

Mechatronics and Making Mid-Term Project Report Exoskeleton Robotic Hand With Wolf Claw Mechanism

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1 Project Objectives and Description

We examined the percentage of people who were victims of stalking in the last year, with 19.9% of women since the age of 16 suffering from this abuse, of which 8.05% were single women². This data highlights the significance of our mechanism, as it increases the safety of the victim when physically approached by the stalker. However, this mechanism would be considered a weapon with the intention of using it for self-defence, which violates the Criminal Justice and Immigration Act 2008⁵. Hence, to legalise our mechanism, we modified the dangerous component (the three wolf claws) into a blunt claw-shaped design made of PLA materials. With the aim of this mechanism serving as a cosplay prop and the objective of helping with self-defence- the self-defence aspect will be further examined in section 2.3, wolf claw mechanism comparison.

1.1 Similar Mechanisms

There are many applications of exoskeleton robotic hands in diverse fields (e.g. rehabilitation medicine) in which most of these exoskeleton hands are powered. Our mechanism is purely passive as it allows a lightweight approach and only relies on the user's instinctive movements. Powered exoskeleton robotic hands tend to have higher demands regarding control schemes and mechanical design (involving actuators).

The robotic hand should have the same DOFs as a human, yet given the compact size of the hand, it becomes impractical to actively control every joint³ when the complexity of the control algorithms increases with the DOFs in a powered exoskeleton robotic hand. Thus, some motions are left passive (passive DOF), power and control signals of the hand must also be routed such that it does not interfere with motion of arm, where we will be placing the wolf claw mechanism. Taking the increased mass and inertia into consideration, we have decided to design our mechanism in a purely mechanical way since there is no reliance on power source and is less susceptible to technical malfunctions.

A 1 DOF kinematic architecture⁴ has been used for the DIP (distal Interphalangeal joint) and PIP (proximal Interphalangeal joint) as it allows precise replication of the natural grasping motion.

1.2 Industrial Applications

The exoskeleton robotic hand of our mechanism is purely passive, providing support for the fingers and hand during tasks that require a sustained grip on tools for long periods. By redistributing the physical load from the fingers to the palm exoskeleton (connected to the wrist and arm) and supporting proper posture, the user is less likely to suffer from overuse injuries. This mechanism could be used for repetitive tasks, such as manual labour in construction, or it could be used in further designing or developing powered exoskeleton hands.

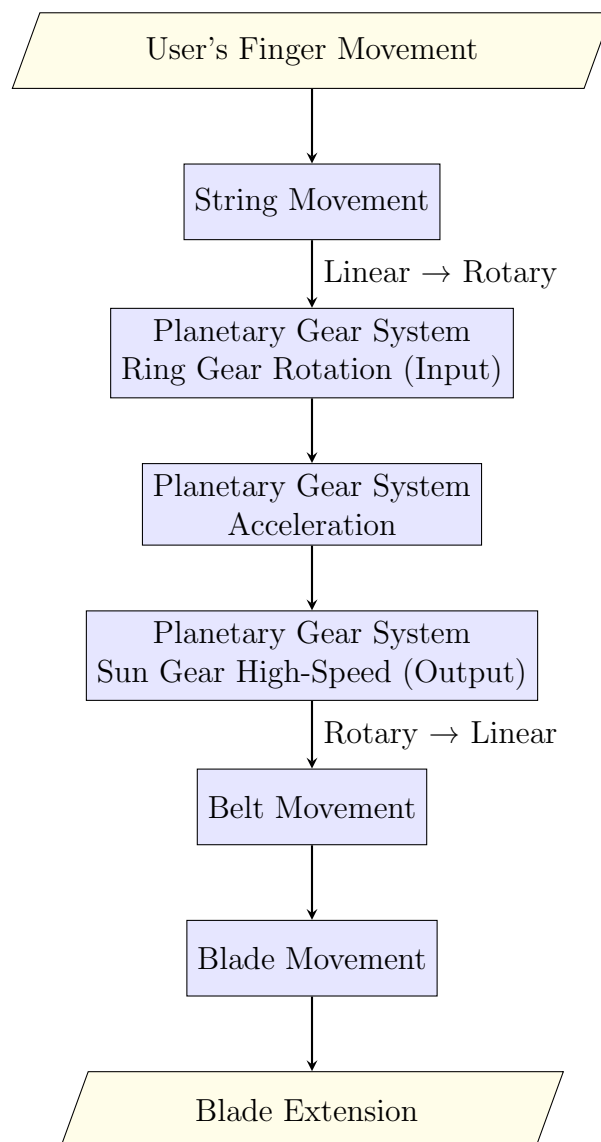
2 Mechanical and Mechanism Analysis

2.1 Drive Method and Transmission

This robotic hand exoskeleton uses an acceleration-based machinery system, amplifying the movements of the finger.

This is achieved using a planetary gear mechanism connected to a string transmission and a pulley and belt system.

Details of the transmission process shown below:



2.2 Hand Exoskeleton Mechanisms Comparison

2.2.1 Hand Biomechanics

The exoskeleton design is based on the anatomy of a hand (figure 1), consisting of 19 bones and 14 joints², excluding the carpal bones. The exclusion of the carpal bones (eight small bones in total) limits the extent the user's hand can bend whilst wearing this exoskeleton hand, this was deliberately chosen based on multiple factors such as the increasing mass and inertia of the exoskeleton, the noise generated from the movement of fingers and the limited space to securely link the carpal bones whilst not affecting the overall movement of adjacent fingers.

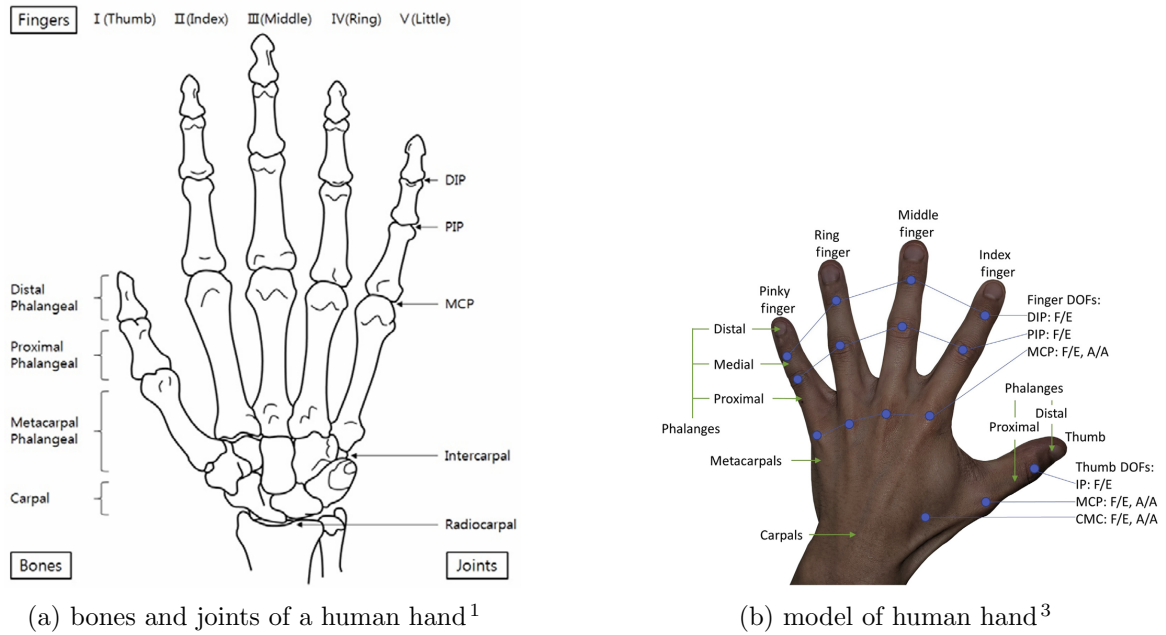


Figure 1: Human Hand

DOF of finger joints³

Metacarpophalangeal joint (**MCP**):

2 DOF (flexion/extension, abduction/adduction)

Distal Interphalangeal joint (**DIP**) and proximal Interphalangeal joint (**PIP**):

1DOF (flexion/extension), this is a 1 DOF kinematic architecture

Carpometacarpal joint (**CMC**):

2 DOF (flexion/extension, abduction/adduction), a saddle joint, allowing circumduction and opposition movements. There is a third degree of freedom in the thumb that enables axial rotation/opposition which we have not included as it is unnecessary for the aim and objective of our mechanism, increasing the mechanical complexity, mass and inertia.

The resting position for these joints is slight flexion, the exoskeleton hand must also be at this position when at rest to prevent joint stiffness and contractures and increases joint laxity, which is ideal for immobilisation and rehabilitation. In the resting position¹, the

MCP joint is in 35° – 45° of flexion, PIP joint being 30° – 45° , DIP joint: 10° – 20° .

Wrist Structure Analysis

The human wrist has 3 degrees of freedom: flexion/extension, radial/ulnar deviation and pronation/supination. Reflecting upon the objective of our design, we consciously excluded the pronation/supination rotational axis, which is where the forearm is rotated to turn the palm since this would lead to the user being injured more easily.

2.2.2 Selection of Mechanism Type

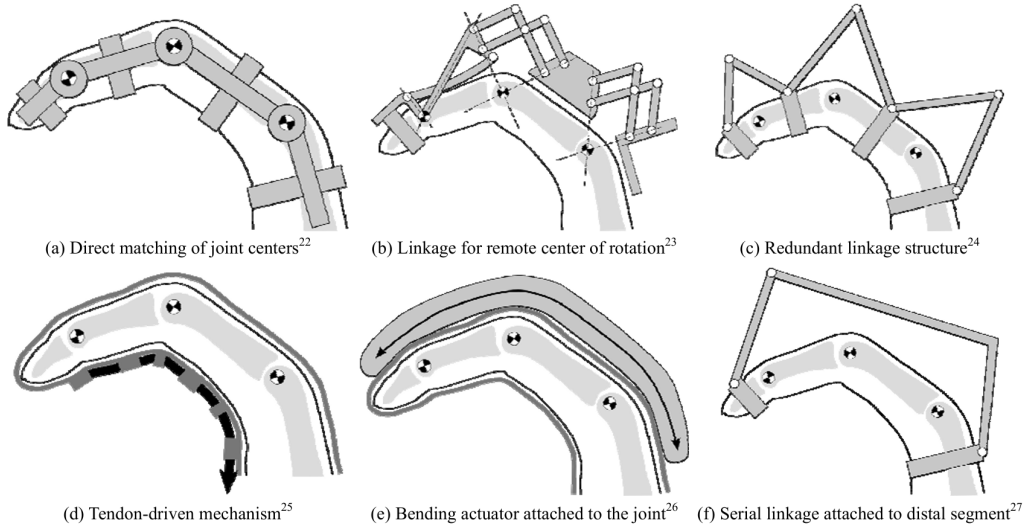


Figure 2: mechanism types¹

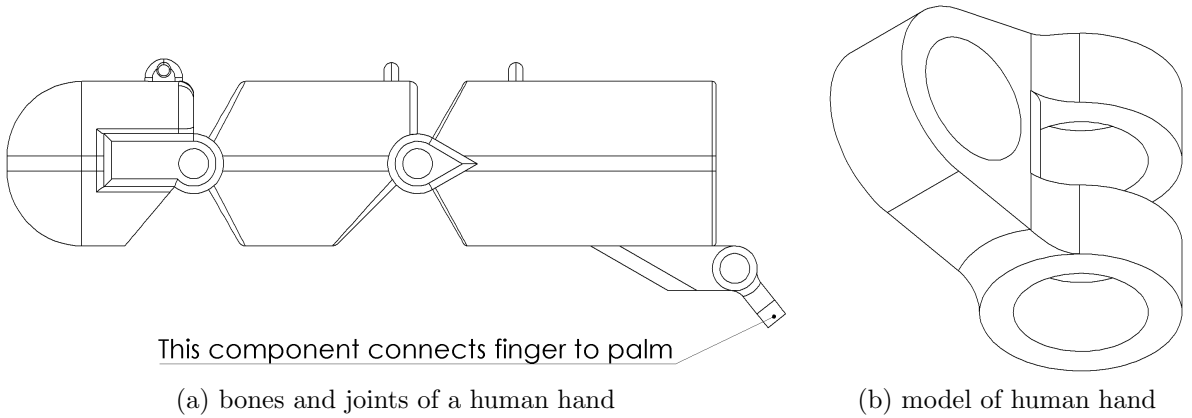


Figure 3: Human Hand

The direct matching of joints (figure 2) provides a structurally simple and compact solution, removing unnecessary components including complex actuation and additional linkages. This arrangement minimises mechanical complexity and simplifies fabrication and control, taking inspiration from this design, we have adapted this design to allow 2 DOFs for the MCP joint. This is achieved by connecting part of the MCP joint with

another component using a rod, with an identical component being linked to the palm exoskeleton (see figure 3).

For the objective to be executed safely, a physical stopper would be placed on both sides of the wrist exoskeleton to prevent the hand from bending backwards. The fingers are also at risk of bending backwards, hence, increasing the thickness of the palm exoskeleton and creating indentations would decrease the strain on the fingers by distributing the force over the volume of the indentations.

To further reduce this strain, a layer of rubber (or any material with a high friction coefficient) could be added to the tip of the fingers and the indentations in the palm. Consequently, we must consider whether the user would be able to clench their first quickly enough in a life-threatening situation.

2.3 Wolf Claw Mechanism

Design of wolf claw

Consider a wolf claw made of multiple sections:

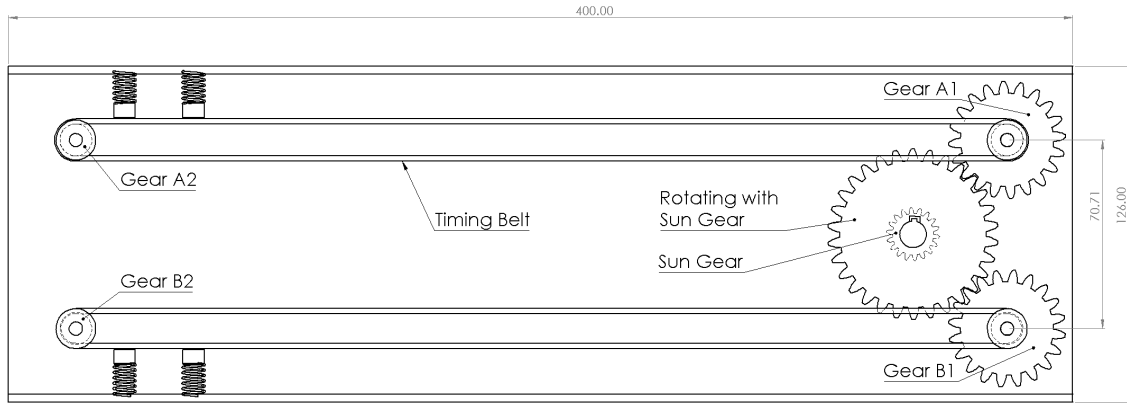


Figure 4: wolf claw blade movements section

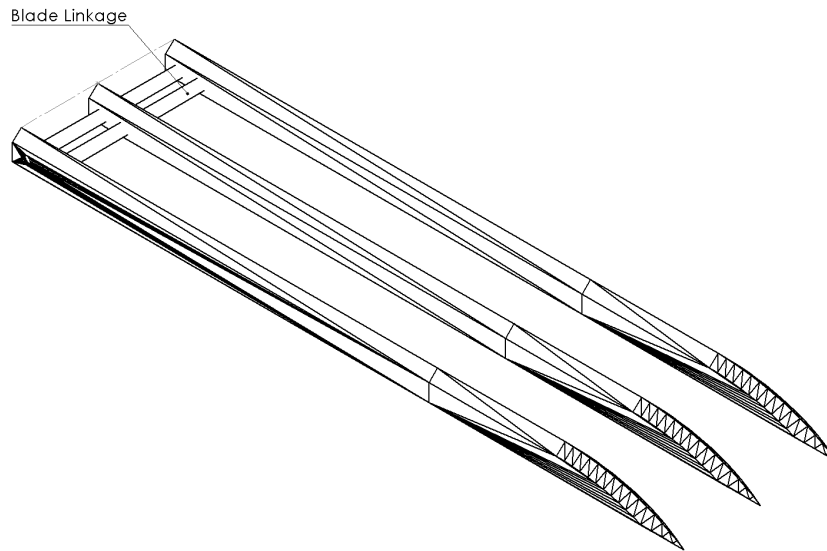


Figure 5: 3 blades

For this prototype the whole mechanism would be more portable due to these retractable features. For these retractable features to be implemented, the inner structure of each section of the wolf claw would be hollow, with only the tip of the claw being solid.

The main challenges in this include how each section is going to connect as the number of sections increase, thus each section becomes thinner and the room for connection between adjacent links being reduced. When this wolf claw is extended, it becomes difficult to ensure the same section of each wolf claw extends simultaneously, smoothly and securely. As a consequence of not having any supports in the wolf claw, there will be oscillations in each section, with the tip of the wolf claw oscillating the most. Reflecting on the objective of this mechanism, this prototype is ineffectual as the structure of this wolf claw would lead to the sections easily snapping.

Hence, we propose a different method, where each wolf claw is modelled as individual blades as it would still fulfil the intended purpose and objective. However, this approach would lead to the box containing the wolf claw mechanism being longer, problems that arise from this include how this box is going to be stabilised to the arm as it would be longer than a forearm of the average human.

The three blades (Figure 5) are connected by a square bar along the top of the blades, perpendicular in the direction of the blades. These blades are not sharpened as the purpose is to act as a cosplay prop but to fulfil the objective effectively, these blades would have a sandpaper coating and be non-backdrivable. To allow this non-backdrivable feature, a spring plunger is integrated at the side of the box, locking the two side blades in position. In this mechanism we aim to make the wolf claw retract semi-automatically, hence we modified the spring plungers (see figure 4) so that they can retract by applying force to the handle.

Transmission Mechanism Selection

The key feature of our design is sliding the wolf claws out, this achieved using a combination of planetary gears as part as a simple gear train. Another approach for the this would be using the structure of a compound gear train, let the two versions be versions one and two respectively. Both methods start with rotary-to-rotary motion, this is then converted from rotary to translational motion through the use of pulley and belt systems.

Version I: Planetary Gear

This version provides a higher gear ratio with a more compact and stable design but requires high precision in laser cutting and 3D printing as several components mesh into the same gear.

Version II: Compound Gear Train

This version is simpler to print and has a higher flexibility in gear ratios, yet there is a lack of stability in the blades as the centre blade drives the two side blades.

Therefore, we would use version 1 for our first prototype.

2.3.1 Version I: Planetary Gear

The light inextensible string would be connected to the ring gear of the fixed carrier planetary gear. Both the fixed carrier gear and the sun gear would be extended to a height of 7 mm, the fixed carrier gear would be fixed to the inside of top of the box. The sun gear will rotate together with another gear and mesh with gears A1 and B1 (shown Figure 4), which are identical and are fixed to the bottom of the box by screws. This forms a simple gear train, further increasing the overall gear ratio.

At the other end of the box, identical gears to A1 and B1 are fixed to the floor parallel to gears A1 and B1, let us call them A2 and B2. By using timing belts (shown in Figure 4), two pulleys and belts systems are formed between gears A1,2 and B1,2, allowing a higher

efficiency with no slippage whilst dampening noise. Challenges in this design being the timing belts being difficult to put together as the timing belts are required to be flexible for our design. When 3D printing each section of the timing belts, removing the supports was an arduous task with low success rates, hence we adapted the gears A1,2 and B1,2 as shown in figure 4 to use the open timing belts and timing pulleys in the innovation lab. The top section will allow the gears A1 and B1 to mesh properly with the sun gear, the bottom half would be glued into the timing pulley, meaning that gears A2 and B2 would just be a timing pulley with a fixed rod through the centre, fixed to the bottom of the box.

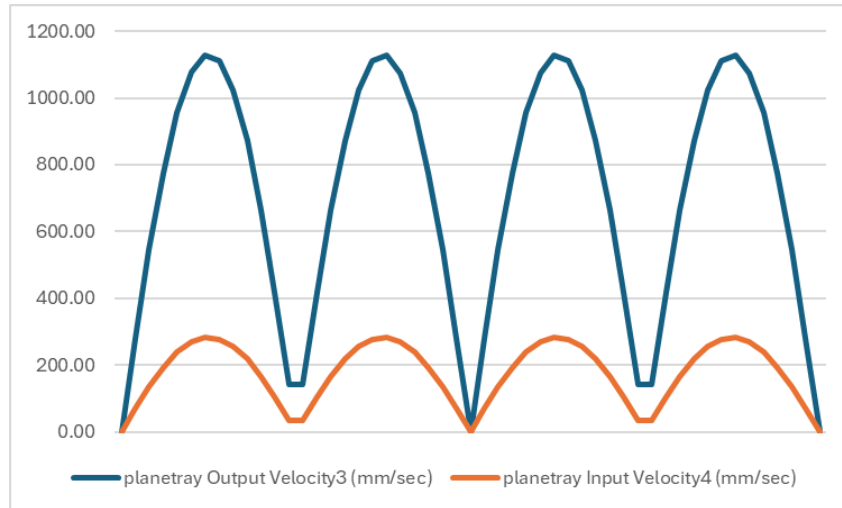


Figure 6: Linear velocity of input and blade out

The two side blades would be fixed to these pulley and belt systems (A1,2 and B1,2) using superglue on the end of the blade, with a centre blade connected to a third pulley and belt system as shown in figure 4. The blades are connected to ensure all three blades slide out simultaneously, and stability of the centre blade can be increased by integrating a third pulley and belt system. This allows the motion of the centre blade to be parallel to the side blades when the whole mechanism is moving or when there is a force applied to the tip of the blades. When there is force applied on the blades, it may be impractical to hold the blades to the belt only by superglue at the end section of the blade, hence screwing the blades to the belt would make this mechanism more secure. Ensuring the open timing belts are tight would be challenging as the glue requires some time to dry and the timing belts must be held together tightly during this time, the difficulty in this being that it must align perfectly with the other end to ensure perfectly horizontal motion of blades.

2.3.2 Version II: Compound Gear Train

The compound gear train (Figure 7a) is dependent on the contact between gears, reflecting on the objective of our mechanism, it is essential to ensure the gears mesh regardless of motion of mechanism.

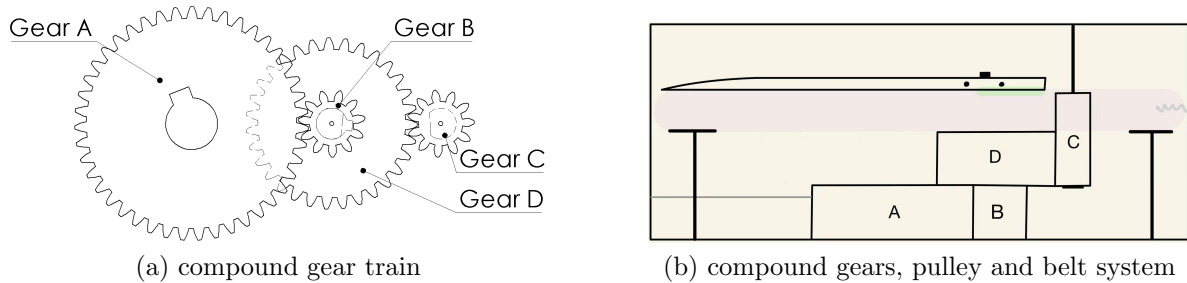


Figure 7: design of version II

Gear A will be connected to the floor by a screw, similar to gears A1,2 and B1,2 in version one, this screw will ensure the gears are in a fixed position yet allow rotational movement to ensure meshing between gears. The same procedure has been utilised for gears B and D, with gear C resting on an upside-down “T” shaped support which is fixed to the top of the box. Gear C has been modified to a similar design to gears A1 and B1, with the upper half glued into the timing pulley and the lower half meshing with gear D.

The pulley and belt system of this version would be supported by two “T” shaped supports, with the end of the centre blade screwed to the side of the timing belt. In this version, the centre blade provides the driving force to the two side blades. To increase the stability of the blades, another two pulley and belt systems guides the side blades. The timing pulleys could be supported by a vertical rod with two horizontal plates, as shown in figure 7b, this support would be made of three components, these three components ensure that the supports are fully vertical. The difficulty of this involves glueing the supports vertically (in the box) and parallel to the other pulley and belt transmissions.

3 Mathematical Modelling and Analysis

3.1 Fingers and Wrist Modelling

Finger and Overhead String Movement

The linear movement of the string that is deployed over the finger is created by the finger's flexion.

Figure 8 has two sub-figures, Figure 8a describes the details and data when finger curved, Figure 8b describes the details and data when finger extended.

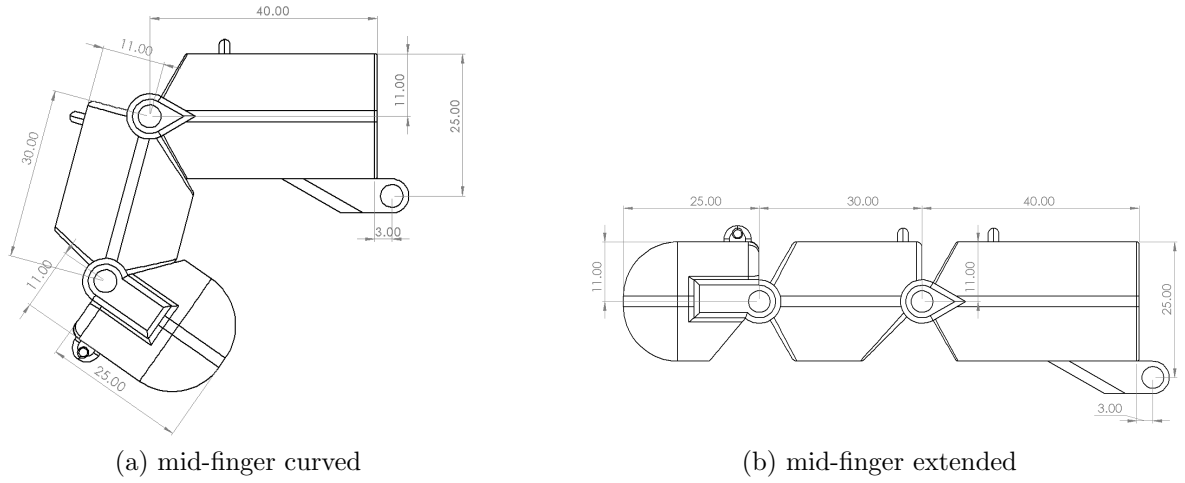


Figure 8: mid-finger exoskeleton design

By modelling the motion of each section of the finger as an arc, with the centre being the joint, we can deduced the extension of the rope through the equation:

$$\text{length of arc} = r\theta$$

Total displacement of the string overhead by calculation:

$$\begin{aligned} \Delta L &= L_{DIP} + L_{PIP} + L_{MCP}, \quad \text{where} \\ L_{DIP} &= 11 \times \frac{45}{360} \times 2\pi \approx 8.64, \\ L_{PIP} &= 11 \times \frac{60}{360} \times 2\pi \approx 11.52, \\ L_{MCP} &= (25 - 11) \times \frac{85}{360} \times 2\pi \approx 20.77 \\ \Rightarrow \Delta L &\approx 8.64 + 11.52 + 20.77 = \boxed{40.93\text{mm}} \end{aligned}$$

Wrist Movement

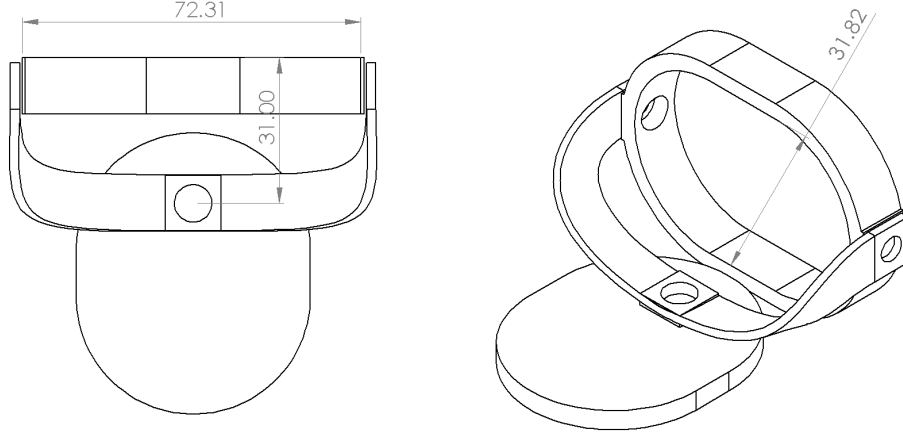


Figure 9: demonstration of wrist

In hand exoskeletons, the wrist section is relatively complex due to its two degrees of freedom (DOFs) for upward-downward and left-right movements, with their rotation centers almost coinciding. This poses a challenge for the design of the mechanical structure. We have designed a special mechanism, functionally similar to a universal joint, to serve as the exoskeleton for the wrist, as illustrated in the figure 9.

The palm is represented by an oval in the diagram, and the linkage structure connecting the palm and fingers still requires careful design due to the constraints of the narrow aperture space.

Conclusion

In terms of a robotic hand exoskeleton, there are totally $3 \times 4 + 3 = 15$ links and $3 \times 4 + 2 = 14$ joints in 3 fingers and a wrist.

In addition, there are 14 DOFs in hand exoskeleton.

3.2 Wolf Claw Mechanism Version 1: Planetary Gear

3.3 Wolf Claw Mechanism Version 2: Compound Gear Train

4 Conclusion and Future Work

References

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