Design of a Rope-Driven Finger Exoskeleton System with a Universal Double Grooved Roller for Adaptive Rehabilitation

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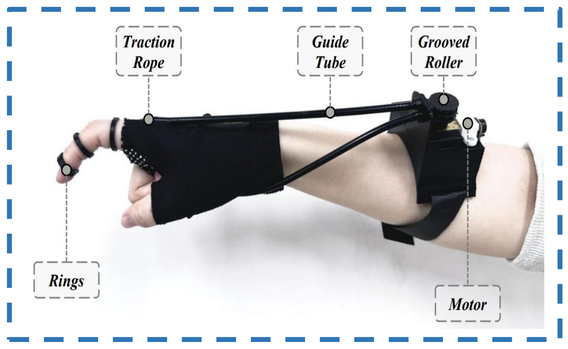
1. Introduction

- Neurological conditions, such as stroke, can severely impair hand function and daily activities.
- Traditional designs face challenges with rope slack and slipping during finger flexion and extension.
- The study introduces a novel universal double-grooved roller design that enables bidirectional control with a single motor.
- This innovative approach reduces weight and cost while enhancing stability and accuracy for effective home-based hand rehabilitation.

2. Methods

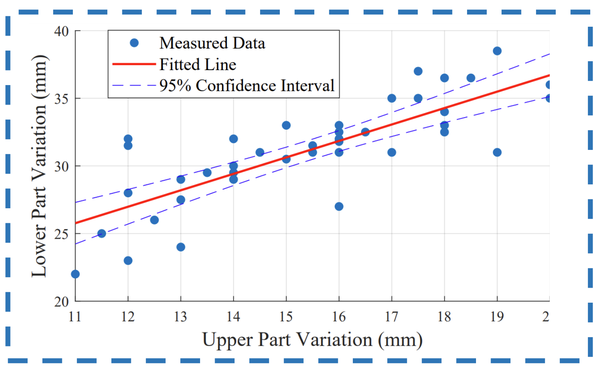
System Overview

- Using rope drive structure to pull finger ring.
- Double grooved roller with large and small grooves to control flexion and extension using a single motor.



Sampling and Analysis

- 40 sets of index finger flexion and extension data collected.
- Linear regression analysis to determine the universal ratio.

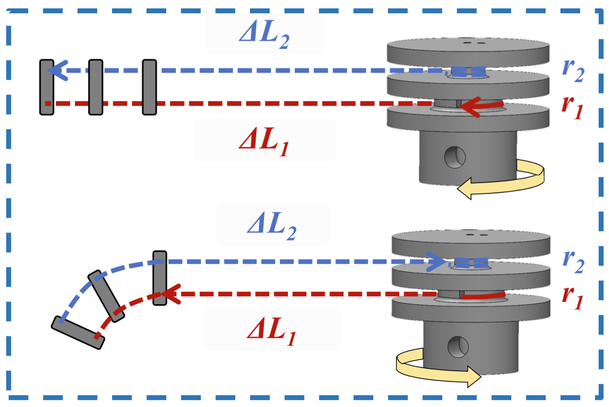


The analyzed universal ratio is 0.488.

To design a double grooved roller structure.

Design of the double-grooved roller

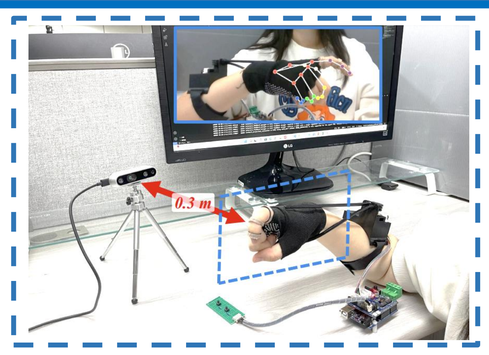
- The double-grooved roller controls both finger flexion and extension by accommodating different rope length changes.
- Set the small groove radius of 2 mm and the large groove radius of 4.1 mm.



3. Experiments and Analysis

Experimental Setup

- Subjects are 7 people with various finger sizes.
- Motion tracking using Mediapipe framework.

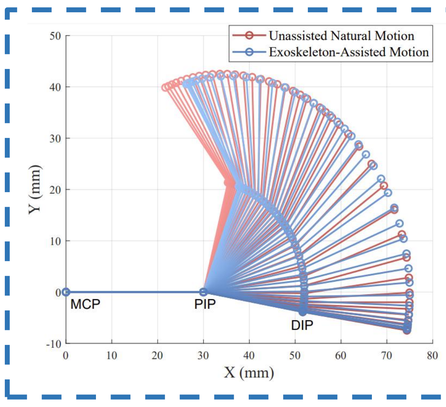


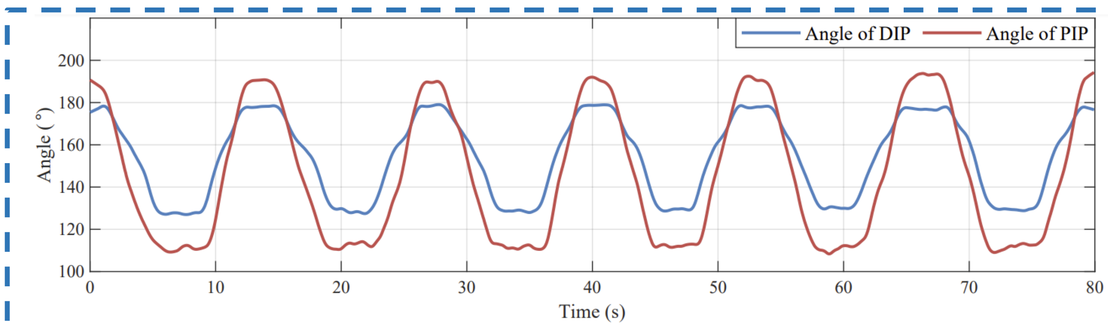
Usability Validation

• **Objective:**
- To validate the effectiveness of the finger exoskeleton in assisting finger movement.

• **Method:**
- The natural motion trajectory of the index finger was recorded and compared with the motion trajectory when assisted by the exoskeleton.

• **Results:**
- The overlap between the assisted and natural motion range was 94%.
- During multiple flexion and extension cycles, DIP and PIP joint angles remained stable.





Universality Validation

• **Objective:**
- To assess the adaptability of the double-grooved roller across different finger sizes.

• **Method:**
- Seven subjects with different finger sizes tested the exoskeleton. Tightness of the traction rope and task completion success were recorded.

• **Results:**

No.	Position	Finger Size	DIP			PIP			Rotation Count	Tightness	Task Completion
			With Exoskeleton	Without Exoskeleton	Completion	With Exoskeleton	Without Exoskeleton	Completion			
1	OnLine	Medium	50°	45°	111.1%	80°	90°	88.9%	1.5	Suitable	Yes
2	In 95%CI	Small	45°	40°	112.5%	95°	100°	95%	1.4	Suitable	Yes
3	In 95%CI	Medium	50°	43°	116.3%	85°	90°	94.4%	1.5	Suitable	Yes
4	In 95%CI	Large	40°	35°	114.3%	70°	95°	73.7%	1.6	Suitable	Yes
5	Out 95%CI	Small	40°	45°	88.9%	80°	90°	88.9%	1.3	Suitable	Yes
6	Out 95%CI	Medium	42°	36°	116.7%	84°	90°	93.3%	2.1	Loose	Yes
7	Out 95%CI	Large	45°	38°	118.4%	90°	95°	94.7%	1.7	Slightly Loose	Yes

- Universal finger sized Subjects (No.1~4) had a stable trajectory of movement and rope tension was appropriate.
- Non-universally finger sized subjects (No. 5~7) had slight slack in the rope.
- Flexion-extension tasks are completed with a 100% success rate.

4. Discussion

- The problem of slackness in the traction rope is significantly improved compared to the traditional double-grooved rollers of the same diameter.
- The universal-size roller works for most people and improves motion precision.
- A single motor can be used to control movement in both flexion-extension directions.

5. Conclusion

- A rope-driven exoskeleton with a universal double-grooved roller was developed and validated.
- Experiments showed 94% motion overlap, stable joint movement, and successful task completion across different hand sizes.
- The design enhances stability, adaptability, and precision, making it suitable for rehabilitation.
- Future work will focus on testing with patients and expanding to multi-finger control.

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