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

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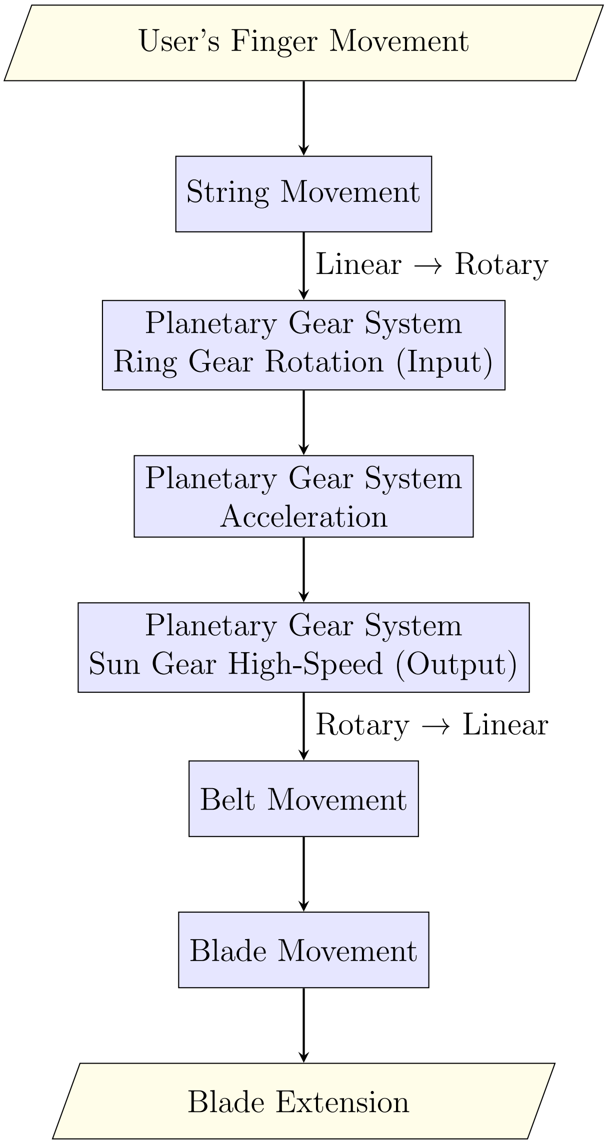
2.1 Drive Method and Transmission

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

2.2.1 Hand Biomechanics

Most human hands have 19 bones and 14 joints[1], excluding the carpal bones.

The design of the hand exoskeleton needs to be based on the natural anatomy of the human hand (figure 1). We have to focus on MCP, PIP, and DIP joints, because they ensure the finger can flex and extend easily.

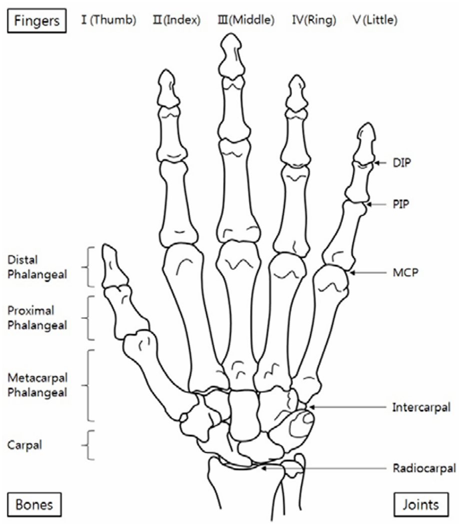


Figure 1: bones and joints of a human hand[1]

The finger joints include 3 types of joints majorly[2]:

Metacarpophalangeal Joint (MCP):
Has 2 degrees of freedom (flexion/extension, abduction/adduction).

Proximal Interphalangeal Joint (PIP):
Has 1 degree of freedom (flexion/extension).

Distal Interphalangeal Joint (DIP):
Has 1 degree of freedom (flexion/extension).

In the resting posture, the angle of MCP joint is approximately 45°, whereas the PIP joint is between 30°–45°, and the DIP joint is between 10°–20°. To define the range of motion and ensure safety in exoskeleton design, it is essential to align our mechanism to the human anatomy.

Wrist Structure Analysis

The wrist has 2 degrees of freedom: flexion/extension and radial/ulnar deviation.

2.2.2 Selection of Mechanism Type

Among the mechanisms illustrated in Figure 2, the direct matching of joint centers (Figure 2.a) was selected for our design because it provides a simple and compact solution without requiring additional linkages or complex actuation. Also, this approach minimises the mechanical complexity, reduces system weight, and simplifies both fabrication and control.

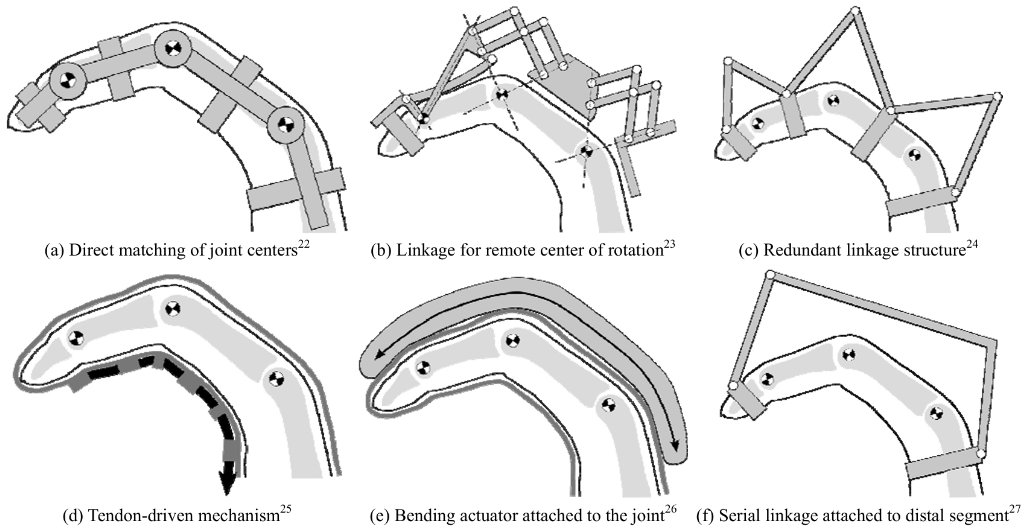


Figure 2: mechanism types[1 2]

The exoskeleton joints directly aligned with the anatomical centers, which ensures high accuracy and reliability. This is because no additional compensation for motion is necessary.

Therefore, the direct joint-center matching method offers the most efficient and practical solution for this application. We have chosen to take a similar approach

2.3 Wolf Claw Mechanism Comparison

2.3.1 Version 1: Planetary Gear

2.3.2 Version 2: Compound Gear Train

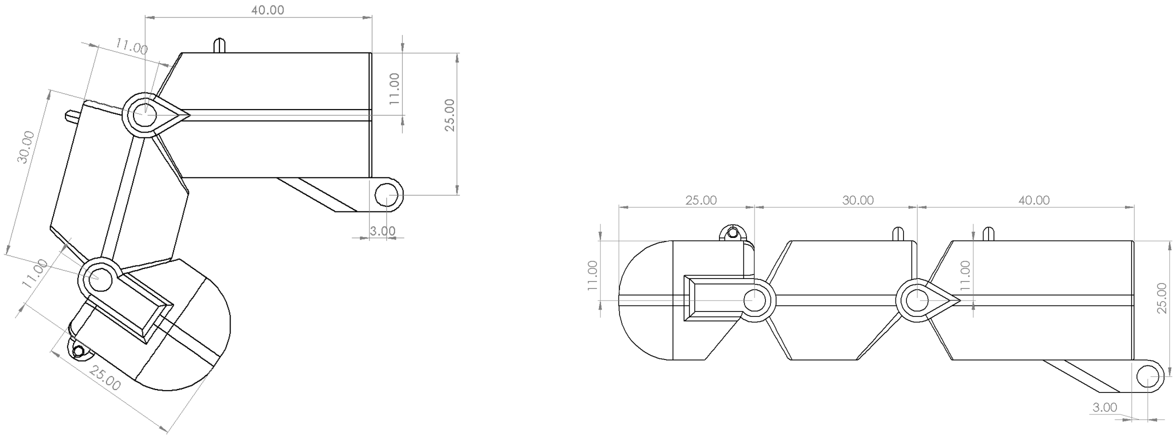
3 Mathematical Modelling and Analysis

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 3 has two sub-figures, Figure 3a describes the details and data when finger curved, Figure 3b describes the details and data when finger extended.



(a) mid-finger curved

(b) mid-finger extended

Figure 3: mid-finger exoskeleton design

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

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 4.

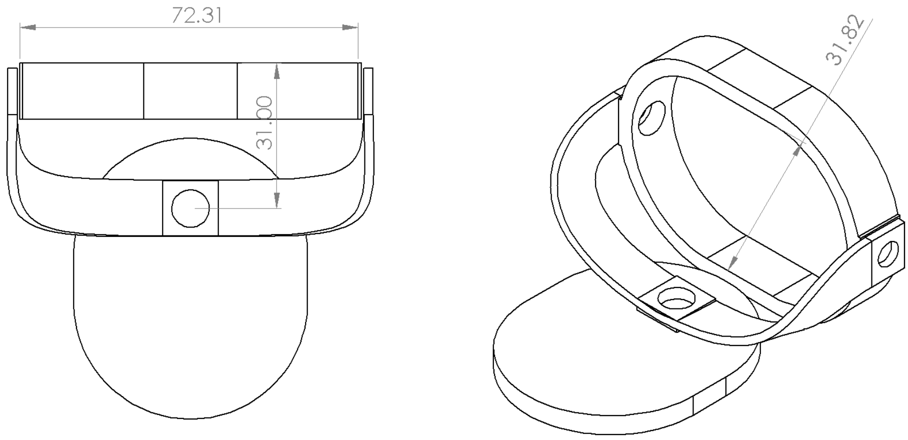


Figure 4: demostration of wrist

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

[1] Pilwon Heo, Gwang Min Gu, S. J. Lee, et al. Current hand exoskeleton technologies for rehabilitation and assistive engineering. *International Journal of Precision Engineering and Manufacturing*, 13:807–810, 2012.

[2] Jacob Rosen. *Wearable robotics: Systems and applications*. Academic Press, 2019.