# Group 13 - Biomechatronics Robot Gripper Report

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## I. Introduction

The human hand is incredibly versatile, allowing us to do everything from handling objects in our daily lives to using gestures in social situations. Around 540,000 people in the U.S. have lost an upper limb, and this number is expected to double by 2050 [1]. In Italy and the UK, about 3,500 and 5,200 upper limb amputations happen each year [2]. Losing an arm or hand can seriously affect someone's ability to perform everyday tasks and lower their quality of life.

Recent advances in technology have led to more capable and dexterous prosthetic hands for amputees. However, there are still challenges when balancing dexterity with the weight, size, and cost of the prosthetic [3]. While robotic hands exist that can match the dexterity of a real human hand [4]–[6], their complexity makes them difficult to control. This complexity often results in heavier and more expensive devices, which are not ideal for everyday use by amputees who need something light, affordable, and practical for ADL.

## II. Related Work

Several types of prosthetic hands are available, from non-functional cosmetic devices [7] to body-powered [8] and externally powered options [9], which allow amputees to perform tasks in daily life. Prices for these prosthetics range from $4,000 to $75,000 depending on functionality [10].

The design of prosthetic fingers plays a crucial role in the overall performance of these hands. To create a simple yet functional bionic hand, two key elements are essential: an anthropomorphic structure and secure, stable grasping [11]. Current research highlights various performance criteria, such as shape adaptability, stability, and weight, as crucial factors for successful prosthetic hand design. Additionally, grasp control systems like those in the "Hand of Hope" project have focused on enabling essential grip functions while keeping costs low [12].

Recent trends in prosthetic hand design emphasize the use of simplified actuation and soft materials, which reduce complexity and weight while improving functionality [13]. Despite these advances, the challenge remains to balance dexterity, affordability, and practicality for daily use by amputees.

## III. Designs

### A. Inspirations and Considerations

During the initial design phase, simplicity was the primary focus. A two-fingered gripper was chosen, as it is the minimum required for actuated gripping from multiple directions, aligning with the goal of creating a practical yet functional device. While five-fingered designs were incentivized with bonus marks, the complexity of incorporating multiple finger types and advanced under-actuation mechanisms—requiring precise force distribution—made this approach less feasible given the project's scope and goals.

This decision aligns with broader trends in prosthetic hand design, where simplified actuation schemes and reduced complexity are prioritized to enhance functionality without overcomplicating the system [13]. Inspired by the Model T42 from Yale, an open-source two-fingered dexterous gripper, we utilized its design framework, including details on tendon routing, joint selection, and general design principles. This provided valuable insights into potential pitfalls and reinforced the emphasis on stability, adaptability, and weight, as discussed in current research [11]. These considerations helped ensure that the final design balanced functionality and simplicity, much like other successful prosthetic hands [12].

Each finger was decided to be cut into 2 segments, with the lower segment corresponding to the middle phalanx on a human finger, and the upper segment to the distal phalanx.

### B. Gripper Base

*1) Motor Housing and UR Attachment:* Using a publicly available digital CAD model of a Dynamixel 64AR, the frame for the motor was created. Initially, only half of the frame was used, but this was eventually updated to use every available screw hole in order to ensure that as the motor exerted a force on the object, the motor was as securely attached to the frame as possible.

Initially the motor housing was part of a large 3D printed base plate, along with the attachment point for the Universal Robotic (UR) arm. The 3D printing, and all subsequent prints, were performed in the University of Auckland Mechanical and Mechatronics labs. With PLA at 15% infill, each new base plate iteration would require an overnight print. To alleviate this, the motor housing and UR attachment point were separated out to be modular, attachable pieces using 3mm screw holes.

*2) Laser Cutting:* The manufacturing method for the base plate was switched from 3D printed to laser cut acrylic. The laser cutting was performed at the University of Auckland using available materials. As both the base plate, and the top plate consisted of large flat sections with cutouts, laser cut was utilised for both.

The base plate and the top plate were 150mm by 90mm rounded corner rectangles with 3mm screw holes at each corner to allow for a platform spacer to separate them out, providing an elevated surface with an area in between to

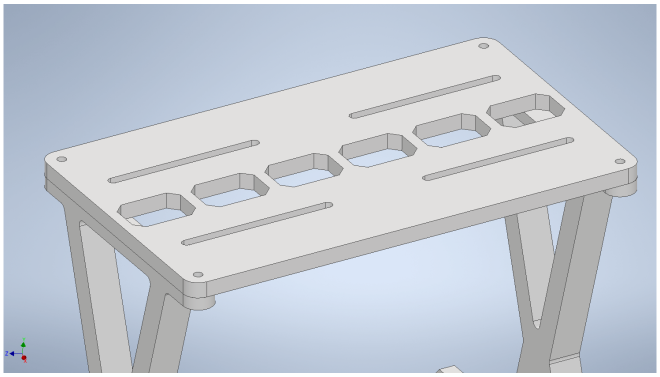

Fig. 1. CAD view of the top plate

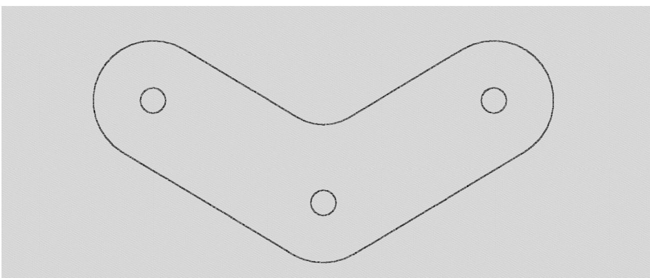

Fig. 2. Whiffle Tree top view

place the motor and tendon routing. The base plate had a further 12 3.1mm screw holes to allow for the connection of the motor housing, and any additional attachments.

The top plate consisted of a 2 parallel slots, 3.1mm wide with a series of holes along the centre. The slots, located 43.10mm apart, were used to attach the fingers. An adjustable positioning of the fingers allowed for fine tuning during the later testing sections. The CAD can be seen in Figure 1.

*3) Whiffle Tree:* In order to distribute the force across the 2 fingers, and allow for independent movement, a single linkage whiffle tree was utilised. The final whiffle tree used was 20mm across, with the middle slot for the motor winch connection in the middle, located 5mm lower than the other 2 slots to allow for a upwards, even distribution of force.

*4) Winch:* The winch was 3D printed. Made of 2 parts, one connected to the shaft coupling piece, and contained the section of the winch which the tendon was to wind about. The section piece was a friction fit on which the end of the tendon was tied to, and prevented the rope from falling off during winding.

*5) Gearing:* Initially, in an attempt to increase the overall strength of the hand to prepare for picking up the water bottle, a gear system was utilised. A 9-1 compound gear system was designed and printed, however it was found to be too difficult to drive due to the number of interlocking gears.

The design was altered to be a 2-1, 2 gear system. However, the space efficiency of the overall design was found to be too low.

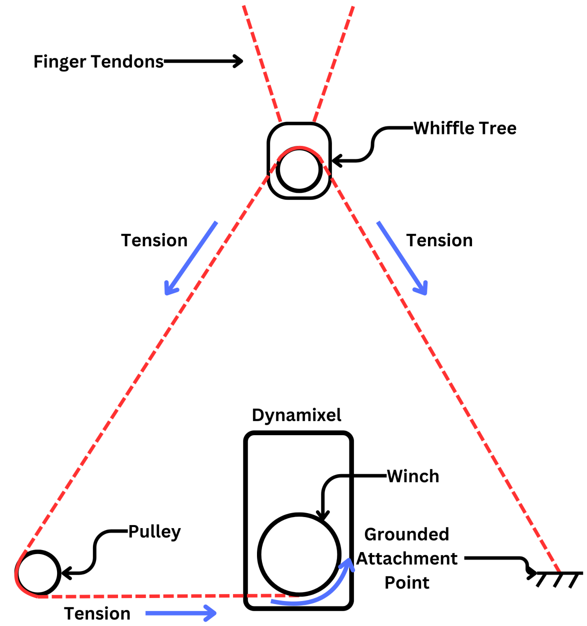


Fig. 3. Pulley mechanism

*6) Pulley:* A design for a pulley was made to perform the same job as the 2-1 gear system. Using the principle of mechanical advantage, the tendon was routed from the winch, through a pulley. The Whiffle tree linkage was used as a pulley, after which the tendon was grounded the opposite size to the first pulley. This creates a system capable of doubling the output force of the motor, whilst maintain space efficiency. The layout can be seen in Figure 3.

### C. Gripper Fingers

*1) Initial Motion Planning:* Before any computer modelling or 3D printing was done, MATLAB was used to map the movement of a 2 segment fingers joints. The forward transformation kinematic equations of a 2 Degree of Freedom (DoF) arm were used, seen in Equation 1. $L_1$ and $L_2$ represent the lengths of the middle and distal phalanges respectively. $\theta_1$ is the angle the middle phalanx makes with the horizontal plane, whilst $\theta_2$ represent the angle between the middle and distal phalanx.

$$\begin{aligned} x &= L_1 \cos(\theta_1) + L_2 \cos(\theta_1 + \theta_2) \\ y &= L_1 \sin(\theta_1) + L_2 \sin(\theta_1 + \theta_2) \end{aligned} \tag{1}$$

By adding an offset and inputting an array of angles into an animation, the movement of the fingers could be viewed. This provided an early way to quickly visual what the range of motion should appear as. With the knowledge of the size of the objects to be picked up, some early lengths and angle ranges were figured out.

*2) Design and Parametrisation:* In keeping with the MATLAB code allow for the input of a range of angles and segment lengths, a parametrisable approach was taken for the 3D modelling of the fingers. Using Autodesk Inventor Professional 2025s ability to input adjustable parameters for

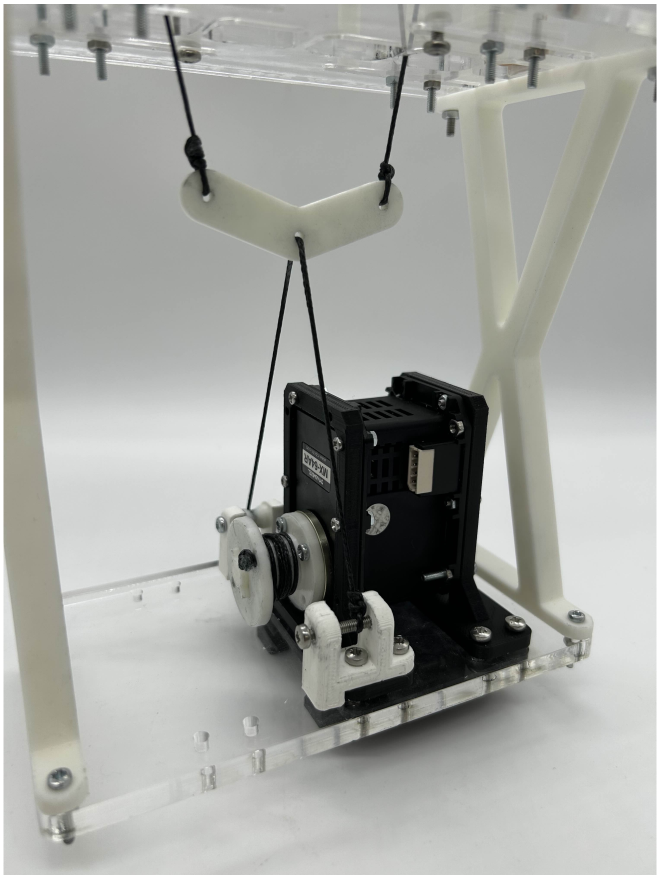

Fig. 4. Physical pulley setup

use whilst creating sketches, each element of the finger was quickly changeable.

This approach was kept consistent for every individual part of the, included the nail later implemented. Included in the parameters was the width of the segments, the size of the screw holes, the segment lengths, and the range of angles.

The overall design of the fingers remained largely consistent. 30mm metal rods, with a diameter of 6mm, were used as the pivots to create hinge joints. Bolts and washers were used to secure the rods for the pivots. The base and the distal phalanx acted as the outer pieces, with a space to place the middle phalanx into. This allowed for the middle phalanx, the largest and most complex of the segments, to have the smallest width. As the joint section of the middle phalanx was the widest, it was also used to restrict the range of angles the finger could perform. As seen in Figure 6, by extending sections tangentially to the hinged joint at the angles desired, the finger would be restricted to certain fully resting and fully extended positions, along both the base joint and the top joint.

Ensuring the finger would return to an open position once the motor was released required a restoring force. L-shaped extensions were added to allow for rubber bands to be connected. As the tendons tightened was altered, differently sized rubber bands could be used to create unique motions due to their ability to act as springs, and with the principle of

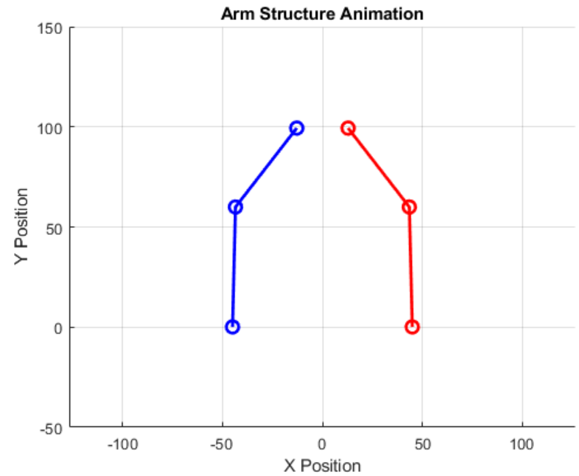


Fig. 5. MATLAB motion planning plot animation

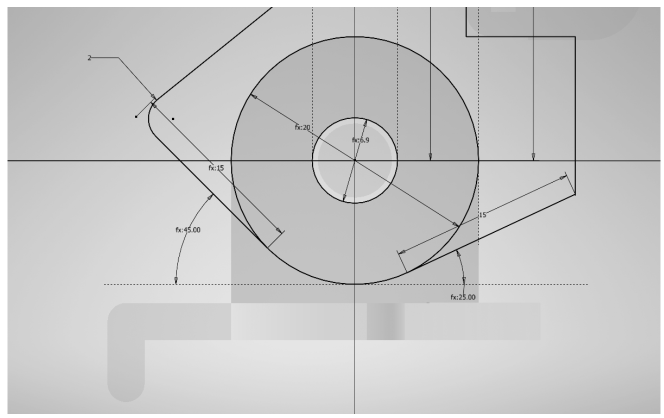

Fig. 6. Angular adjustment design

Hooke's law, $F = Kx$ where the force (F) was proportional to the spring constant (K) and the extension of the spring (x). Having a tighter connection between the distal and and middle phalanges (a higher K), with a looser connection on the bottom (a lower K), would cause the bottom join to move first. Once the middle phalanx had reached its final position, the tension in the tendon would act to overpower the tighter rubber bands on the top, allowing for extension to occur.

With the spring constants distributed in the described pattern, this provided the best motion for grabbing smaller items with the tip of the distal phalanx, whilst ensuring the fingers would still be able to wrap around the larger objects.

*3) Finger Tendon Routing:* Using the principles of torque about a pivot, $\tau = r * F$, the slots for the tendons were placed as far from the joint centre as possible, whilst attempting to keep the tendon perpendicular. The tendon was routed to the back of the middle phalanx after entering, to allow for a gripping section on the inner side of the finger. The tendon routed back to the inner side to ensure that once force was distributed through the tendon, the torque was applied to rotate the finger inwards. On the distal phalanx the tendon was routed to the back and secured. With retrospect, placing the securing point further from the join may have provided a higher maximum torque on the distal phalanx.

During the iteration process, the tendon routing remained the same, with slight improvements to make the process of routing easier. The holes were widened to make wiring new tendons easier and the exit points were made more perpendicular to the entrance holes.

*4) Iteration and Modularity:* During the iteration process, alterations were made to the sizing and movement range of the finger. The relaxed position was extended to sit in a more open position. The closed range was expanded to overlap across each other, with the intent of allowing a greater force distribution during the strength test, rather than limiting the movement to stop before the fingers touched each other.

To ensure the fingers could still be iterated upon whilst gripping moulds were developed in tandem, a slot was placed on both the distal and middle phalanges. The slot would remain the shape size whilst the finger was updated, provided a place for moulds containing the gripper material to be placed with in. On the opposite side of the mould ridges were added to allow for the use of a zip-ties to secure the gripping moulds down.

Doing so allowed for a modular swapping of the gripping sections. Once the best material was determined, it was possible to quickly swap parts out.

*5) Nails:* In order to pick up the smaller objects such as the washer and credit card, a nail was attached. This was deemed as necessary due to the compliance of the silicon, and the potential difficultly of ensuring it was able to scoop these smaller items.

2 holes were added to the back of the distal phalanx to allow for a 3D printed nail to be screwed down. Different nails could be printed and modularly swapped out. The nail was altered until a decent length and angle capable of approaching the nail on the opposite finger at an appropriate angle was found. The angle needed to be flat with the surface of the floor which the item being picked up on was. This allowed for scooping of the items.

During testing, it was found that the nails needed to be sanded down to provide a sharper tip for scooping the items. With careful tuning of the sanding amount, a sharpness was found suitable for picking up all the items.

### D. Grippers

*1) Initial Testing and Material Selection:* Several silicon materials were tested in the early iterations, for use in the gripping sections of the fingers. Basic moulds were made, and one batch of each silicon type was created in order to ascertain which materials would act as the best grippers, and learn more about what made a decent mould.

The trials revealed that VytaFlex-30 and VytaFlex-40 were the best for gripping material. VytaFlex-30 provided a compliant, flexible pad suitable to moulding around non-uniform shapes. VyrtaFlex 40 was less compliant, but provided a stronger gripping section less prone to shearing. PMC 770 was far less compliant and more resistant to flexure, making it less suitable as a gripping material.

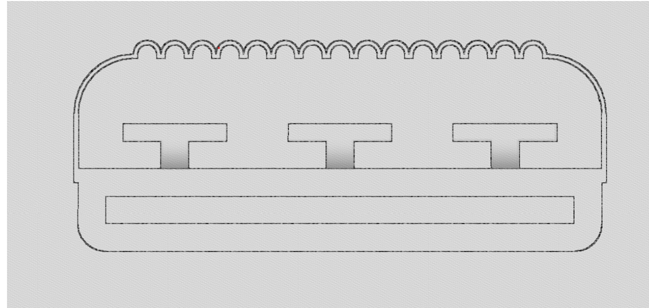

Fig. 7. CAD view of silicon mould

Early on, it was considered to use flexure joints using the PMC 770, however due to the to the trial and error which would come with attempts to define the strength of each pivoting point, and the range of available motion. Pivot joints provide far easier motion control in conjunction with the use of rubber bands, acting as an adjustable spring force.

*2) Mould Design:* The design principle used for the moulds was to use a 1 layer thick wall and floor. The wall could contain shapes such as ridges, as the ridged shape could provide an additional aspect of grip and compliance. Within the mould was a T-shape, designed to provided a way for the mould to stay stuck to the shape once the wall had been removed.

Early testing showed that the fingers were too thick to allow for the top of the distal phalanges moulds to approach each other whilst perpendicular to the floor. To alleviate this, the mould was extended to wrap up and around the tip.

*3) Attachment:* To allow for zip-ties to connect the gripping moulds to the finger, a slot was implemented onto the side of the mould. A simple solution to attachment, it allowed for a secure connect with the ability to easily swap out.

This proved useful towards the end, when it was found that having different mould types on each finger greatly assisted in the ability to pick up the hammer and the spanner. Having once finger act as a more secure wall, whilst the other fingers grippers moulded about the other side made picking up heavy, flat, complex shapes far more feasible. VytaFlex 40 was used on one side adn VytaFlex 30 was used on the other.

*4) Palm:* The palm consisted of a rectangular flat VytaFlex 30 pad. Spacers were added to raise the pad to a position where the water bottle would be pressed against the pad whilst the fingers were closed. It was found that having the palm pad greatly assisted in the ability to hold the water bottles weight without the finger grippers shearing off.

*5) Final Finger Design:* The dimensions related to the final finger design can be found in Table I. relating to Figure 8. Although $L_2'$ was never an initial part of the design, it had a large significance in determining the full range of motion. A side view of the CAD can be seen in Figure 9.

| Dimension Table | |
|---|---|
| **Parameter** | **Value** |
| $\theta_{BottomLimitBack}$ | 45° |
| $\theta_{BottomLimitFront}$ | 25° |
| $\theta_{TopLimitBack}$ | 5° |
| $\theta_{TopLimitFront}$ | 60° |
| $L_1$ | 60 mm |
| $L_2$ | 38.5 mm |
| $L_2'$ | 60 mm |

TABLE I
STYLISH TWO-COLUMN TABLE WITH DIMENSIONS

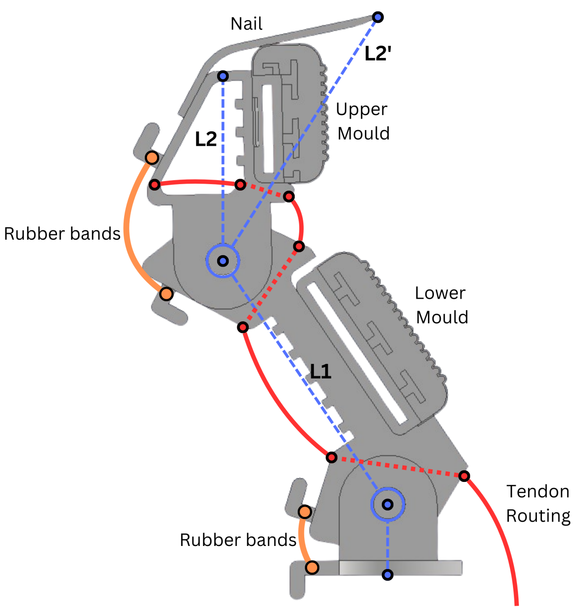


Fig. 8. Overall design setup of finger

## IV. RESULTS

Table II showcases how the hand performed across the range of items it was tasked to pickup.

As shown, it was able to pick up every item demonstrating a high level of versatility, and the feasibility to replicate a real hand.

A strength test was performed, where it the hand was able to reach a force of **50.4N**. The whiffle tree bottlenecked the strength, being the first item to break during this test. Although approximately 10-fold lower than what a human hand can achieve performing a similar test, this was still an impressive strength output from the provided motor.

## V. CONCLUSIONS AND FUTURE DIRECTIONS

The under-actuated design proposed, designed, ad tested proved to be a feasible gripper when tasked with picking up a diverse range of items, with varied shapes and weights. The iterative, parametrised, and modular approach to design the gripper proved vital in ensuring its success.

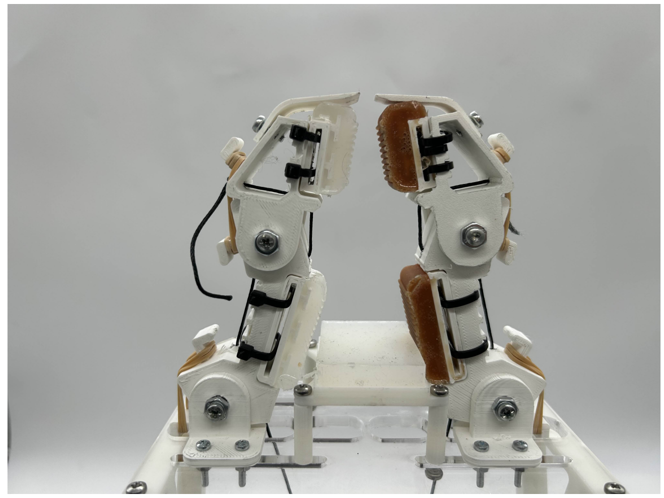

Fig. 9. Final grippers used in demonstration

| Item Pickup Demonstration | |
|---|---|
| **Item** | **Success** |
| Washer | Yes |
| Credit Card | Yes |
| Egg | Yes |
| Chain | Yes |
| Spanner | Yes |
| Hammer | Yes |
| Water Bottle | Yes |

TABLE II
TABLE OF SUCCESSFUL ITEM PICKUPS

### *A. Future Works*

Despite the success, there a several takeaways for future works in this area.

*1) Weight Reduction:* As a stand in for a human hand, the overall weight of the gripper weighed in on the higher size, at approximately 603 grams. Although below the weight limit, this would still prove too heavy to use as a stand-in for a hand replacement.

*2) Strength Increase:* The overall strength output of 50.4N, although decent given the situation, still remains far below what a real hand would realistically achieve. Further strength increases would be required to replace a real hand.

*3) Size Reduction:* Reducing the size of the base section with a tighter whiffle tree and pulley design would be ideal in future works. Although the full range of distance was utilised, a more efficient packing of room would make the design more comparable to a real hand.

*4) Biological Hand Mimicry:* Each of the previous desired improvements all lead themselves towards one goal: improved mimicry of a real hand. The most clear differences lie in the number of fingers. Altering the design to be a 5 fingered configuration would be the greatest alteration which could be made, involving a complete re-design of the hand. Although aspects of the current design could still prove useful in such a setup, ultimately much of what was done would require scrapping as the original design never aimed for a significant amount of biological hand mimcry.

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