re-purposing materials that would otherwise persist in the environment for centuries.

2.1 Conceptual Design

The main electronic systems of our robot comprise the grippers and the spine. The grippers, essential for the opening and closing actions, are driven by servo motors. In contrast, the spine functions through a linear actuator mechanism, utilizing DC motors to facilitate the rotation of the screw. It's important to note that the digital pins of the motor are directly connected to the digital PWM-capable pins of the micro controller. The current setup is capable of adjusting the speed and direction of the motors, as well as precisely switching them on and off, to ensure the proper operation of the grippers, linear actuator, and rack and pinion system. The quadrature encoder is used so that 2 switches do not have to be used when homing the robot incase the linear rail goes too far up or down. We can measure the number of counts the encoder reads and knowing the resolution of the encoder we know how far the linear rail has displaces. Now during homing, we only move the linear rail down until one switch has been closed. The upper set point is set in code based on the length of the wooden rod and mathematical calculations described in section 1.1.

The micro controller is the central unit that coordinates the actions of both the grippers and spine systems. It receives time-of-flight sensor data in the form of distance of the head of the robot from the branches, and accordingly sends appropriate signals to both the servo and motor drivers. The time of flight sensors use I2C to communicate so will be connected to the appropriate SDA and SCL capable pins on the micro controller.

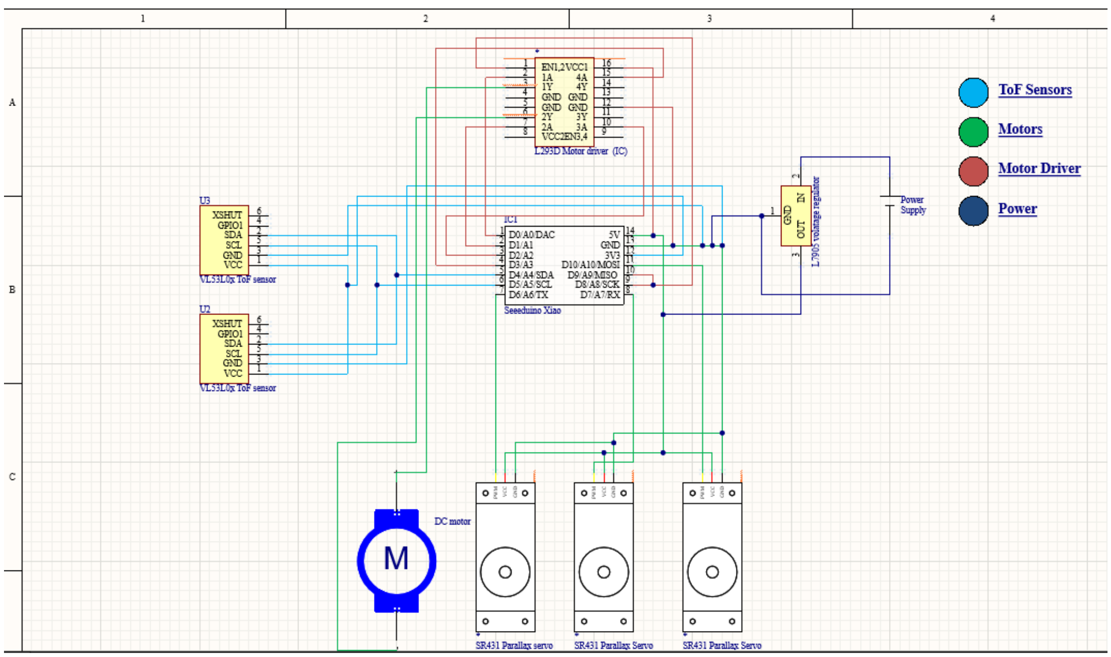

Figure 11. Schematic

The provided schematic (Figure 10) delineates the initial configuration of our circuit, serving as a foundational framework that we will iterate upon and refine throughout our testing and development stages.

Our robot is controlled using a Seeeduino XIAO SAMD21 micro controller which is renowned for its small compact size and powerful computing power. It is a 32 bit micro controller with a higher clock speed so can execute more instructions per second than the other options from Arduino that were available to us. Due it being lightweight, it makes sure our robot can stay as close within the weight limit as possible. The other benefit is that all the pins of the Seeeduino XIAO can be used as interrupts and are PWM capable which is useful as we are using quadrature encoders and servos that requires lots of pulses in a small duration of time.

To the left flank, we incorporate two VL53L0X sensors, strategically placed to monitor both the frontal and rear aspects of the robot. Employing I2C communication, these sensors interface seamlessly with the Seeeduino Xiao, utilizing its dedicated SCL and SDA pins for data exchange. Furthermore, these sensors draw power from the 3.3V pin of the Seeeduino Xiao. This positioning and integration are pivotal for enabling comprehensive environmental awareness and navigation.

Nestled at the lower section are three servo motors and a DC motor featuring an encoder. The DC motor interfaces with the L293D motor driver IC, positioned prominently at the apex. This configuration allows for efficient control and manipulation of motor operations. The PWM pins of the servos find their connection to the digital pins D6, D7, and D10, facilitating precise servo motor control.

The L293D motor driver interfaces directly with the Seeeduino Xiao, establishing connectivity via its Input 1, 2, 3, and 4 GPIO pins, alongside the EN 1 and 2 pins to regulate the speed of the DC motor. This integration enables effective motor control and synchronization within our system architecture. The L293d is a dual channel motor driver, however, as we are using 1 motor that has a current draw close to the L293D max current handling capability, we will tie the channels together as well as the EN pins so that we can draw more current and have the L293D heat up less. Had we used 2 DC motors, we would not be able to do this.

On the right side we integrate a crucial component which is the 5V step down voltage regulator (L7805). This will step down the 12V input to a stable 5V to be used for controlling the servo motors and general electronics. The 12V will be used to drive the DC motor via the L293D motor driver.

By strategically placing and interconnecting these components, we ensure an optimized and robust circuit design, primed for further refinement and performance enhancements as we progress through our developmental journey.

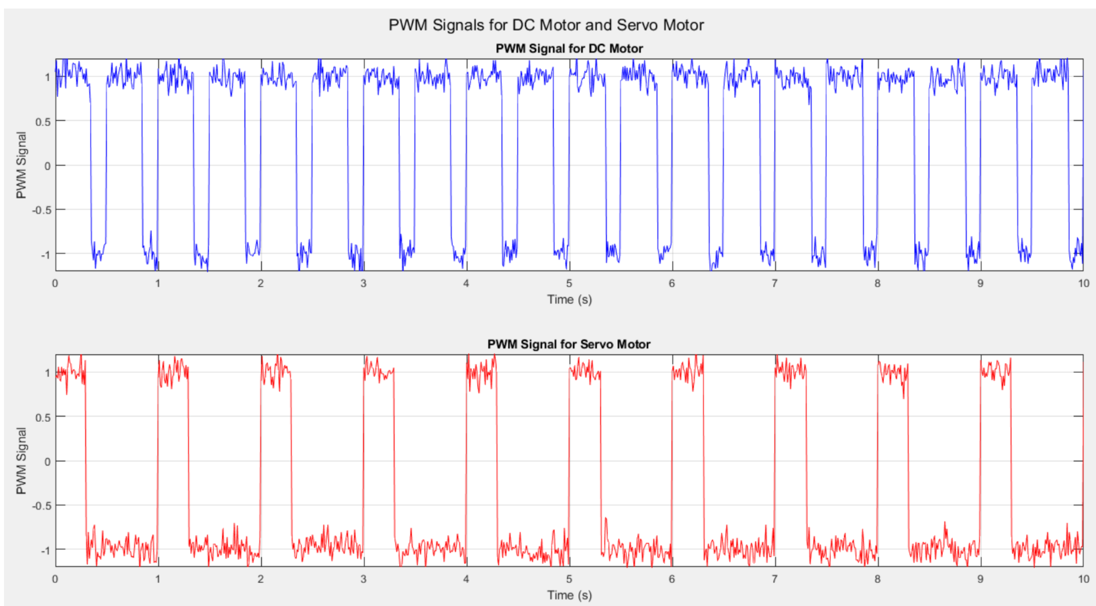

Figure 12. PWM signals

In our project, both the PWM signals (Figure 11) for the DC motor and the servo motor are vital components enabling the functionality of our tree climbing robot, the approximation graph of which is displayed above. PWM, or Pulse Width Modulation, is the method by which we regulate the direction of the DC motor and the position of the servo motor.

For the DC motor, the PWM signal controls its speed and direction. This signal consists of a square wave with a variable duty cycle, representing the proportion of time the signal spends in its high state (ON) relative to the total period. By adjusting this duty cycle, we can effectively control the average voltage applied to the motor, influencing its speed. This precise control allows our robot to ascend, descend, or halt as required during its traversal of the tree canopy.

Similarly, the PWM signal for the servo motor determines its position, contributing significantly to the precision of our robot's gripping and motion mechanisms. Like the PWM signal for the DC motor, it comprises a square wave with a fluctuating duty cycle. However, while maintaining a constant frequency, the duty cycle varies to denote the desired angular position of the servo motor. By manipulating this duty cycle, we can precisely adjust the angle of rotation for the servo motor, enabling tasks such as adjusting the orientation of the grippers or finely tuning the engagement of the rack-and-pinion mechanism.

Furthermore, controlling the speed of the DC motor presents an interesting control problem. The relationship between angular velocity and linear velocity can be observed in the given equations 5 and 6. The goal of this control problem will be to achieve a target linear velocity, with input signals including the angular velocity from the built-in **quadrature encoder**, pitch, diameter, RPM, and length of the screw. PID tuning can be employed to achieve the desired target velocity of the DC motor that drives the linear actuator.

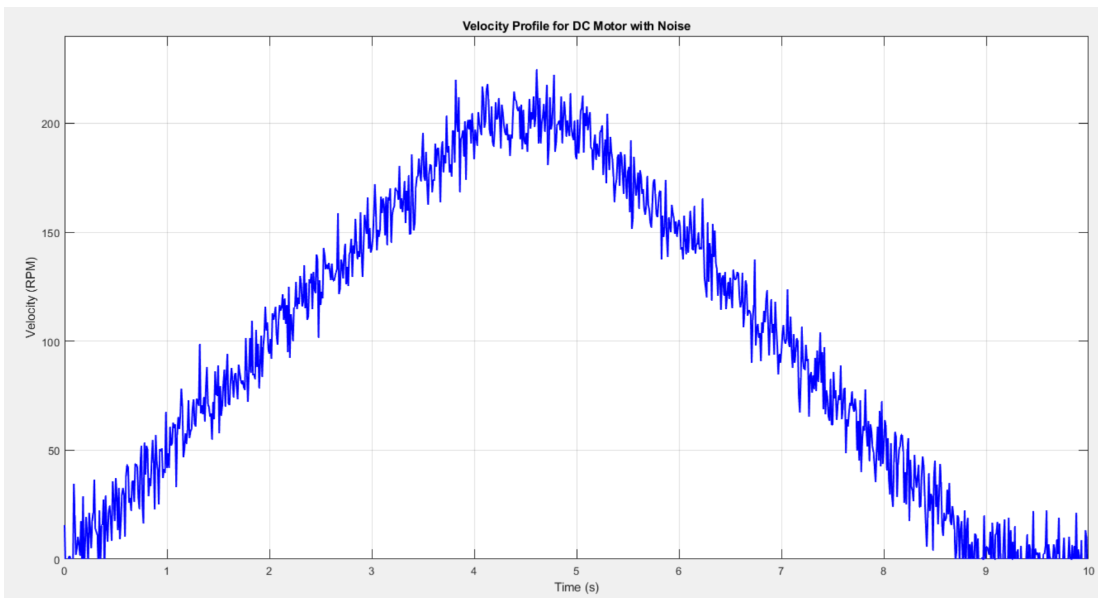

Figure 13. DC motor velocity profile

The velocity profile graph (Figure 12) of the DC motor is pivotal for controlling the motor's speed as our tree climbing robot navigates the tree trunk. This graph illustrates how the motor's velocity changes over time, influencing the robot's movement dynamics.

Initially, the velocity gradually increases as the motor accelerates, ensuring smooth startup and controlled ascent or descent. At its peak velocity, the robot achieves maximum speed, facilitating efficient traversal along the tree trunk.

Towards the end of the profile, the velocity decreases gradually as the motor decelerates, enabling smooth and safe stops when approaching obstacles or reaching the desired destination.

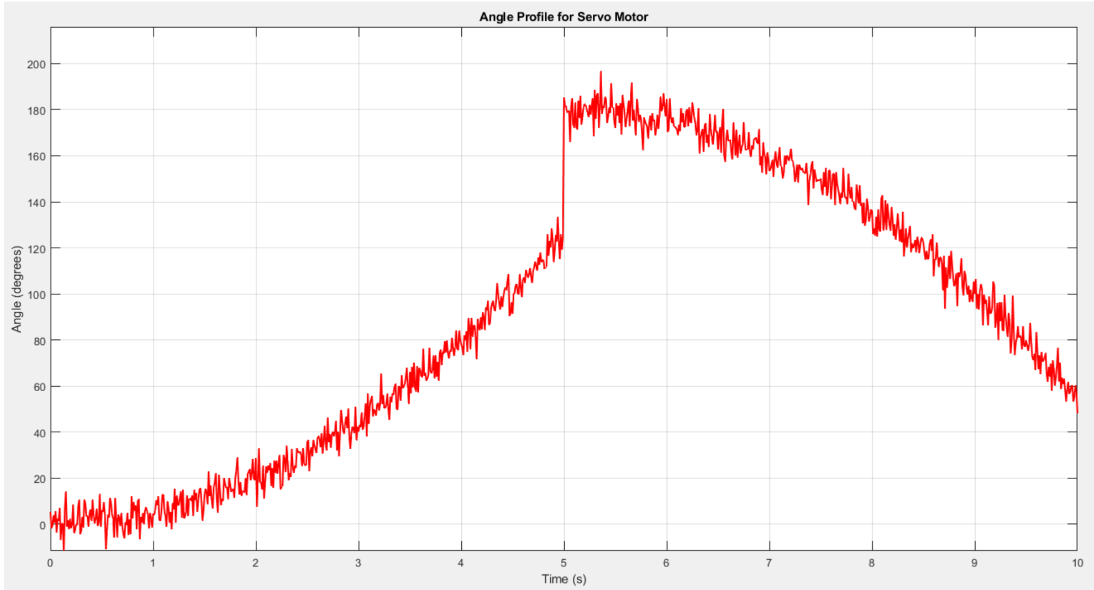

Figure 14. Angle profile of servo motor

The servo motor angle profile graph (Figure 13) is instrumental in dictating the precise positioning of our tree climbing robot's gripping and motion mechanisms. It outlines how the servo motor's angle changes over time, crucial for ensuring accurate manipulation of the robot's components.

At the outset, the angle profile depicts a gradual increase as the servo motor rotates, initiating the gripping or motion action smoothly. This gradual rise ensures precise control over the initial movement, crucial for gripping or engaging with the tree trunk securely.

Upon reaching the midpoint of the profile, the servo motor achieves the desired angle, allowing the robot to execute its intended task effectively. This phase represents the optimal position for the robot's grippers or motion mechanism, ensuring precise and reliable performance.

Towards the end of the profile, the angle decreases gradually as the servo motor returns to its initial position or adjusts its orientation. This controlled descent ensures smooth and accurate repositioning, enhancing the robot's overall efficiency and effectiveness in navigating the tree canopy

2.2 Practical Implementation

Equipment

2x DS3225 25Kg/com torque servo motors- These will be used for the grippers.

1x 270 degree servo- This is to control the rotating mechanism. A high range of motion allows the mechanism to rotate more so than with a 180 degree servo.

1x Brushed geared DC motor rated at 12V - This will be utilized in the linear actuator to drive the rotation of the threaded rod, facilitating linear motion conversion. The gearbox allows high torque ensuring the robot climbs even with a payload attached.

1x Seeed Studio Seeeduino XIAO, Arduino Compatible Board- This micro controller was selected for its compatibility with the Arduino IDE and compact size.

2x VL53L0x Time of Flight sensors- These will be employed to detect incoming branches and transmit the corresponding signals to the micro controller.

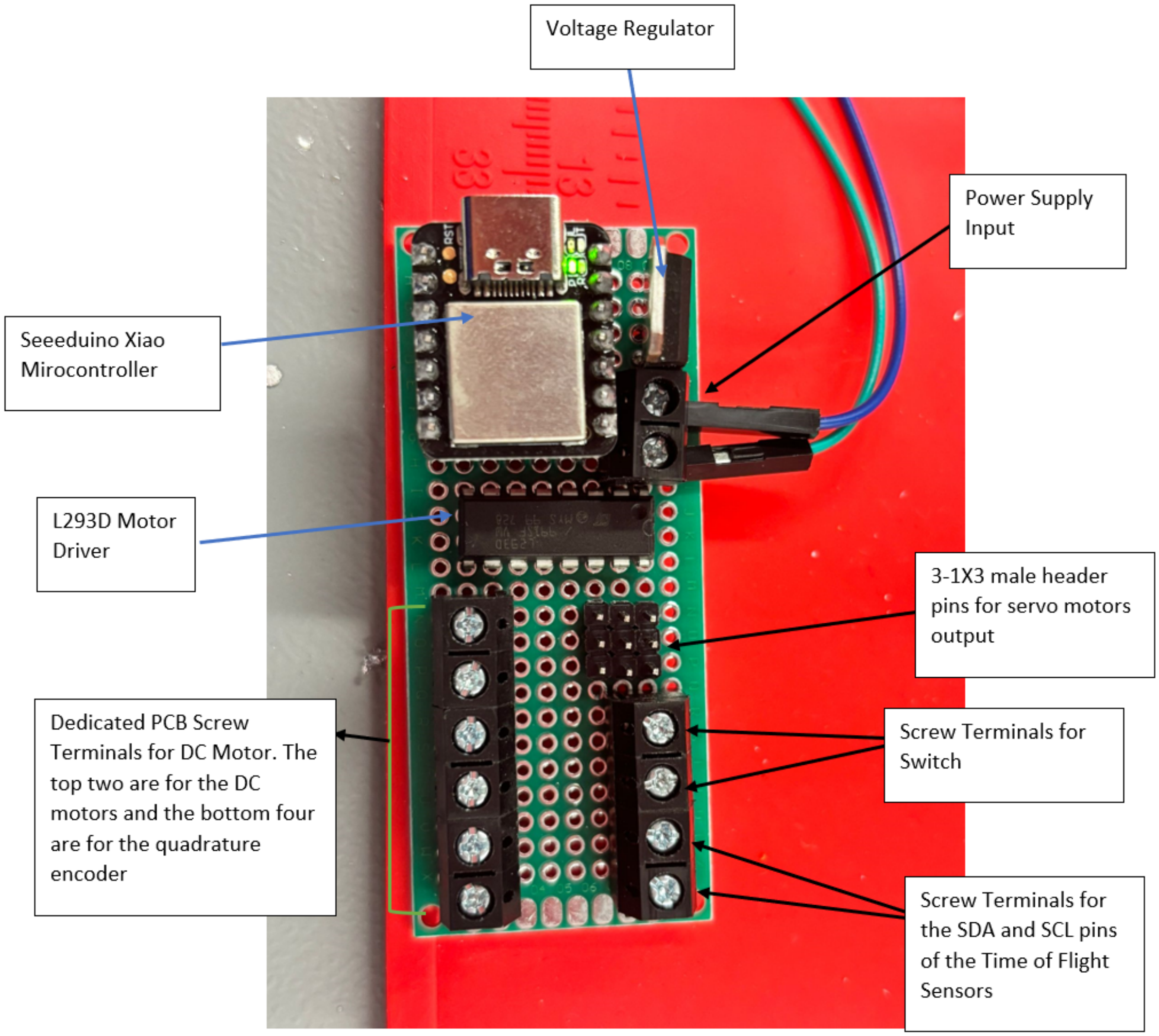

Figure 15. Prototype Board Soldering

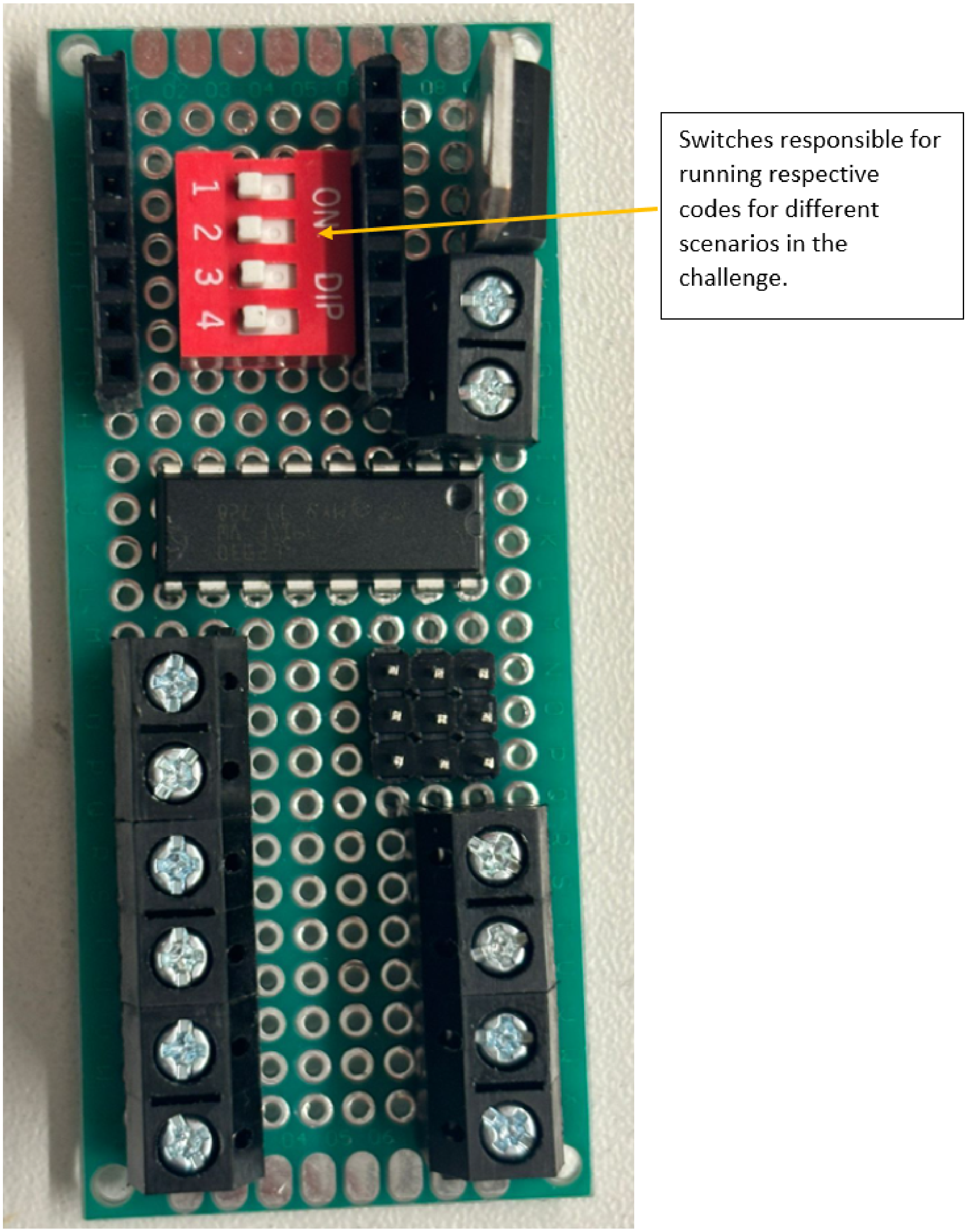

Figure 16. Prototype Board Soldering

These switches are carefully placed below the micro controller to serve as a safety and precautionary measure against unwanted or accidental activation's during specific tasks. This placement ensures that the micro controller provides an additional layer of protection.

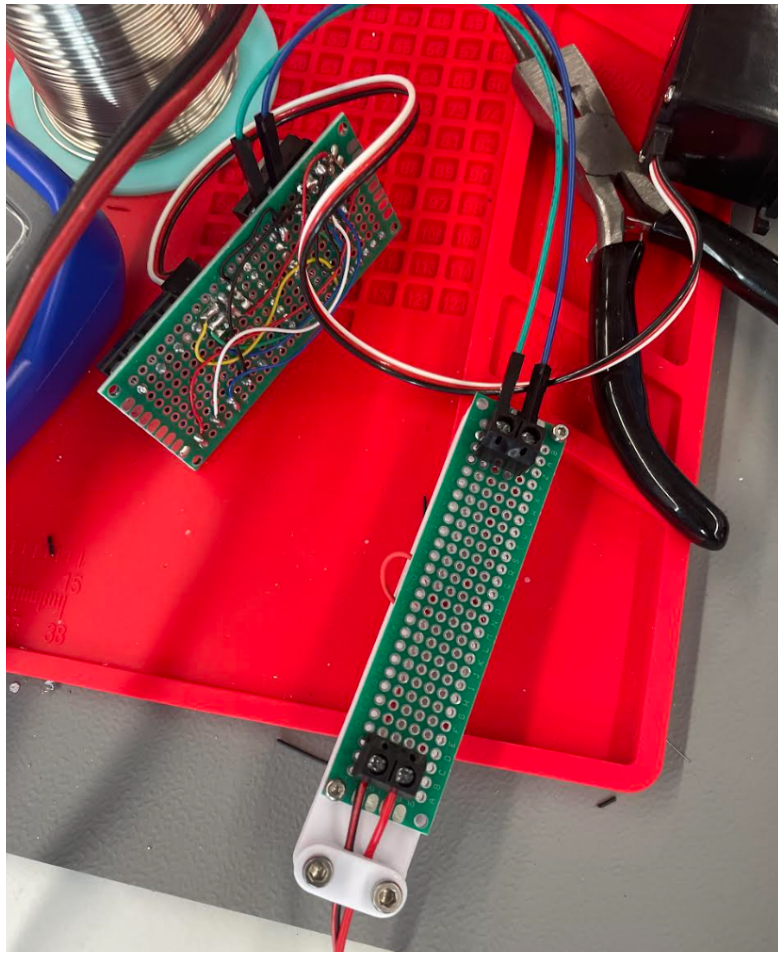

Figure 17. Prototype Board Soldering

Figure 14, 15 and 16 depict a well-organized Prototype Board setup for a tree climbing robot, equipped with various components critical for its operation. Here's a detailed description and technical expansion based on the provided components and their assembly:

Microcontroller (Seeeduino Xiao): Acts as the central processing unit for the robot, controlling the operations of motors and sensors based on programmed instructions.

L293D Motor Driver: This component drives the DC motors for the linear actuator, managing the direction based on signals from the microcontroller.

Voltage Regulator: Ensures that all components receive a stable and consistent 5V based on the input 12V power supply. Noise in the power supply does not translate into the system.

Power Supply Connections: Critical for providing the necessary power to the PCB and subsequently to all connected components.

3-1X3 Male Header Pins for Servo Motor Outputs: These pins are used to connect servo motors that control the two grippers and one rack and pinion mechanism.

Screw Terminals for Switch: Used for easy connection and disconnection of switches that are using in homing (accurately bringing the robot reach its initial position).

Screw Terminals for the SDA and SCL pins of the Time of Flight (ToF) Sensors: These terminals connect the ToF sensors that are used for detecting branches in the path of the robot, essential for autonomous navigation.

Dedicated PCB Screw Terminals for DC Motor and Quadrature Encoder: Provide robust connections for DC motors and quadrature encoder, ensuring secure and reliable electrical contacts.

Photos of Final Assembly

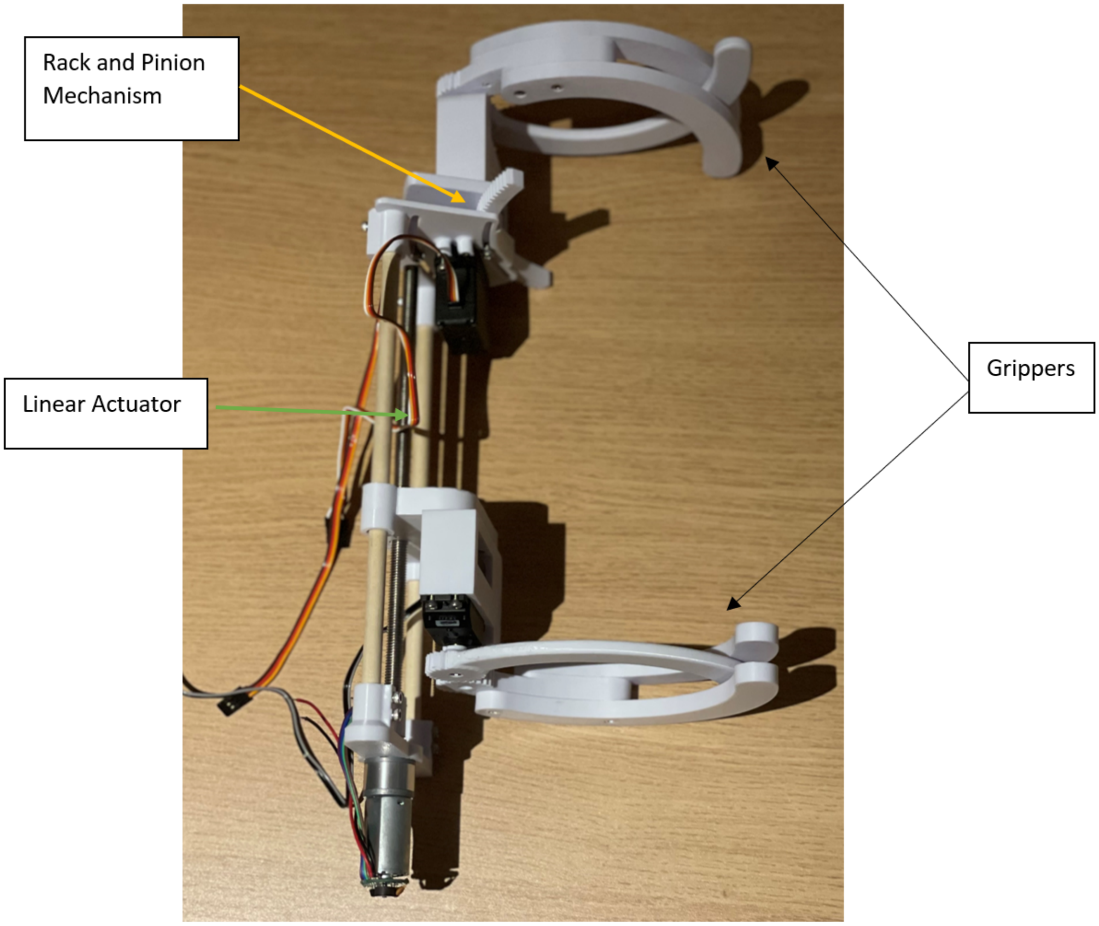

Figure 18. Final Robot Assembly

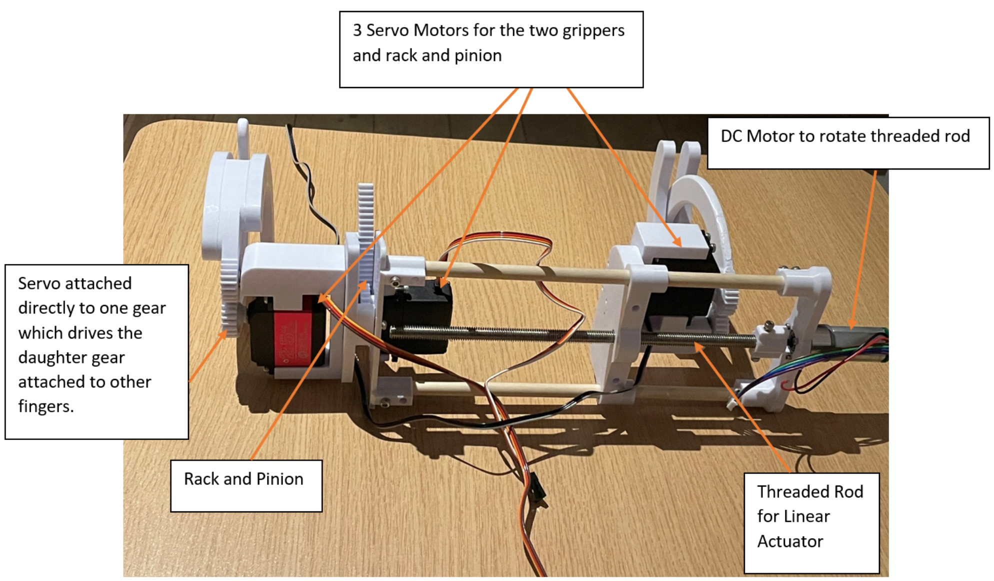

Figure 19. Final Robot Assembly

In Figures 18 and 19, the robot grippers were tested in various configurations using servo testers. Specifically, the upper gripper was closed while the bottom gripper was open, replicating the expected configuration during the robot's ascent of the tree (Figure 19). Additionally, in Figure 18, both grippers were closed, simulating the robot's resting position at the start and end of its operation.

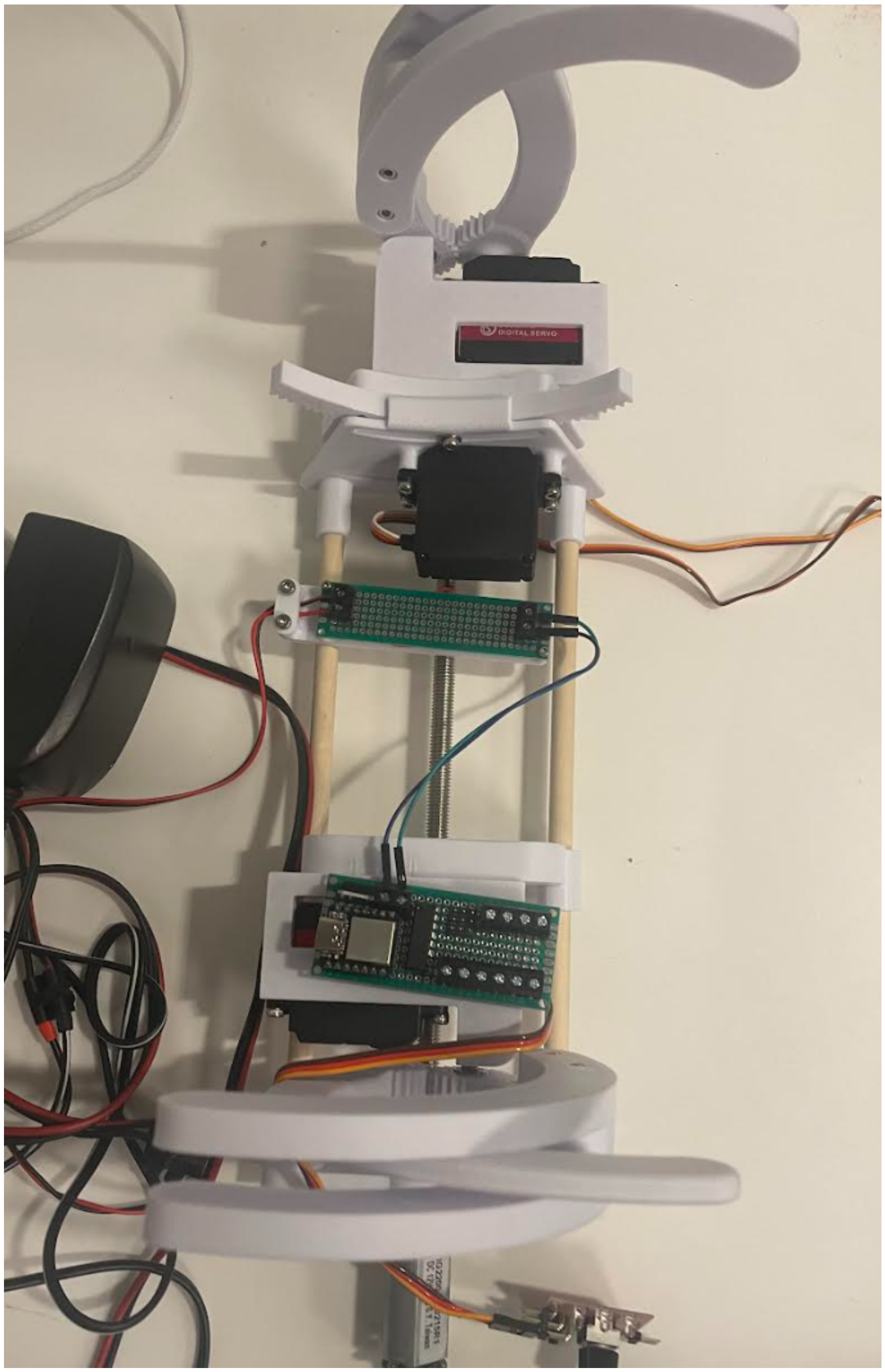

Figure 20. Configuration Check

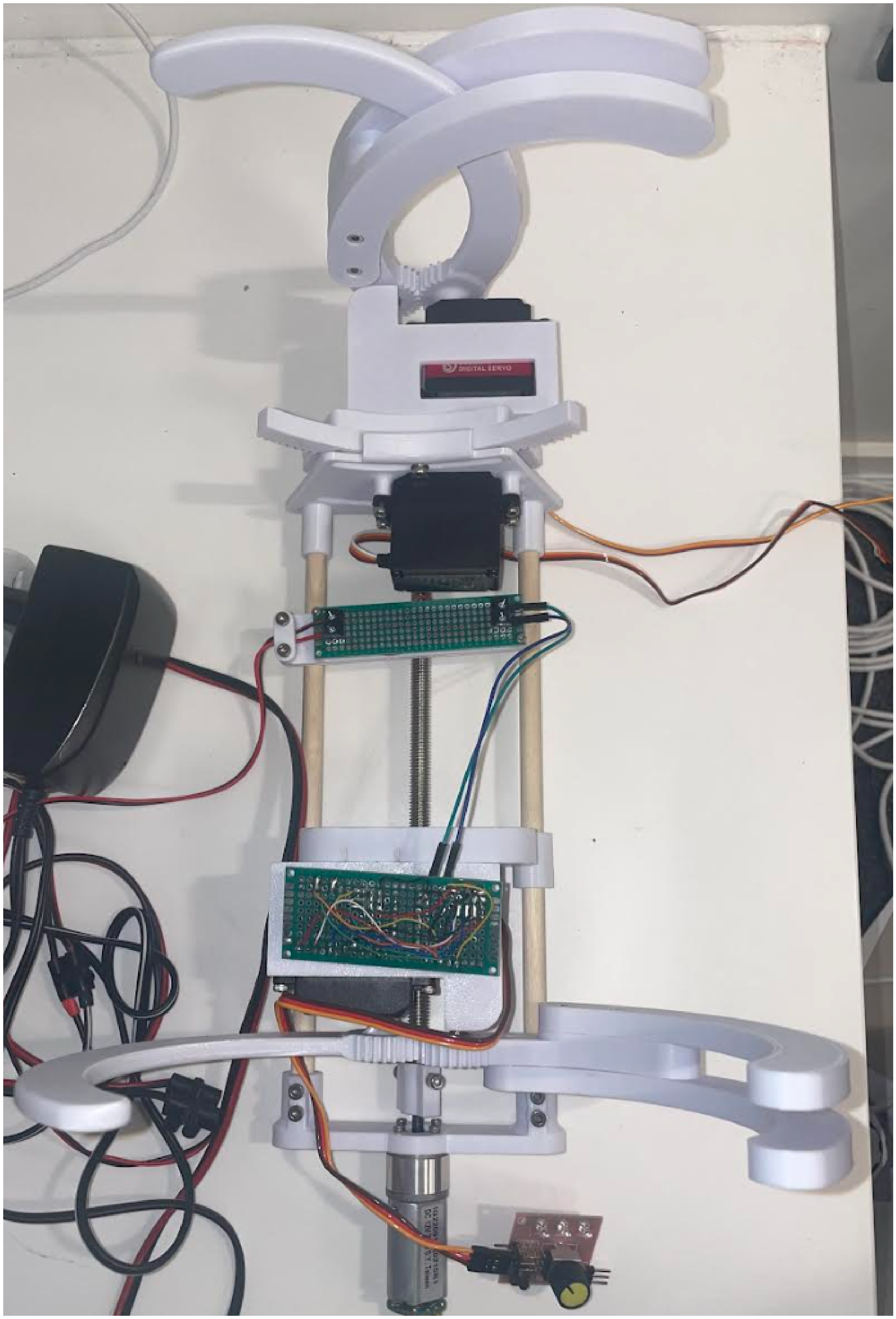

Figure 21. Configuration Check

Testing of Robot

In Figure 20, the gripper was tested on a smooth trunk to assess its holding capability and duration. The investigation revealed that while the gripper could maintain a tight hold, there were minor downward movements. Consequently, it was decided to add rubber strips to ensure a more secure grip. The robot was subsequently tested on various tree trunks (Figure 21) to validate this improvement.

Figure 22. Final Gripper Test

Figure 23. Final Robot Test

Overall, the manufacturing and electronics of the tree climbing robot presented a thoughtful and engaging challenge. The primary goal of the team was to avoid overcomplicating the 3D modeling, making efficient design choices, and ensuring the electronics were reliable and robust. We aim to see the robot perform effectively in all three scenarios.

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