2025 IEEE/SICE International Symposium on System Integration (SII)
January 21-24, 2025, Munich, Germany

# Customizable Robotic Device for Arm and Hand Rehabilitation of Hemiplegic Patient at Home

Y. Furudate, H. Sato, K. Chiba, Y. Ishida and S. Mikami, *Member, IEEE*

***Abstract*— Home-based upper-limb rehabilitation robot is required for the hemiplegic patient to continue the rehabilitation after discharge from the hospital. Many researchers have been proposing robots dividing into body parts such as robot for arm rehabilitation and for hand rehabilitation. However, rehabilitation robots specialized for a certain body part are difficult to introduce because the patient needs to purchase a robot for each body part. To overcome this problem, we have been developing the upper-limb rehabilitation robot which can rehabilitation both the arm and the hand only by single unit. Our key idea is customizability. The robot is designed so that it is easy to assemble. We found that our robot has possibility to monitor and assist the user's rehabilitation while changing its hardware from experimental result.**

## I. Introduction

The hemiplegic patient loses upper-limb motor function to perform activities of daily living such as eating and dressing [1]. The patient undergoes the rehabilitation to regain motor function, but often do not recover sufficiently during hospitalization. Therefore, the patient needs to rehabilitate his/her upper-limb at home.

To realize the home rehabilitation, many researchers have proposed home-based technologies such as arm rehabilitation robot [2, 3] and hand rehabilitation robot [4, 5]. Among them, there are some examples that are commercially available [6, 7]. However, it is difficult for the patient to purchase multiple robots every body parts due to cost and space problem. These problems have prevented the installation of rehabilitation robots into home environment and there have been many patients whose paralysis remains unrecovered.

From these background, we have developed the home-based rehabilitation robot that can deal with both arm and hand only by single unit. In realizing our robot, we propose the customizability as key idea to overcome the problem in previous studies, allowing the user to freely assemble our robot according to the body part he/she wants to rehabilitate. The overview of our robot is followings:

- The robot consists of three components: the component for arm rehabilitation, hand rehabilitation and commonly used in both parts.
- When the user carries out the arm rehabilitation, he/she assembles the robot so that the common component is placed on the component for arm rehabilitation (the bogie). The user performs the reaching movement in training session and the user's movement is monitored by the load cell connecting two components.
- The user assembles the robot using the common component and the component for hand rehabilitation when carrying out the hand rehabilitation. In training session, the user performs single index finger movement. Our robot individually measures all finger movements by load cells and evaluates how much the user can do the task as well as healthy subjects.

Y. Furudate is with the Biomedical Science and Engineering Research Center in H.M.A Nursing and Rehabilitation Academy, Hakodate, Hokkaido, Japan, phone: +81 138-43-8282; e-mail: furudate@hma-ns-reha.ac.jp

H. Sato, K. Chiba and Y. Ishida are with the H.M.A Nursing and Rehabilitation Academy, Hakodate, Hokkaido, Japan.

S. Mikami is with the Future University Hakodate, Hakodate, Hokkaido, Japan..

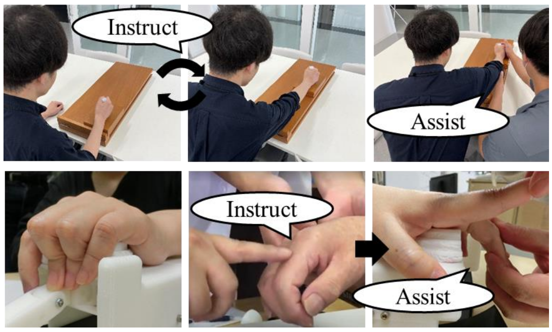


Figure 1. Arm rehabilitation and hand rehabilitation by the therapist

## II. Clinical Rehabilitation

### A. Arm Rehabilitation

Loss of arm movement makes it difficult to carry the hand to a certain position and hold it there. Therefore, the goal of arm rehabilitation is to enable the user to reach out towards his/her desired position and hold it there.

In clinic, the patient undergoes the reaching training which is widely introduced as clinical practice (Fig. 1 top). In this training, the therapist first indicates where the patient should reach out. Then, the patient extends arm towards the indicated point. If the patient cannot extend his/her arm, the therapist assists its movement. These procedures are one trial and the patient tries to improve the ability to coordinate the hand position.

### B. Hand Rehabilitation

In hand rehabilitation, it is important to regain the ability to perform individual finger movement (finger independence). This is because the finger independence forms the basis of movements requiring a dexterity such as using chopsticks.

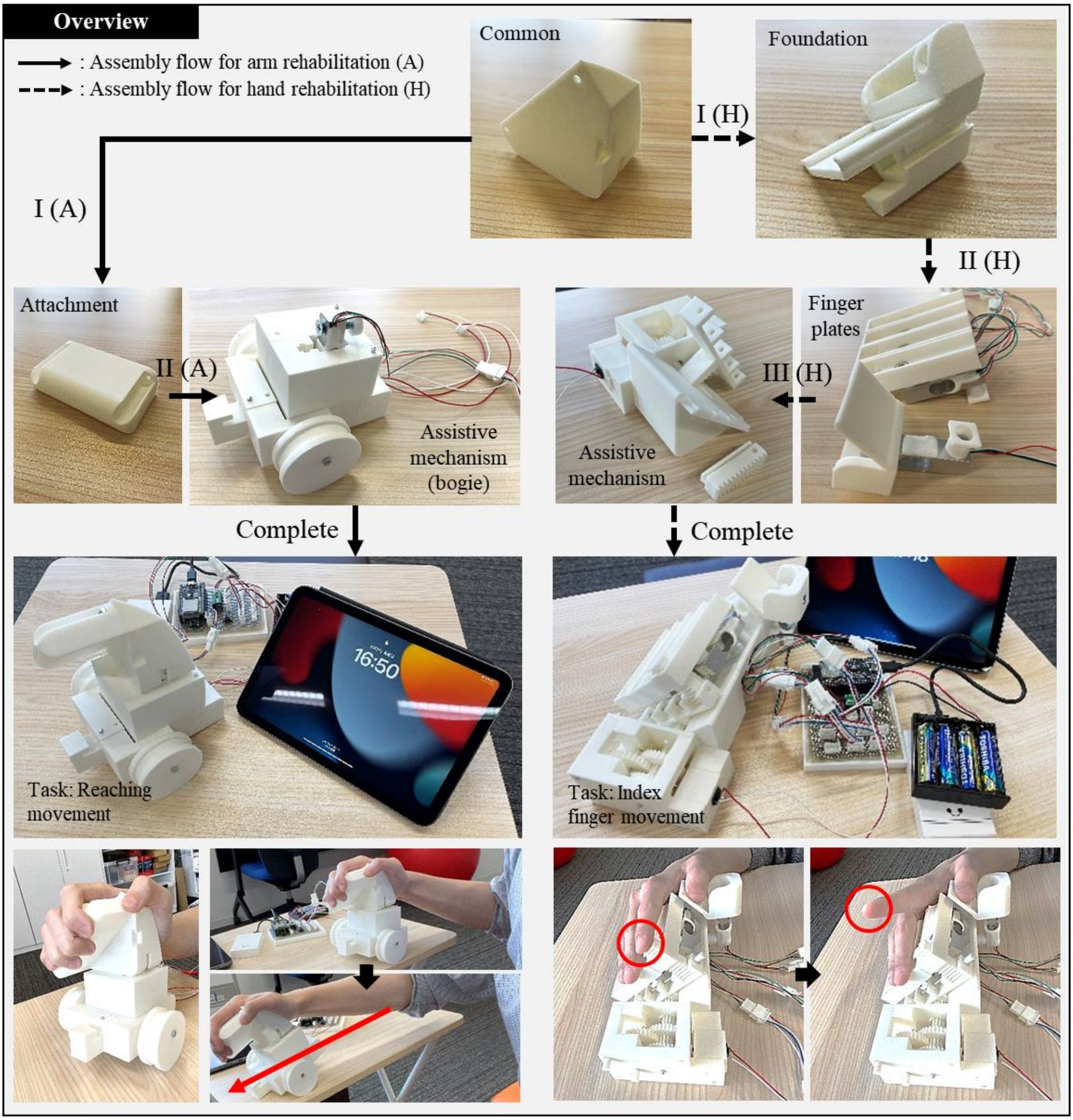


Figure 2. The overview of assembly flow and tasks that the patient perform

Fig. 1 (bottom) shows the typical intervention for the hand. The therapist first instructs the patient to extend one finger. If the patient cannot extend instructed finger at all, the therapist assists and demonstrates how to extend the finger. On the other hand, if the patient can extend instructed finger but other fingers are extended together, the therapist asks the patient not to move uninstructed fingers. As these, it is important to instruct the patient to move instructed finger and not to move uninstructed fingers to regain the finger independence.

### C. *Requirements for Hardware Development*

To summarize, the therapist (1) monitors and (2) assists the patient's movement. Because these are common in arm and hand rehabilitation, both procedures are need to be implemented in the robot. At the same time, we need to consider the different purpose and intervention between the

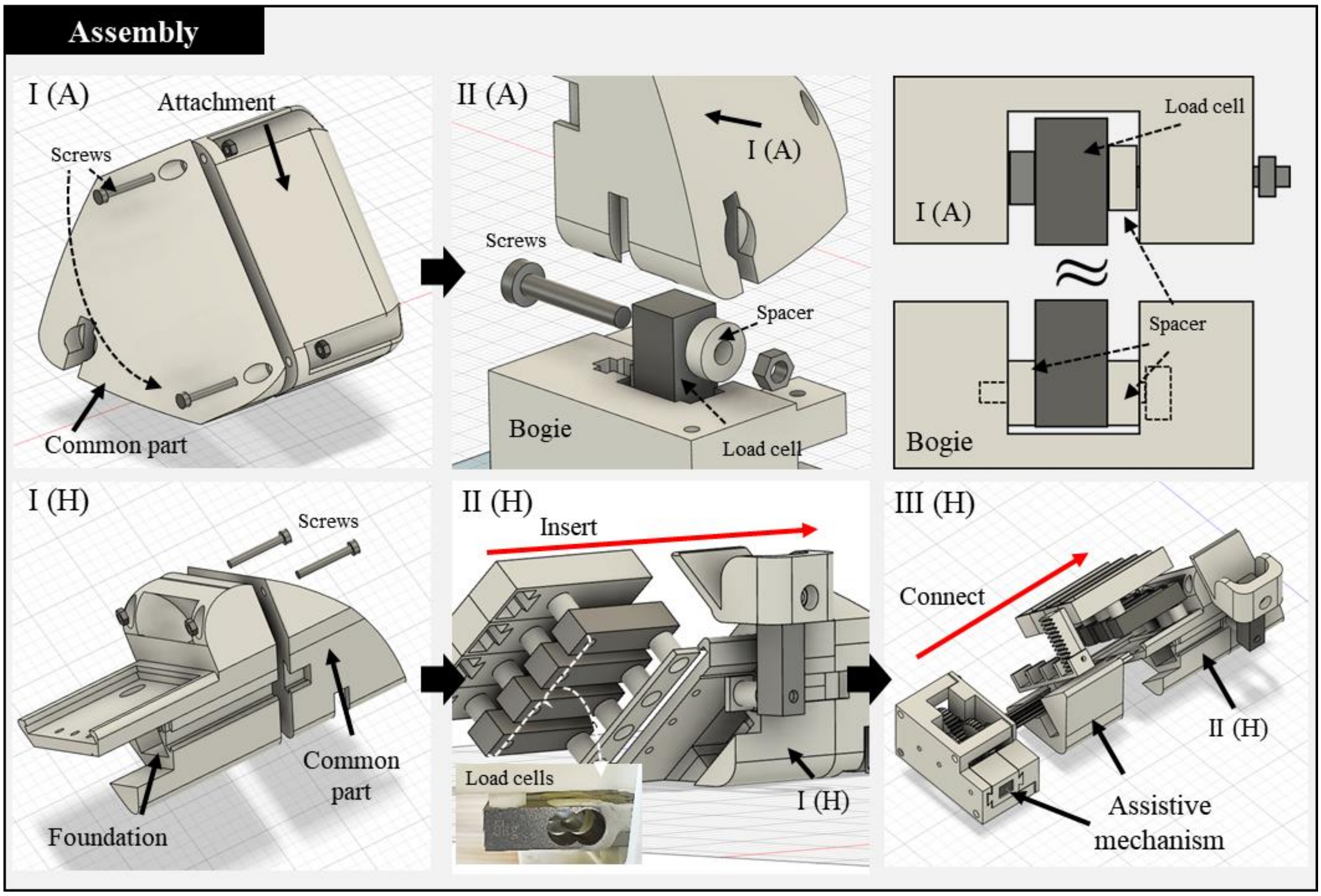


Figure 3. Details of assembly for arm rehabilitation (top) and hand rehabilitation (bottom)

arm and the hand. Based on this, following requirements are need to be implemented:

- In arm rehabilitation, the robot needs to recognize the movement direction in the reaching movement. In addition, the robot assists with movement by pulling on the user's upper-limb.
- In hand rehabilitation, the robot needs to measure all fingers movement individually. It is also necessary not only to assist the user's movement but also to instructed the user not to move unnecessary movement in uninstructed fingers.

Based on these requirements, we describe the detail of our hardware from next chapter.

## III. Hardware Design

### *A. Overview*

Fig. 2 shows the overview of our robot. The robot allows the user to assemble by providing dedicated components.

For arm rehabilitation, three components are prepared: a common component, an attachment and an assistive mechanism (the bogie). After the user completes to assemble the robot, he/she puts his/her hand on the robot and performs the reaching movement by moving the robot back and forth. On the other hand, the user assembles the robot using four components: a common component, a foundation, finger plates and an assistive mechanism. The user performs single index finger movement during training session.

We also have developed iOS application (app) to visualize the user's movement. The app is connected to ESP32-WROOM-32e (ESP) via Bluetooth Low Energy (BLE). ESP is used to process data representing the user's movement and we use load cells to measure the user's arm movement and all finger movements. All measured data are transmitted to the app using BLE. From next section, we describe the detail of hardware design including the assembly flow (Fig. 3), and the detail of our app.

### *B. Hardware for Arm Rehabilitation*

Prior to arm rehabilitation, the user assembles the robot according to the following steps. First, the user attaches the attachment to the common part with screws (I (A) in Fig. 3). Then, the user connects it to the bogie equipping the load cell (II (A) in Fig. 3). The bogie consists of the gear box housed inside a 3D-printer case (Fig. 4 top). The gear ratio is 12.7:1 (TAMIYA) and two geared motors (400 rpm / 1.6kgcm at 6 V no-load / halt) are connected to the gearbox.

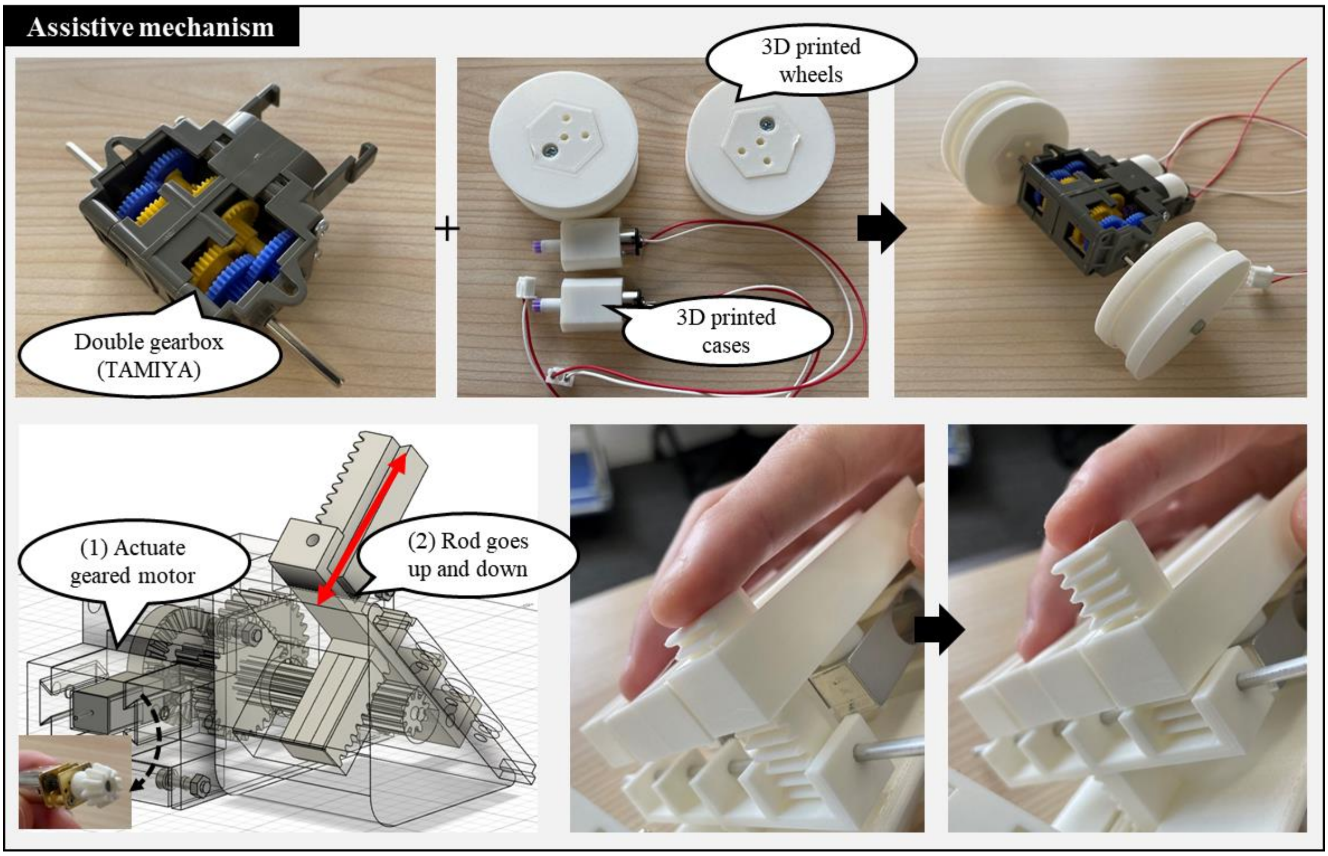


Figure 4. Assitive mechanism for arm rehabilitation (top) and hand rehabilitation (bottom)

The drive of the bogie is determined by the data of the load cell. ESP normalizes the data so that the data at no load becomes zero, allowing itself to recognize the direction from the sign of normalized data. Based on this, the robot regards that the user tries to move forward (back) it if a positive (negative) value is observed. The bogie is actuated to follow the user's movement by PWM control according to the absolute value of normalized data.

### C. *Hardware for Hand Rehabilitation*

The user first attaches the common part to the foundation with screws (I (H) in Fig. 3) and finger plates are placed on the foundation (II (H) in Fig. 3). Here, the load cell is placed under the finger plate to measure all finger movements individually. Finally, the user attaches the assistive mechanism to the end of previous part (III (H) in Fig. 3).

The assistive mechanism consists of gear box and the rod (Fig. 4 bottom). Here, the gear ratio was adjusted in previous study [8] so that the assistive mechanism exerted the more force than 5.0 kg, which is the pinching force in Japanese healthy young male [9]. One geared motor is connected to gearbox and it is actuated according to the data of the load cell at index finger. If no change in data is observed at index finger, the assistive mechanism works. Once the assistive mechanism is actuated, the rod repeats going up and down. By this, the assistive mechanism helps the user extend his/her index finger.

### D. *iPad*

The app plays the role of instructing the task and visualizing the user's movement (Fig. 5). The app first notifies the user to choose the body part which the user wants to carry out the rehabilitation (top right in Fig. 5). Once the knob is operated, the user is instructed the task (bottom right in Fig. 5) and the app initiates monitoring of the user's movement (middle right in Fig. 5). Here, real-time forces that the user apply to load cells are described as pin locations. In arm rehabilitation, the pin indicating the force applied to the load cell extending from the bogie is located in the center of scale when no load is applied. If a positive (negative) data is observed, the pin moves to right (left). On the other hand, pins are located in left side of scale when the user chooses hand rehabilitation. When the user applies a large force to load cells, pins are move to right. The user carries out the task while receiving the feedback of his/her movement.

## IV. REHABILITATION PROGRAM

### A. *Arm Rehabilitation Program*

The user performs reaching movement as the procedure described in section II-A. Once the user turns the knob counterclockwise, arm rehabilitation program starts. First, the robot instructs the user to move the robot forward for 8 seconds. Then, the user keeps its posture for 3 seconds. Finally, the robot instructs the user to move the robot back

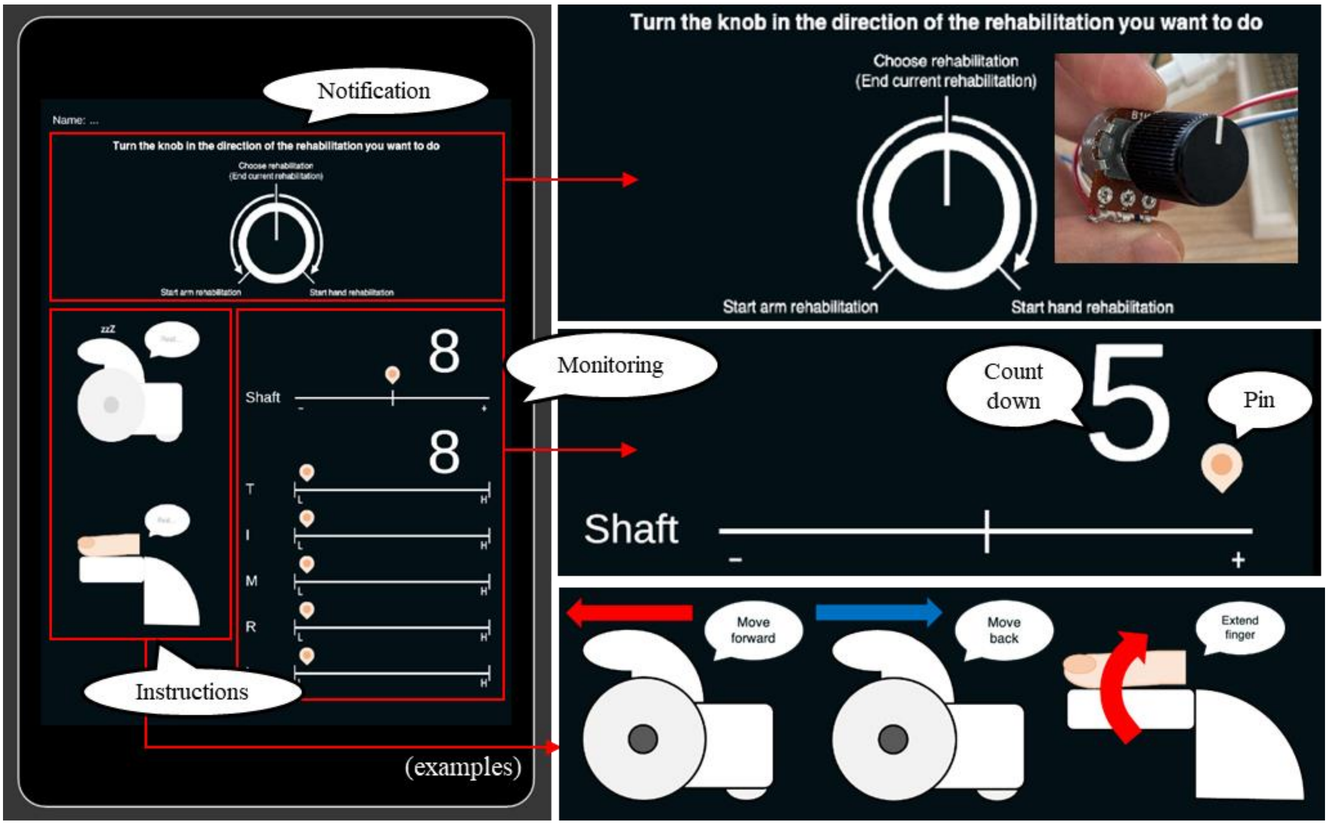


Figure 5. User interface of the app

for 8 seconds. These procedures are 1 trial. During the trial, if the user cannot move the robot forward, the robot assists reaching movement by same procedure as the trial unless the user returns the knob to original point.

## B. Hand Rehabilitation Program

In this rehabilitation program, the user performs single index finger movement. This task follows two important points described in section II-B: the assistance of user's movement and the instruction not to do unnecessary finger movement.

Once the user turns the know clockwise, hand rehabilitation program starts. The robot first instructs the user to extend index finger within 8 seconds and keep its height in the rest time. After that, the robot asks the user to lower index finger. These procedures are one trial and the user repeats them many times. In duration the user is asked to extend his/her index finger, if the user cannot extend index finger, the robot assists the movement. This assistant is also carried out until the user returns the knob to original position. On the other hand, if the robot detects finger movement other than index finger, the robot instructs the user to redo the task while indicating the finger that the user unnecessarily move.

# V. EXPERIMENT

In chapter II, we described that (1) monitoring and (2) assisting the patient's movement are required when considering the development of rehabilitation robot. Therefore, we conducted the experiment to verify if our robot could meet these requirements. Note, we have revealed that the hardware for hand rehabilitation could meet requirements by previous studies [8]. Therefore, we conducted the experiment only in the hardware for arm rehabilitation.

## A. Monitoring the Movement

In arm rehabilitation hardware, the monitoring results are used to determine if the user needs assistance. To verify if the robot can detect the user's movement, we evaluated the difference of data among following movements. Note, following movements were performed by a healthy subject because this experiment was a basic evaluation of hardware before we applied our robot to an actual patient.

- (Condition 1) Movement as instructed by the robot. The user properly moved the robot following the instructions. This condition assumed the perfect movement in an actual patient and this result was used as the reference.
- (Condition 2) Intermittent movement. The user intermittently moved the robot. This condition assumed the patient's paralysis gradually recovered, resulting in partial successful of movement.
- (Condition 3) No movement during a trial. The user did nothing regardless of the robot's instructions. This condition assumed the situation where an actual patient couldn't move his/her arm due to the severe paralysis.

Fig. 6 shows the experimental result in all conditions. The graph in condition 1 shows the data with different sign at the timing of moving forward and back. On the other hand,

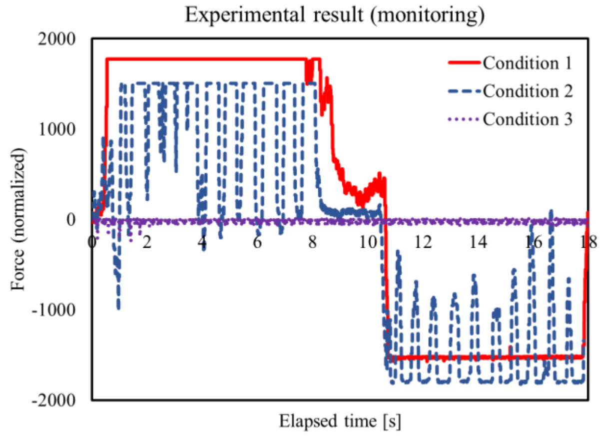


Figure 6. Experimental result of each conditions in monitoring experiment

Figure 7. Experimental setup in the experiment of assitive force

condition 2 shows same pattern as condition 1 but there are irregularly large fluctuations over the trial. In condition 3, there are few change in graph during trial, indicating no movement by the subject.

From these results, we could verify there is difference on data among each condition, suggesting that our robot has possibility to (1) detect the movement and (2) differentiate the degree of recovery. However, we have not been able to define the standard of successful pattern as for now. Therefore, we will plan another experiment to determine a threshold which differentiate successful pattern and failure.

### B. *Movement Assistance*

To properly assist the reaching movement, the assistive mechanism needs enough force against the dead weight of arm. Because it is known that the arm's own weight accounts for approximately 6% of its body weight [10], we checked if the assistive mechanism exert over 4kg force, which is the weight of an assumed 60 kg person.

Fig. 7 shows the experimental setup. We prepared sandbags of different weight. When we conducted the experiment, we eliminated part of bogie and put sandbags on it. The maximum weight was defined as the weight when the bogie stopped. As a result of experiment, the bogie stopped at 11 kg of sandbags. This result suggested that the robot has enough force to assist reaching movement.

Although we could find that our robot meets the force requirement, we have not been able to conduct the experiment for the evaluation of usability yet. We will plan to conduct experiment by actual patient in the future.

## VI. Conclusion

In this study, we have proposed the home rehabilitation robot which enables the user to rehabilitate his/her arm and hand only by single device. We found that our customizable robot could assist the user's rehabilitation for each part of the body, leading to solve the problem to require the user to prepare multiple expensive robot. In the future, we will conduct experiments by actual patient and evaluate accuracy of assist, quantification of recovery of arm paralysis and usability.

## Acknowledgment

This work is supported by JSPS KAKENHI Grant Number 23K17264.

## References

[1] A. Pollock et al., "Interventions for improving upper limb function after stroke," *Cochrane Database of Systematic Reviews*, vol. 11, 2014.

[2] S. Guillén-Climent et al., "A usability study in patients with stroke using MERLIN, a robotic system based on serious games for upper limb rehabilitation in the home setting," *Journal of NeuroEngineering and Rehabilitation*, vol. 18, no. 1, p. 41, 2021.

[3] M. Sivan et al., "Home-based Computer Assisted Arm Rehabilitation (hCAAR) robotic device for upper limb exercise after stroke: results of a feasibility study in home setting," *Journal of NeuroEngineering and Rehabilitation*, vol. 11, no. 1, p. 163, 2014.

[4] F. Amirabdollahian et al., "Design, development and deployment of a hand/wrist exoskeleton for home-based rehabilitation after stroke – SCRIPT project," *Robotica*, vol. 32, pp. 1331-1346, 2014.

[5] P. Polygerinos, Z. Wang, K. C. Galloway, R. J. Wood and C. J. Walsh, "Soft robotic glove for combined assistance and at-home rehabilitation," *Robotics and Autonomous Systems*, vol. 73, pp. 135-143, 2015.

[6] Syrebo, "Hand Rehabilitation Robot SY-HRC12," Access:2024/08/11. https://www.syrebo.com/rehabilitation-equipment-for-home/new-gen-soft-robotic-rehabilitation-gloves-sy.html

[7] ARTICARES, "H-MAN The only arm rehabilitation robot you will ever need," Access:2024/08/11. https://articares.com/h-man/

[8] Y. Furudate, K. Chiba, Y. Ishida and S. Mikami, "Customizable Home Rehabilitation Robot for Hemiplegic Patient to Improve Finger Indepence," *2023 Seventh IEEE International Conference on Robotic Computing (IRC)*, 2023, pp. 121-124.

[9] M. Kurosaki, "Reliability and clinical judgement of key pinching force and pulp pinching force from second to fifth finger in young adult, " *Journal of Occupational Therapy*, Japan, vol. 40, no. 6, pp. 774-783, 2021.

[10] R. Nakamura, H, Saito and H. Nagasaki, *Fundamental Kinesiology*. Tokyo: Ishiyaku Publishers, Inc., 2003, pp. 348-351.