

Sensing and Navigation

To traverse a staircase with two 90-degree turns, we decided to use a tilt sensor (SW-520D) to detect whether the vehicle was level or on an incline. This would allow the vehicle to determine two things: 1. If it needed more effort to ascend, and 2. If it was on a flat surface. Additionally, we used an ultrasonic sensor (HC-SR04) to detect walls, enabling the vehicle to turn right when needed. I contributed to the construction of the basic movement code.

Code Snippet: Motor Control

This piece of code is designed for basic functionality that can be built upon. It drives the vehicle forwards and backwards by controlling the motors using the motorDriving function.

```
// Initialised all Variables

Initialize encoders:
    wheelSet1 = Encoder(encoderA, encoderB)
    wheelSet2 = Encoder(encoder2A, encoder2B)

Function motorDriving(speed, motorA, motorB, motorE):
    If speed < -255:
        speed = -255
    If speed > 255:
        speed = 255

    If speed > 0:
        Set motorA to HIGH
        Set motorB to LOW
    Else If speed < 0:
        Set motorA to LOW
        Set motorB to HIGH
    Else:
        Set motorA to LOW
        Set motorB to LOW

Setup:
    Set motor and encoder pins as OUTPUT or INPUT
    Start Serial communication

Loop:
    Call motorDriving with -255 for motorA, motorB, motorE (move forward)
    Call motorDriving with 100 for motor2A, motor2B, motor2E (move forward)
    Set motorNA to HIGH, motorNB to LOW
    Set motor2NA to HIGH, motor2NB to LOW
```

Figure 11. Basic movement Pseudo-code

Electronics

Components

- 1x Arduino Uno
- 4x JGA25-371 25MM Motors
- 2x L298N H Bridges
- 1x HC-SR04 Ultrasonic Sensor
- 1x SW-520D Tilt Sensor

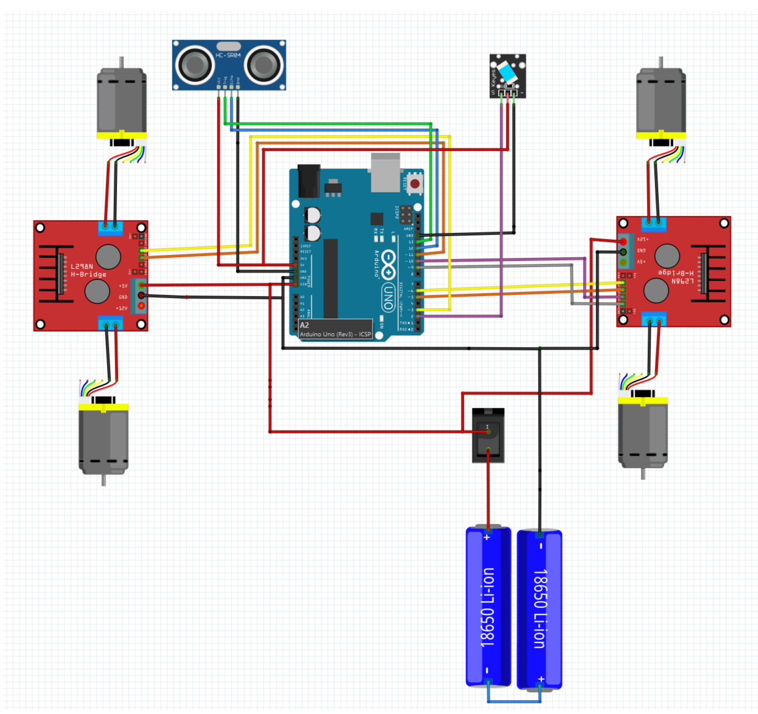

Figure 12. Electronic Components.

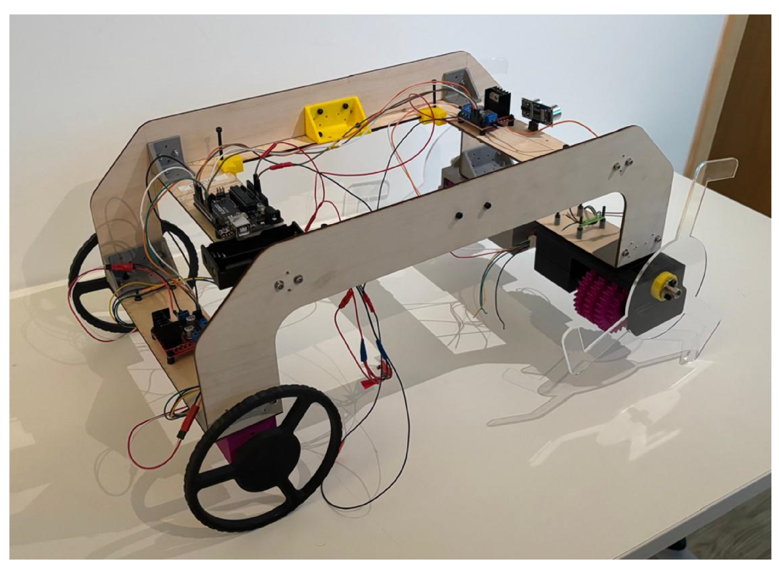

Figure 13. New Frame and Wiring.

Conclusion and Reflections

By the end of this project, I learned the importance of ongoing research as problems arise, rather than just at the start and end. I also had to remake several gears multiple times to get them working, which taught me the value of iteration and testing early. Although I wanted to explore a different wheel design, I didn't give myself enough time to do so.

The test frame design was helpful but overengineered it could have been simpler and still achieved the same result. This project has reinforced the need for adaptability, efficient use of time, and the importance of testing throughout the design process.

References

[1] S. Qi, W. Lin, Z. Hong, H. Chen, and W. Zhang, "Perceptive Autonomous Stair Climbing for Quadrupedal Robots," in *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 2313–2320, Sept. 2021. ISSN: 2153-0866.

[2] Y. Kim, J. Kim, H. S. Kim, and T. Seo, "Curved-Spoke Tri-Wheel Mechanism for Fast Stair-Climbing," *IEEE Access*, vol. 7, pp. 173766–173773, 2019. Conference Name: IEEE Access.

[3] A. Kahraman, "Free torsional vibration characteristics of compound planetary gear sets," *Mechanism and Machine Theory*, vol. 36, pp. 953–971, Aug. 2001.