Independent Donning and Doffing Robotic Hand System: An Innovative Solution for Stroke Home-Rehabilitation

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ABSTRACT

Stroke survivors often experience hand spasticity, making it difficult to wear a robotic hand independently. However, consistent rehabilitation is essential, and home-based rehabilitation offers a practical solution. The major limitation of existing robotic hand systems is that **patients require assistance from caregivers for donning and doffing, which reduces their autonomy in rehabilitation.**

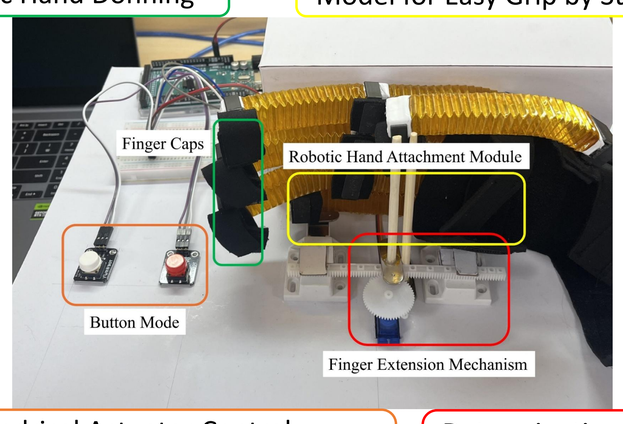
In this work, **we developed a self-applicable robotic hand system that enables users to don and doff the device independently.** The system features a button-operated mechanism that gently opens and closes the hand without excessive strain. The results showed that **the proposed system significantly reduced donning time and lowered pain levels compared to manual donning.** These findings suggest that the system enhances accessibility and usability for home-based rehabilitation, promoting independence for stroke patients.

METHODS

Hand Setup Station

Attachment of Finger Caps for Secure Robotic Hand Donning

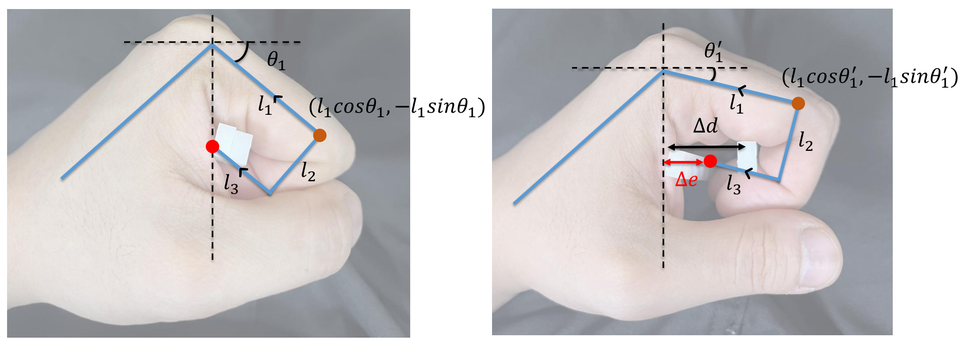
Selection of a Thin Cylindrical Actuator Model for Easy Grip by Stroke Patients



Two-way Cylindrical Actuator Control
Red (↕): Insert / Remove Actuator in Hand
White (↔): Extend / Retract Actuator

Determination of Extension Distance and Speed Based on Finger Kinematics

Finger Kinematics

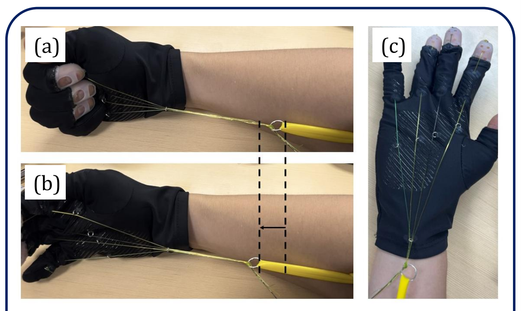


$$l_1cos\theta_1 - l_2sin\theta_2 - l_3cos\theta_3 = 0$$
$$l_1cos\theta_1' - l_2sin\theta_2' - l_3cos\theta_3' = \Delta e$$
$$\sqrt{(l_1cos\theta_1' - l_1cos\theta_1)^2 + (l_1sin\theta_1 - l_1sin\theta_1')^2} = \Delta d$$

Pneumatic Robotic Hand, Hand Spasticity



The robotic hand utilized **Pneumatic Origami Muscle Actuator (POMA)** to achieve controlled and adaptive finger movements.



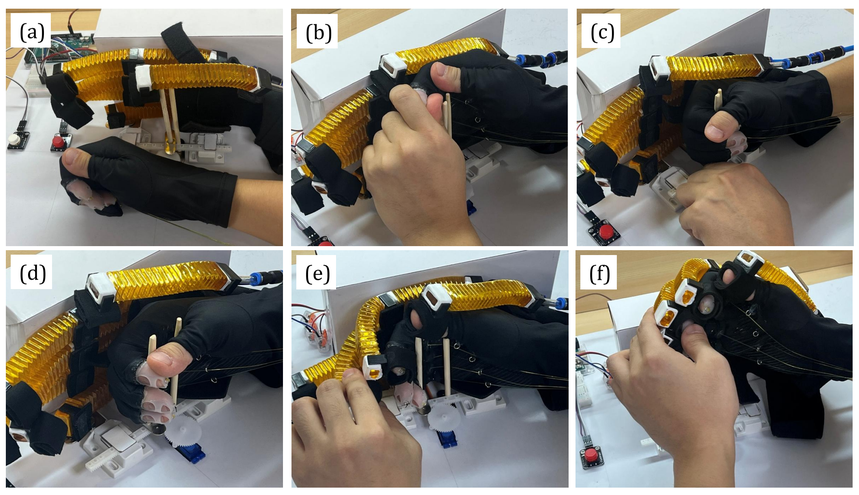
To replicate severe spasticity, **average stiffness coefficient of 0.8 N/mm** spring is used. By replacing the spring, the resolution of rigidity can be increased

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RESULTS

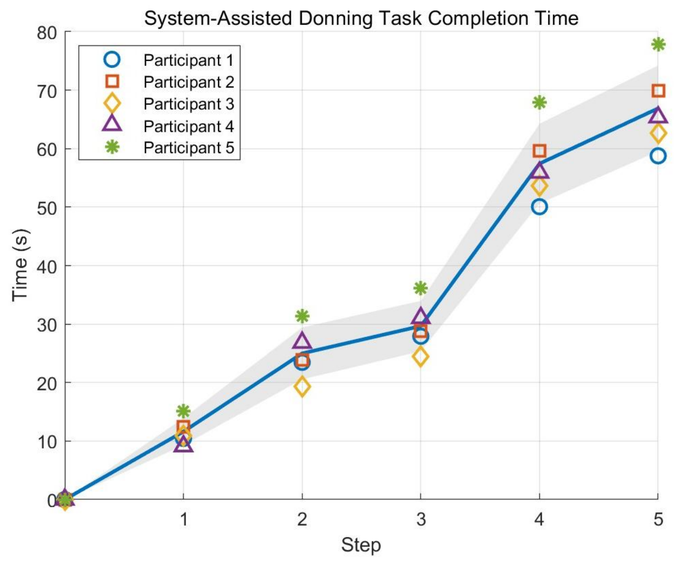
Experiment Procedure

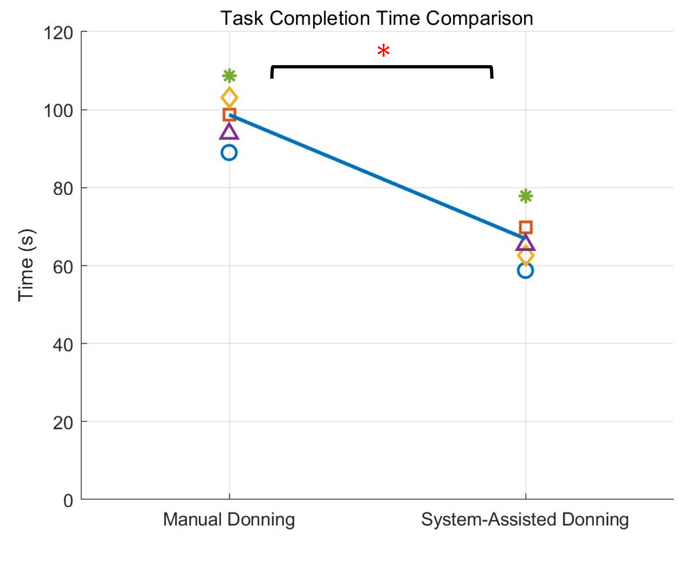


Step	Description
1	Extend the paralyzed hand fingers and grasp the cylindrical actuator.
2	Attach the wrist strap of the robotic hand to stabilize the device with patient's hand.
3	Press the white button to expand the hand attached to the robotic hand device.
4	Attach the robotic hand's fingertip caps to the fingers of the paralyzed hand.
5	Press the white and then red button to detach the hand wearing the robotic hand.

Task Completion Time

- To evaluate system performance, we conducted experiments with **five healthy participants** (3M / 2F, age 30 ± 3.4 yrs).
- **Stroke-like spasticity** was simulated using a glove with a **0.8 N/mm stiffness spring** to replicate moderate to severe hand rigidity (MAS spasticity level 2).





- In the system-assisted condition, **step-by-step task times were recorded.**
- Total completion time was significantly reduced with the system:
  - **Manual: 98.68 ± 7.68 sec**
  - **System-assisted: 68.89 ± 7.33 sec**
  - **30 % reduction**, $p < 0.05$, $T - statistic = 14.31$
- Step 3 (button press) was the fastest, while Step 4 (attaching fingertip caps) took the longest. The longest delay occurred during fingertip cap attachment, which may be shortened through repetition training or design improvements.

Usability Evaluation

Participants N=5, 5-point Likert Scale
RED: MANUAL, BLUE: SYSTEM-ASSISTED

	1	2	3	4	5	
Difficult		2			4.4	Easy
No Pain			2.2	3.8		Extreme Pain

- Participants rated **usability and pain level** after completing both conditions.
- Participants found **the system easier, more comfortable, and less physically demanding** with the system-assisted donning.

CONCLUSION

- We developed a **self-applicable robotic hand system for stroke patients** with a finger extension station that enables users to don and doff the device independently.
- The system significantly reduced donning time and pain levels while improving usability.
- These findings suggest that **automated hand preparation improves both the efficiency and comfort of the donning process.**
- The intuitive control and repeatable setup procedure support consistent, self-driven rehabilitation at home.
- We are currently conducting clinical experiments with patients under IRB approval. **Based on user feedback,** we are refining the system by **adjusting the button positions,** and **the distance and speed of the extension mechanism** for personalized use.
- Patients with severe spasticity often experience paralysis extending to the wrist, making it difficult to rest the hand flat on a table surface. Therefore, our next key objective is to develop a **customized plate with ergonomic curvature tailored to the individual hand posture of each patient.**