Robotics Challenge- Interim Report

Kanav Mehta, Harmish Zala, Hassan Shahzad

ABSTRACT

In this report, we create a tree-climbing robot using grippers, a linear actuator, and a rack and pinion.

Keywords: Electronics, Microcontroller, Mechanism, 3D Modelling

1 MECHATRONICS DESIGN

1.1 Theory and Background

For the tree climbing challenge, we plan to employ three primary mechanisms to replicate caterpillar-like motion. These include two mechanisms for vertical movement and one for horizontal rotation around the tree, addressing the requirements of scenario 3. Our motivation was to integrate various mechanisms to achieve our goals efficiently without overcomplicating the design. We went through several iterations before finalizing our current approach. Initially, we considered using vertical and horizontal wheels for navigation, but the tree's surface made us rethink our design. Another concept involved a different type of movement with the grippers and spine: we planned for the lower gripper to rotate 180 degrees and position itself above the initial upper gripper. However, after thorough consideration of the tree's characteristics, we realized that this method may not be practical for scenario 3. Ultimately, taking into account the tree's parameters and the feasibility of meeting all scenarios, we decided to proceed with our current design.

For upward and downward mobility, we will use a dual-gripper system mounted on the tree trunk. Connecting these grippers is a spine that can extend and retract, powered by a linear actuator mechanism (Figure 1) that is used in the lifting and lowering of heavy objects. [4].

Figure 1. Linear Actuator [3]

To navigate around branches, we will incorporate a rack and pinion system (Figure 2) attached to the upper gripper. This system will allow the lower gripper to detach, while the upper gripper uses the rack and pinion to rotate, thereby pivoting the entire system around the tree trunk and effectively avoiding obstacles. There is another benefit of rotating the upper gripper which is that the sensors can better detect branches ahead. We employ a time of flight sensor capable of getting the distance to the nearest object however it has a limited 27 degree field of view. By pivoting the sensor around the center the tree we can detect branches slightly offset from the middle of the robot thus being better at navigating and avoiding branches [1].

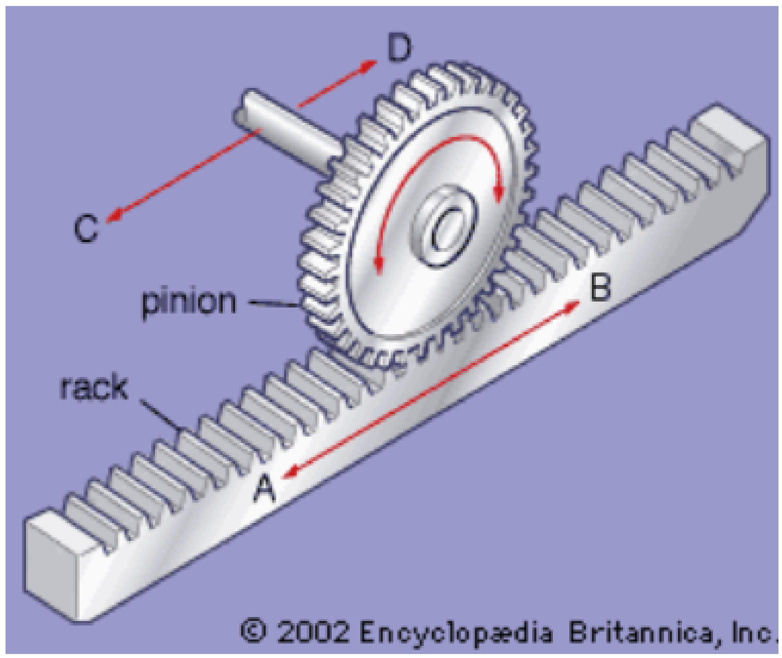


Figure 2. Rack and Pinion Mechanism [2]

Here are some images that summarize our mechanisms and motion when the robot moves up:

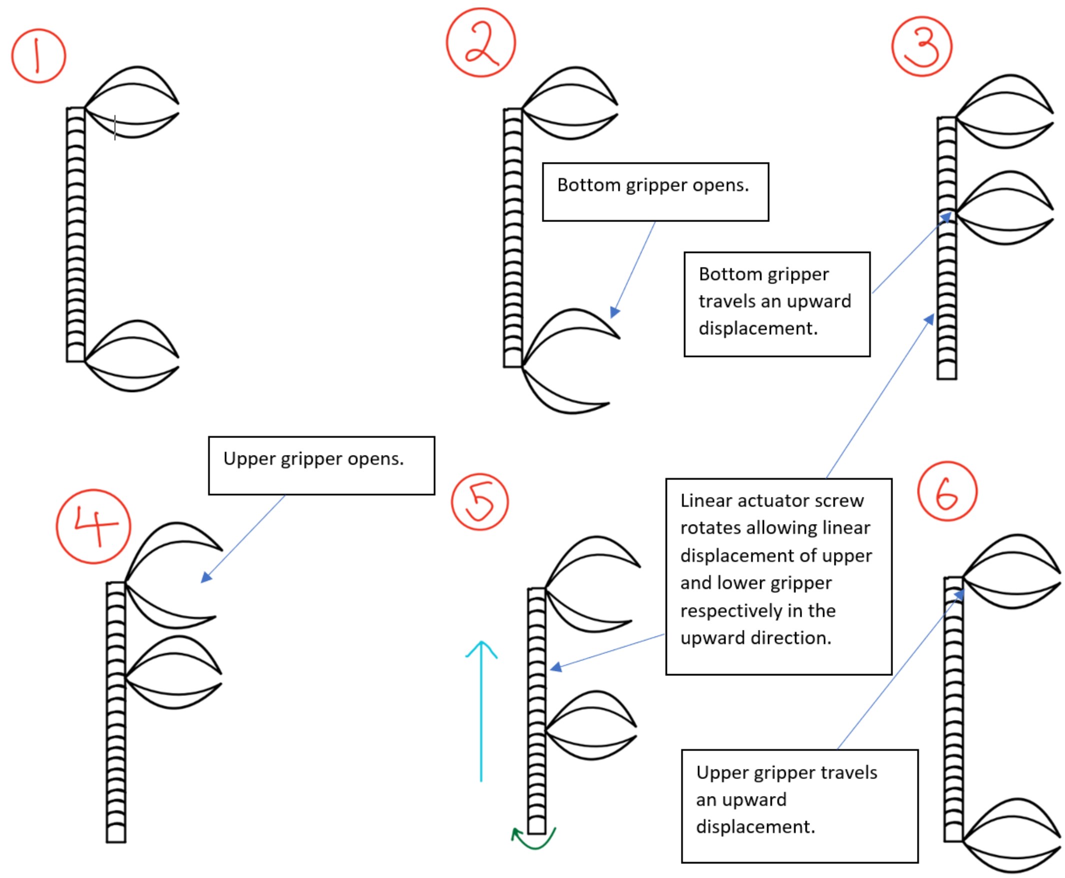


Figure 3. Summary of the Mechanism

Steps 1 and 6 represent the starting and ending positions of the robot, roughly covering the length of the threaded rod used in the linear actuator. Therefore, the length of the rod will be an important parameter in the design of the robot. Furthermore, to **move down**, the robot will follow the same mechanism but in the **opposite direction**.

Kinematics

The kinematics of the gripper mechanism, involving a spine that extends and compresses, can be analyzed using principles similar to those of a telescopic structure.

The vertical position of the robot can be mathematically calculated using the length of the spine D and the height of the two grippers (which will be constant) C.

$$h(t) = D + C \tag{1}$$

Considering the tree's structure and the fact that the spacing between branches is 30 cm, we will ensure that the vertical displacement h(t) remains within 30 cm. The value of D, which represents the spine's extension, will be adjustable and dependent on the length of the threaded rod involved in the linear actuator mechanism.

We are also focused on determining the number of rotations required by the DC motor to achieve a specific linear displacement, ideally equivalent to the length of the spine. To address this, we'll utilize a fundamental mathematical formula:

$$s = n \times p \tag{2}$$

where s represents the linear displacement, n is the number of rotations, and p is the pitch. With s and p being measured values, we can calculate n:

$$n = \frac{s}{p} \tag{3}$$

Having accurate values for s and p will enable us to program our DC motor optimally.

If w(t) is the angular velocity, the linear velocity v(t) of the actuator can be found by differentiating equation 2: s is the displacement so differentiating displacement with respect to time will give velocity, n is theta so differentiating theta with respect to time will give angular velocity and p remains constant.

$$v(t) = p \times \omega(t) \tag{4}$$

Understanding these equations will help in designing the control system, predicting the behavior of the actuator, and optimizing its performance for various applications.

It is also important to understand how the RPM of our DC motor will affect the angular velocity of the screw. Given the RPM of our servo motor r(t), the relationship between the RPM and angular velocity is:

$$\omega(t) = \frac{2\pi \times r(t)}{60} \tag{5}$$

This can be substituted into the linear velocity formula:

$$v(t) = p \times \frac{2\pi \times r(t)}{60} \tag{6}$$

This relationship clearly shows that higher the RPM of the motor, higher the linear velocity- an important information to be considered when designing the code for the electronic schematic.

Furthermore, the diameter of the screw plays a crucial role in the torque requirement. The torque needed to drive the screw against a load depends on the screw's diameter, thread pitch, and friction. Torque Requirement:

$$T = \frac{d}{2} \times F \times f \tag{7}$$

Where d is the mean diameter of the screw, F is the axial load on the screw, f is the coefficient of friction between the screw threads and the nut (In this case, the coefficient of friction f will be nearly negligible due to the application of lubricants).

A larger diameter can increase the torque needed because it affects the mean diameter (assuming thread depth is proportionate to diameter), but it can also reduce the strain per thread engagement, potentially reducing wear and increasing the efficiency by spreading the load more effectively.

Another important mathematical consideration we need to make before 3D modeling our gripper is the size and number of teeth of the actual gears that drive the range of motion for the gripper

Currently both gears are identical. Therefore, the gear ratio between the driving and driven gears is 1:1. This means the torque output is the same as the input torque (minus some loss due to friction), and the angular displacement is directly transmitted without change. However, if we decide to keep the parameters of the gears different:

$$\text{Output torque} = \text{input torque} \times GearRatio \tag{8}$$

$$\text{Output angle} = \frac{\text{input angle}}{GearRatio} \tag{9}$$

In these equations, input angle refers to the angular displacement of the servo shaft and the output angle refers to angular displacement of the gears attached to each halves of the gripper. This mathematical relationship will be important in determining the range of motion of our gripper. If we increase the gear ratio, it will require more rotations to cover a particular angle compared to when the gear ratio is decreased below 1.

Parameters

Width and diameter of the gripper- This will be important in the 3D modeling especially since we are given the approximate range of diameters of the tree trunk.

RPM of motors- This will be important in controlling the speed of the extension and compression of our linear actuator.

Pitch of the Threaded Rod- This will determine the linear displacement per revolution of the rod and is critical for calculating the linear speed and the torque required.

Diameter of the Threaded Rod in the Linear Actuator- This defines the range of movement the robot can achieve ie the maximum and minimum distance between the two grippers.

Gear Ratio of rack and pinion and the gears attached to the Gripper- They are crucial parameters because they directly influence the performance and functionality of the robot in terms of the torque conversion, speed control and load handling.

Number of teeth on the gears- This is important as it will vary the torque applied to the grippers.

Fillet radius of gripper- This is important as it helps reduce stress concentrations at corners and transitions, enhancing the mechanical durability and operational lifespan of the gripper.

1.2 Mechanical Design and Manufacturing

Design of the Gripper: The final design of the gripper represents the third version. Initially, the first iteration featured two fingers positioned on the same plane. This design led to a problem where the fingers would collide with each other as the gears operated, restricting their range of motion. The gripper was not able to grip the bark properly as well. In the second iteration, the fingers were set on separate planes to resolve this issue. However, this adjustment caused the entire robot to rotate when the gripper closed. Furthermore, in the design iterations, the gears were not fully aligned with each other and were only partially touching, making the parts less robust and durable in the long run.

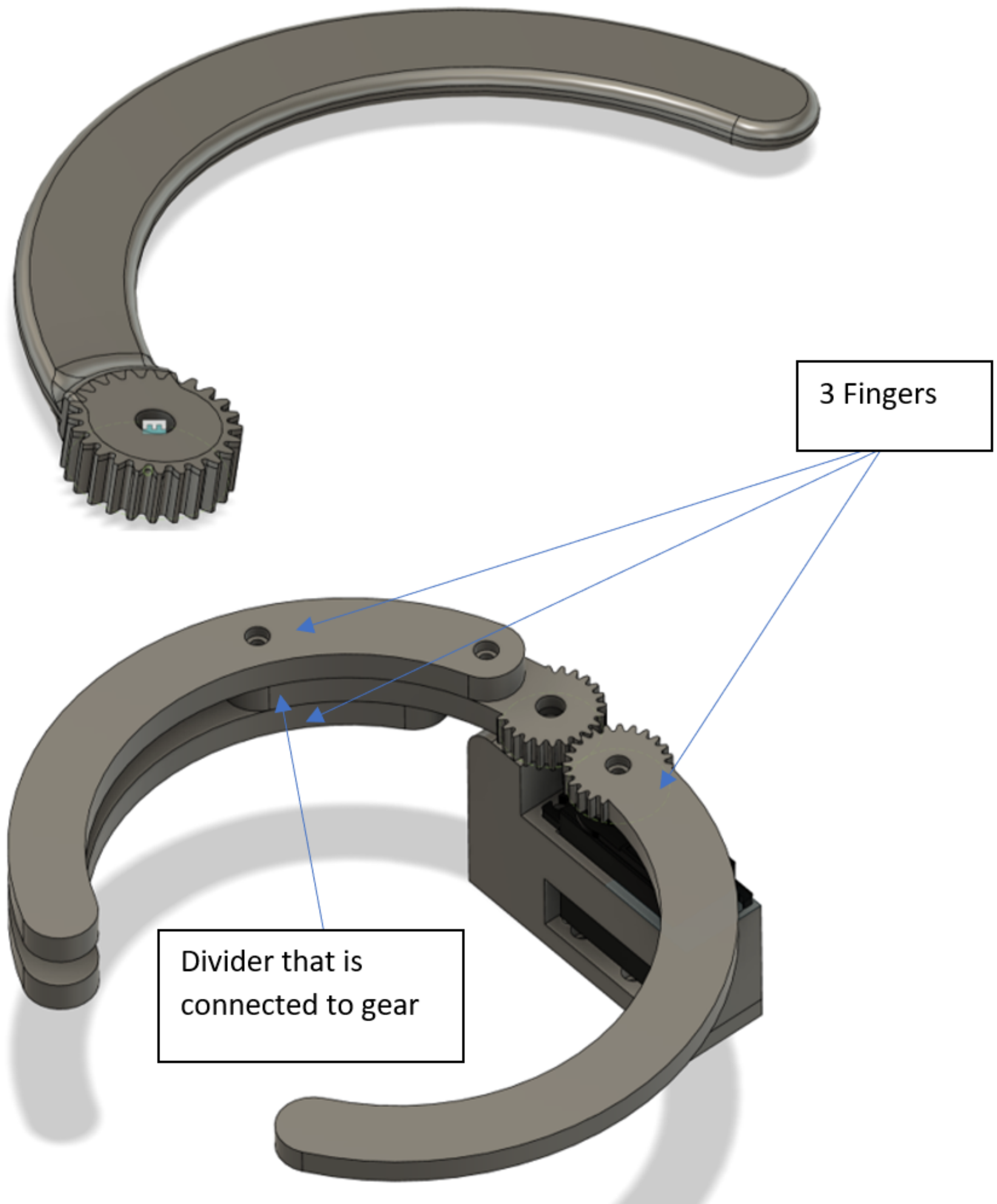
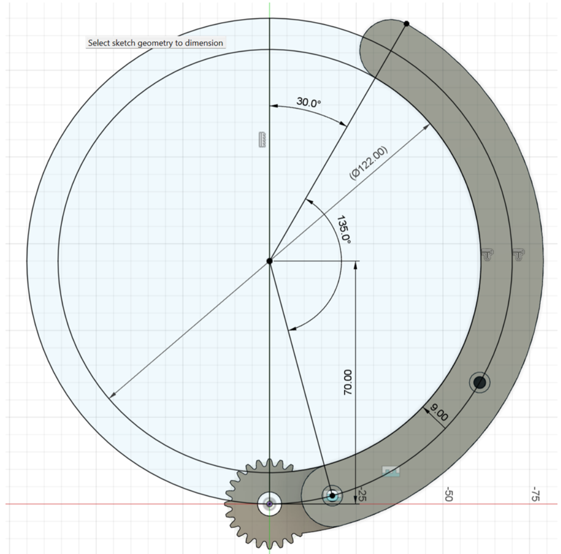


Figure 4. Gripper CAD

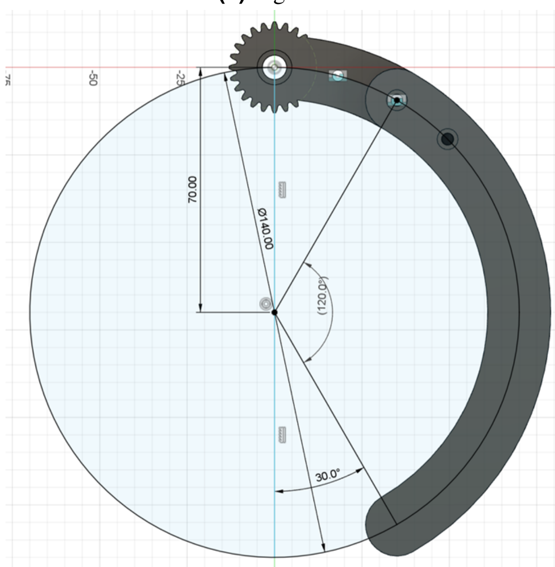
After careful thought, the final gripper design (Figure 4) is equipped with three fingers, arranged on different levels or planes: two fingers are positioned on one side and one on the opposite side. The fingers are attached above and below the divider. This configuration allows the gripper to securely grasp the bark. The single finger on the gripper is slimmer than the other two and has been filleted in Fusion 360. This filleting serves as a fail-safe measure to ensure that if the hands collide, the smooth edges from the fillet will allow the hand to slide and close effectively. To avoid the rotation problem in the second iteration, the distance between the fingers were widened by modifying the middle section of the gripper with two fingers and adding a small divider (Figure 4) to prevent the slimmer finger from fully passing through. The gripper mechanism was also modified to include a bearing in order to reduce friction.

Furthermore, the side of the gripper with two fingers is connected to a servo motor through a gear, while the corresponding daughter gear is attached to the single-finger side. This system utilizes a simple setup consisting of just two gears instead of having a third gear attached to the servo. These gears operate with a 1:1 gear ratio, enabling them to move in opposite directions. This design choice minimizes the number of moving parts, enhancing the system's reliability and reducing friction. The symmetrical 1:1

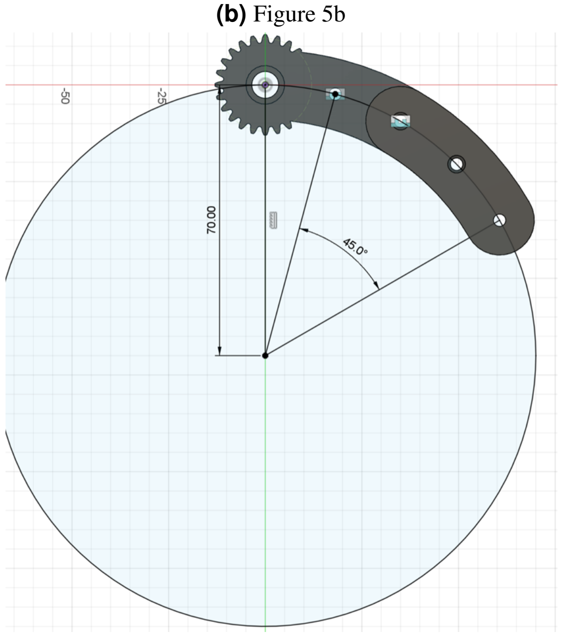
gear configuration ensures balanced and efficient operation. Furthermore, rubber strips will be attached to the edges of the fingers. This should increase the friction coefficient between the gripper and the bark, helping reduce the slipping of the robot. To calculate the length and width of the rubber strip, the following CAD figure can be referred to:



(a) Figure 5a



(b) Figure 5b



(c) Figure 5c

Figure 5. CAD of Fingers

Figure 5 represent the dimensions of the different fingers of the gripper. Using the circumference formula, the length of the rubber strips can be found.

Finger 1/ Figure 4c (Radius: 61mm, Angle: 45 Degrees) :

$$\left(\frac{\pi}{180}\right) \cdot 45 \cdot 61 = 48\text{mm} \tag{10}$$

Finger 2/ Figure 4b (Radius: 61mm, Angle: 120 Degrees) :

$$\left(\frac{\pi}{180}\right) \cdot 120 \cdot 61 = 127\text{mm} \tag{11}$$

Finger 3/ Figure 4a (Radius: 61mm, Angle: 135 Degrees) :

$$\left(\frac{\pi}{180}\right) \cdot 135 \cdot 61 = 143\text{mm} \tag{12}$$

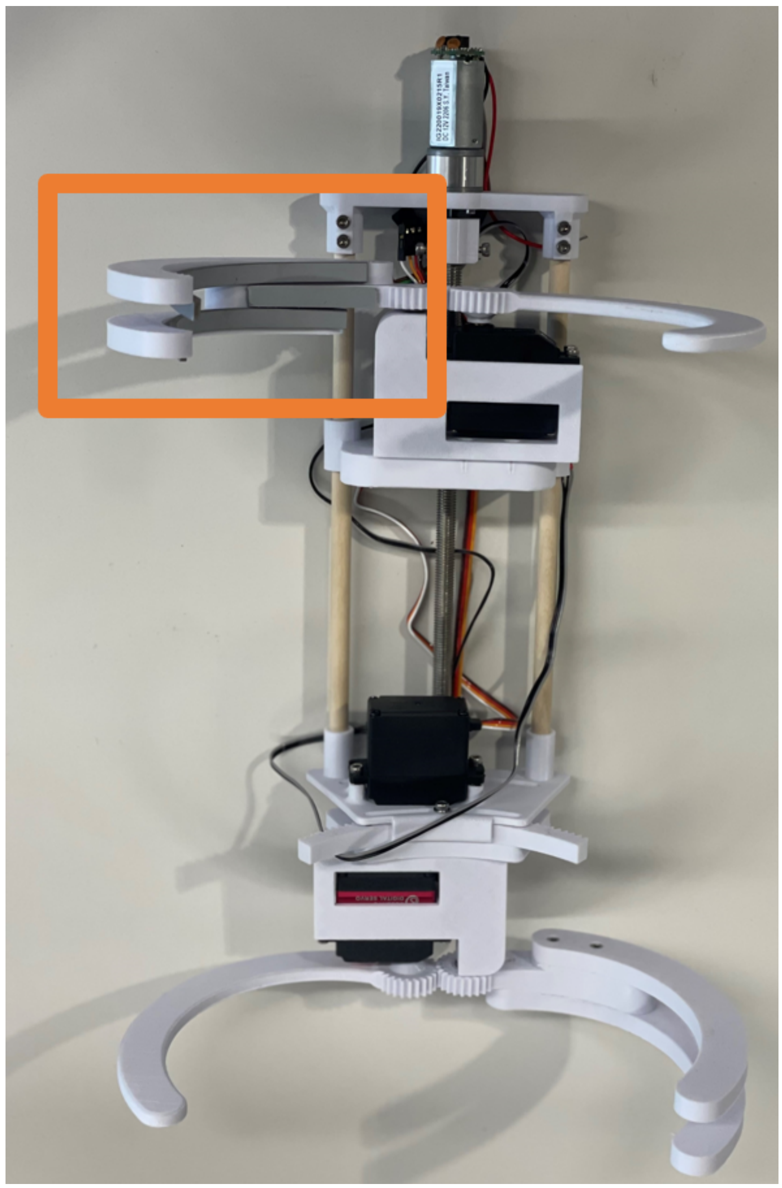
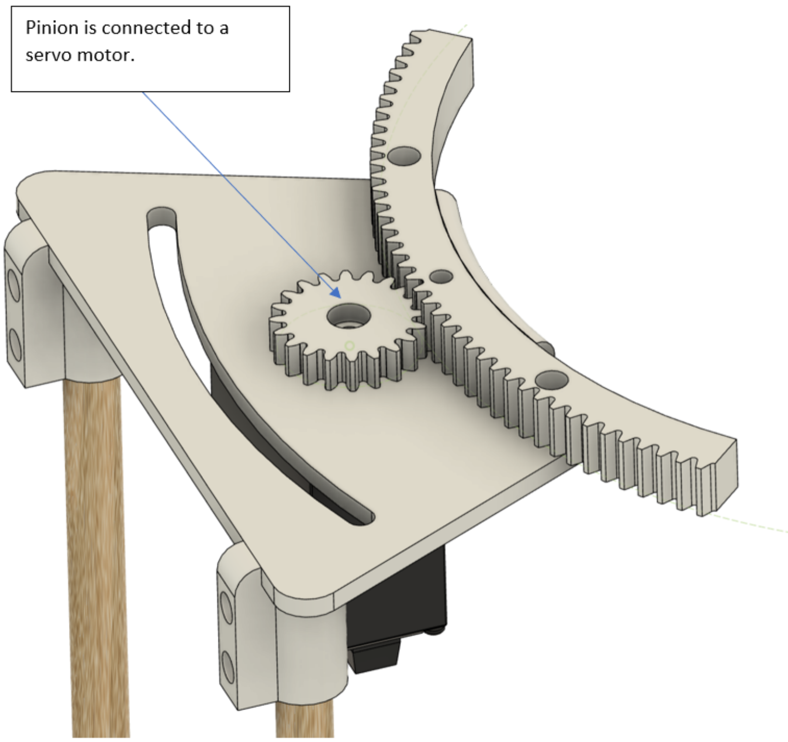


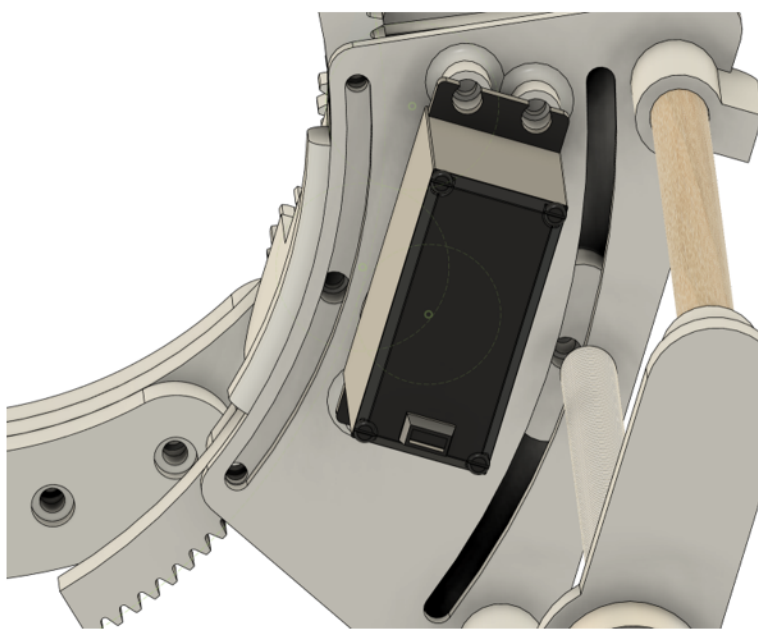
Figure 6. Rubber Strippers Lazer Cut

As seen in Figure 6, the length of the rubber strips fit accurately.

Design of the Rack and Pinion: The rack and pinion mechanism typically consists of two gears, with one gear extended and flattened into a linear form.



(a) Figure 7a



(b) Figure 7b

Figure 7. Rack and Pinion Mechanism

Given the curved nature of tree trunks, the mechanism has been adapted to include a curved rack (Figure 7). At first the rack and pinion only had one screw as support and was bending/lifting the rotating mechanism when the robot hanged. This was modified to have 2 screws as support and the contact where it touches the tree was curved to reduce the friction for the rougher material. The length of the rack was strategically selected to avoid encircling the entire circumference of the trunk. This design choice is critical, as a complete encirclement would restrict the mechanism's ability to bypass branches, thus a gap was intentionally included to enable this functionality. The rack and pinion has a gear ratio of 1:7 (1 being for the pinion and 7 for the rack). This was intentionally decided as the gear ratio indicates a mechanical advantage where the force exerted by the pinion is magnified. This means that every turn of the pinion amplifies the force exerted on the rack. This is particularly beneficial in applications requiring high force to move a load – in this case to maneuver around obstacles like branches. The increased torque allows the system to handle greater resistance or load with less effort from the motor. If the gear ratio was too high, while the torque would increase, the speed at which the rack moves would be reduced relative to the rotation speed of the pinion. This gear ratio was suitable for more controlled and stable movements, which is essential for precise navigation around the tree.

In addition to the rotation mechanism depicted in Figure 7, a structure to support the gripper must also be integrated at the top. Consequently, screws have been installed to facilitate this addition (Figure 8). Screws have also been added to allow the pieces to be printed separately reducing the need for support material, making the prints faster and wasting less plastic. This was an intentional manufacturing choice that was more efficient and environmentally friendly.

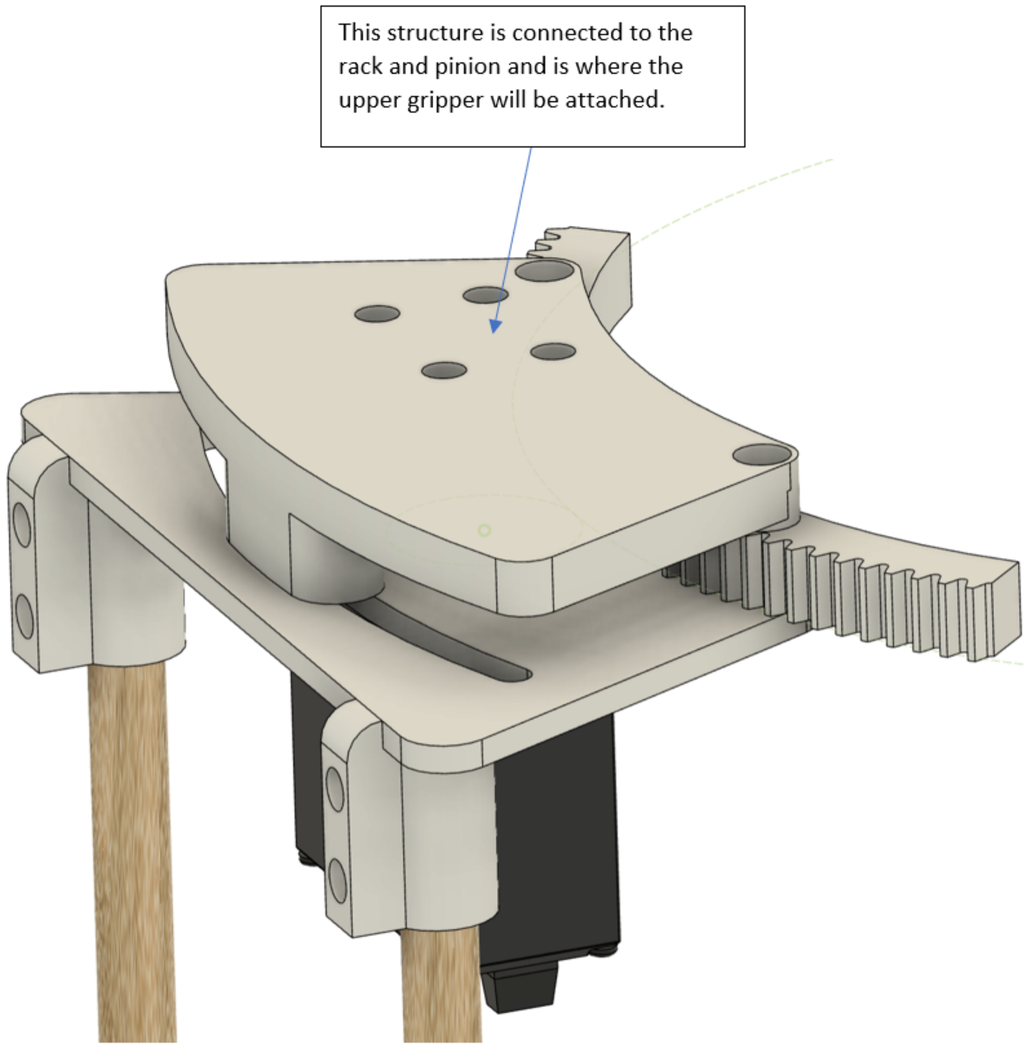


Figure 8. Rack and Pinion Mechanism

Figure 8 shows two circular slots that have been screwed into place. One slot accommodates the rack, while the other supports the gripper. When the bottom gripper releases, the upper gripper must bear the entire weight. The inclusion of these two screws is crucial for maintaining balance and preventing the structure from bending or collapsing. This arrangement was rigorously tested multiple times before finalizing the design.

Design of the Linear Actuator (Figure 9): The threaded rod has a diameter of 8mm and a length of 23cm. The length was intentionally chosen to be less than 30cm since the distance between each branch is around 30cm. This length seems appropriate and the most efficient in terms of the number of iterations the robot goes through to avoid each branch. If it was close to 30cm, then there would be a risk of collision. Conversely, a length shorter than 15cm would lead to inefficiency, as the robot would require multiple iterations— the bottom gripper releasing, moving up, and the upper gripper doing the same—resulting in extended time intervals between each branch interaction. The threaded rod is connected to the bottom gripper and controls its vertical movement. When the rod rotates in one direction, it moves the bottom gripper up. Once the bottom gripper grips the tree, it remains stationary even as the threaded rod begins to rotate in the opposite direction. Under normal circumstances, this reverse rotation would cause the bottom gripper to move down. However, because the bottom gripper is gripped and stationary, this action instead causes the upper gripper to move up. Essentially, the fixed reference position of the bottom gripper forces the entire mechanism, except for the bottom gripper itself, to adjust accordingly, resulting in the elevation of the upper gripper.

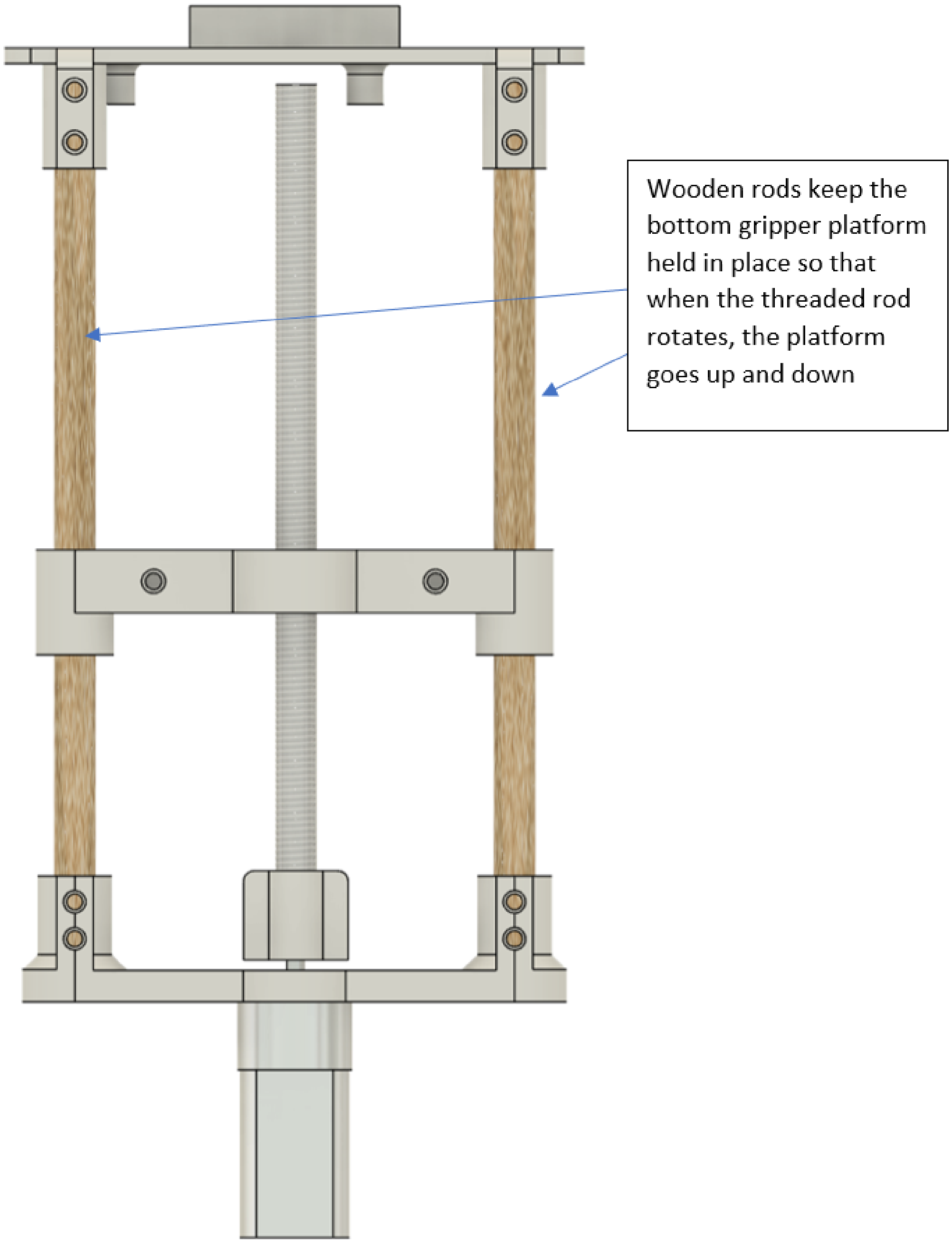


Figure 9. Linear Actuator CAD

Additionally, in Figure 9, the four screws at the top and bottom allow the wood rods to be held firmly in place. Without the screws, the robot could fall apart while hanging.

Figure 10 displays the final rendered CAD model for a better viewing and understanding of the final robot design:

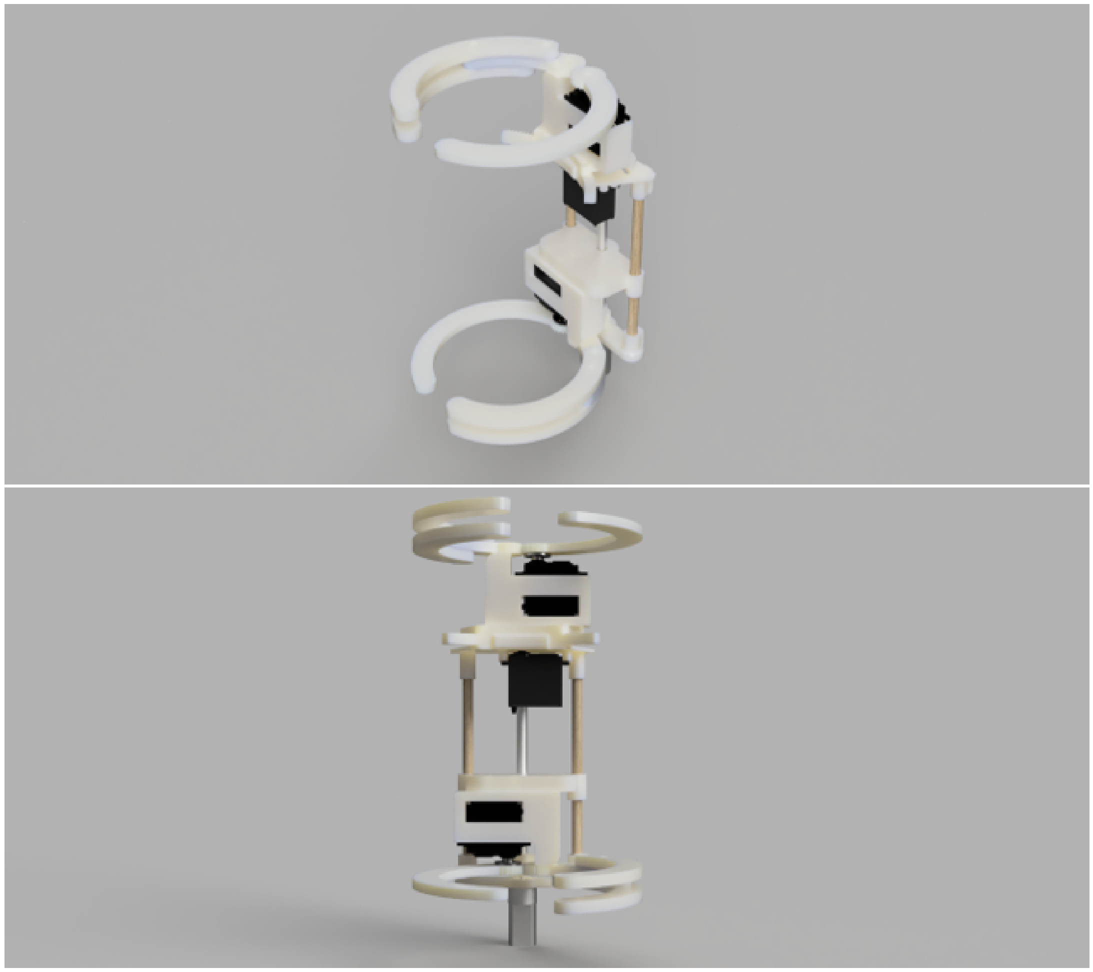


Figure 10. Rendered CAD

1.3 Ethics

Link to Digital Ethics Canvas: https://docs.google.com/document/d/17hzJeyRwOigLH2P5MNlP2-1goOHVNEbZdzQZc

The combination of the tree-climbing robot and the sensors equipped can raise some ethical concerns. Some potential misuses of the system include the ability to take photos and record audio. This can lead to concerns about surveillance, particularly if the robot operates in areas where individuals might expect a degree of privacy. This raises questions about consent and the appropriate use of recorded materials. Furthermore, handling the data securely, especially personally identifiable information (PII) or sensitive environmental data, is critical. All this data will be collected by the robot. There must be robust data protection measures in place to prevent unauthorized access and data breaches when the data is transmitted via 5G networks and stored on potential cloud servers.

During the design process considerations were made regarding the physical interaction of the robot with the trees. The design should prevent any damage, such as bark stripping or branch breaking, which could negatively impact tree health. This is why it was decided not to use any nails or sharp teeth on the edge of the gripper to enhance the gripping process, as it may damage the tree trunk. Therefore, during the 3D modeling, the edges were filleted to ensure smoothness.

Most of the robot's components were fabricated using 3D-printed plastic primarily for two reasons. Firstly, plastic's lightweight nature helps reduce the overall mass of the robot, which is crucial in scenarios where the robot navigates bends in the tree trunks. This careful consideration helps to avoid placing excessive strain on the tree, minimizing the risk of damaging or breaking it. Secondly, by opting to reuse non-biodegradable plastic, we are making a conscious effort to minimize environmental waste. Reusing plastics in this way not only helps in reducing landfill waste but also aligns with sustainable practices by