A Rehabilitation Device to Improve the Hand Grasp Function of Stroke Patients using a Patient-Driven Approach

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***Abstract*—This paper proposes a robotic hand rehabilitation device for grasp training. The device is designed for stroke patients to train and recover their hand grasp function in order to undertake activities of daily living (ADL). The device consists of a control unit, two small actuators, an infrared (IR) sensor, and pressure sensors in the grasp handle. The advantages of this device are that it is small in size, inexpensive, and available for use at home without specialist's supervision. In addition, a novel patient-driven strategy based on the patient's movement intention detected by the pressure sensors without bio-signals is introduced. Once the system detects a patient's movement intention, it triggers the robotic device to move the patient's hand to form the normal grasping behavior. This strategy may encourage stroke patients to participate in rehabilitation training to recover their hand grasp function and it may also enhance neural plasticity. A user study was conducted in order to investigate the usability, acceptability, satisfaction, and suggestions for improvement of the proposed device. The results of this survey included positive reviews from therapists and a stroke patient. In particular, therapists expected that the proposed patient-driven mode can motivate patients for their rehabilitation training and it can be effective to prevent a compensational strategy in active movements. It is expected that the proposed device will assist stroke patients in restoring their grasp function efficiently.**

Keywords: Rehabilitation, Grasp, Stroke, Robot assist

I. INTRODUCTION

Every year, according to the World Health Organization (WHO), 15 million people suffer from strokes [1]. People with motor impairments resulting from a stroke have numerous difficulties in their activities of daily living (ADL). At least 30% of stroke victims cannot recover to their pre-stroke condition and abilities.

Fortunately, the brain structures related to stroke injuries can be reorganized and motor functions can be restored via neural plasticity. This has led to the development of various methods of rehabilitative training [2, 3]. Numerous studies have demonstrated that active, repetitive, intentional, and functional training has a significant impact on the recovery of impaired motor functions after brain injuries or strokes [4, 5]. Therefore, conventional therapists assist patients to overcome their motor deficits and improve their motor patterns with repetitive movement practice [6]. This approach is effective for stroke therapy, but it is extremely labor intensive and sometimes requires a long training period, which can lead to financial issues [7].

Recently, in order to solve these problems, robot-assisted physical therapy has been proposed. Robots that perform autonomous and repetitive movements can alleviate the labor intensive physical work by therapists and can be easily customized through varying the velocity and intensity values. Liao demonstrated that the effect of robot-assisted physical therapy for stroke patients is similar to that of conventional physical therapy [8].

Hand functions are essential for ADL, such as grasping a spoon or a fork. However, these functions are difficult to completely recover or rehabilitate. Furthermore, hand impairment causes significant discomfort to stroke patients. Thus, there have been numerous studies on the development of robotic hand rehabilitation devices. Park proposed a haptic upper limb rehabilitation device for pronation and supination therapy; patients use this device to play games that are controlled using various haptic effects that provide more enjoyment to the patients [9]. In a study involving interworking with serious games, Sietsema demonstrated that an activity involving game interworking improves arm reach results [10]. Weinberg made a 2-degree of freedom (2-DOF) hand device using a fluid damper and interworked it into a game scenario for hand rehabilitation [11]. This system has already been applied in hospital therapy; however, it is difficult to use it at home because the fluid device requires a large and heavy control system.

For a grasp rehabilitation system, Lambercy proposed *haptic knob* rehabilitation device for opening/closing and pronation/supination function [12]. He demonstrated the

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positive effects of standard clinical assessments with his proposed rehabilitation device. The *Amadeo* system and its effectiveness have been reported [13, 14]; however, the high cost of the *Amadeo* system limits the application. Exoskeleton rehabilitation devices have also been designed: Ho proposed a hand rehabilitation device to detect the intention of opening/closing movements using electromyography (EMG) [15]. Furthermore, he demonstrated the significant improvement in patients' motor tests through rehabilitation training using the proposed exoskeleton device. In addition to these innovations, Riener presented the concept of patient-driven motion reinforcement (PDMR) control for the control of a functional electrical stimulation (FES)-supported system [16, 17]. In this approach, it is hypothesized that patient-driven training can improve therapeutic outcomes compared with classical rehabilitation strategies.

Recently, brain computer interface (BCI) technology has begun to be applied to rehabilitation applications. This technology has surmounted an insufficient patients' participation found in conventional robot-assisted training. For example, if a patient cannot voluntarily move, the robot assists the patient to move their upper limb after detecting the patient's intention based on motor imagery [18-20]. Although this technology is useful in directly using neuroplasticity, it requires technical assistance from experts in order to measure the patient's intention. Also, patients experience discomfort while the electrodes are attached to their head in order to record electroencephalography (EEG) signals.

In this paper, a hand grasp rehabilitation device is proposed that allows a patient to train the grasping behavior based on their intention and that is easy to use at home as well as in medical contexts. The patient's intention is detected using the press sensors in the device handle when the patient attempts the movement. In addition, the affordable cost and portable size are also advantages of the proposed system.

II. Structure

The proposed system consists of a control unit, two actuators, an infrared (IR) sensor, and pressure sensors in the grasping handle as shown in Figure 1. The main processor of the control unit is a TMS320F2801 digital signal processor (DSP) and it communicates with a PC through a USB channel. The model of actuators is LSA-3024SM by PoteNit. It's stroke lengh is 24 mm and the maximum force is 30 N. These actuators assist the grasping, closing a hand movement, in both passive and patient-driven modes. The model of the IR sensor module is GP2Y0A41SK0F by Sharp. The distance range of the IR sensor is 3 to 5 cm, and it measures the distance that the handle is pulled. The model of pressure sensor is FSR-402 by Interlink. The pressure range of the pressure sensor is 0 to 175 psi, and it measures the pressure of the grasping area. A scenario, such as 'squeeze a lemon', is incorporated into the rehabilitation device; hence, it is expected that patients will be more immersed in and more encouraged to participate in the rehabilitation therapy.

III. Rehabilitation Protocol

A. Passive Mode and Active Mode

In the passive training mode, the proposed device guides the grasping movement for patients who do not have voluntary hand and finger movements. At this time, the patient's hand

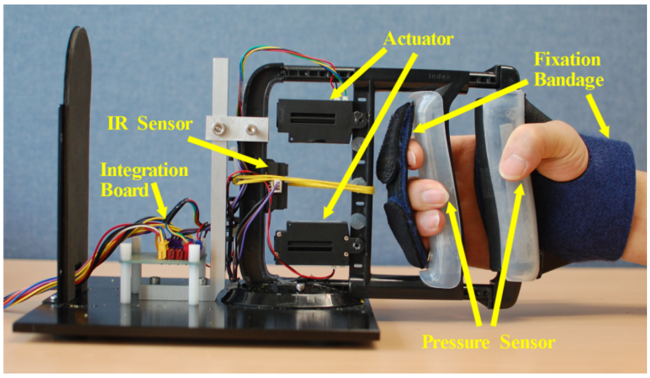
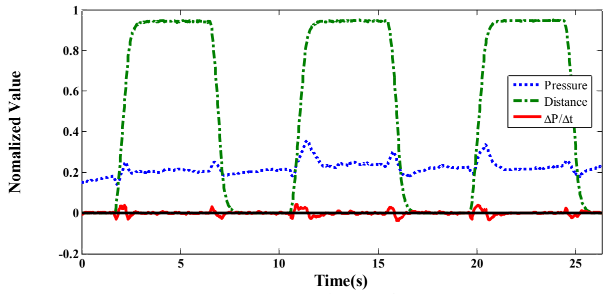
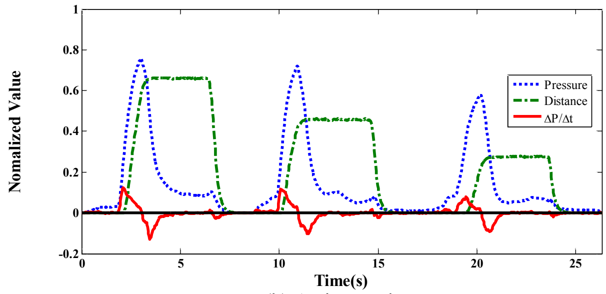


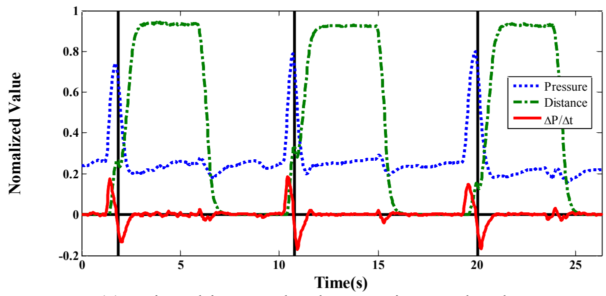
Figure 1. Grasping rehabilitation device.



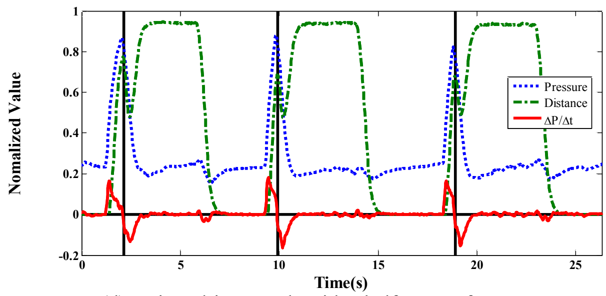
(a) Passive mode.



(b) Active mode.



(c) Patient-driven mode when a patient can barely grasp.



(d) Patient-driven mode with a half range of movement.

Figure 2. The normalized value of pressure and IR pressure sensor and the differential value of pressure for each task mode. The vertical line of the patient-driven mode is the detention of a point to need assistance.

must be fixed to the grasping device; thus, a fixation bandage is included as shown in Figure 1.

In Figure 2, distance is the normalized distance of the handle movement and it is measured using the IR sensor. Pressure indicates the normalized value of the pressure sensor; $\Delta P/\Delta t$ is the difference value of pressure. Min-Max normalization method is used for data normalization. The minimum and maximum values of distance and IR sensor are measured by previous test operation. As shown in Figure 2(a), in the passive mode, the grasping movement is performed regularly. However, the pressure value is too small for the patient's voluntary movement. This demonstrates that the patient does not participate in the grasping movement or participates very little in the grasping task. Even if movement does not occur in the section, there is a baseline pressure. This is the reason for the hand being fixed to the handle of the device as shown in Figure 1.

The active training mode is operated when the proposed device does not need to assist the patient's movement. Stroke patients who have mild effects and almost recovered can train for the grasping movement in this mode. Figure 2(b) shows the active mode. While the patient attempts to grasp, the value of the pressure sensor increases. However, the distance measured by the IR sensor does not reach the maximum value. This indicates that the user could not complete the grasping task. The distance values of the second and third trials are shorter than that of the first trial. It is inferred that in these situations, the patient is becoming exhausted.

B. Patient-Driven (Active Assisted) Mode

Patient-driven (active assisted) mode can be operated using the movement intention for patients with minimal voluntary hand and finger movements. When a patient attempts to move the handle for grasp training, the device detects the patient's attempt through the pressure sensors between the patient's hand and the handle. Figure 2(c) shows the pressure value and device position of the patient-driven mode when a patient can barely grasp. In order to determine the patient's intention, the threshold is established using Equation (1), which is a simple algorithm to determine the timing (vertical black lines in the figure) of the robot assist. At each time frame, the two actuators push the handle of the device to accomplish the grasping behavior.

$$(P_t + \alpha) - P_{t-1} < 0 \qquad (1)$$

where P_t and P_{t-1} are the pressure values at times *t* and *t-1*. α is the sensitivity coefficient.

Figure 2(d) demonstrates when a patient can perform the grasping movement to some extent, but they cannot finish the grasping movement completely as a result of their small range of movement (ROM), even though they attempt it. The vertical line in Figure 2(d) shows the time taken to detect the decrease in the patient's grasping force using Equation (1). After that time, the device assists the patient to complete the grasping movement. In this way, the device can detect the patient's movement intention based on the pressure changes without requiring additional bio-signal devices.

This patient-driven approach can encourage patient participation in training, improve the rehabilitation effect, and result in greater use of neuroplasticity. Meanwhile, conventional robot-assisted rehabilitation is undertaken by moving the patient's impaired limbs passively without considering the patient's intention.

IV. User Study

A. Interview Questions

A small scale, semi-structured interview of two rehabilitation therapists and one stroke patient was conducted. The interview questions focused on usability, acceptability, satisfaction, suggestions for improvement, and general comments. The interview questions and their categories are presented in Table I. The interview data was analyzed as presented below according to the question categories.

TABLE I. INTERVIEW CATEGORIES AND QUESTIONS

Category	**Question**
Convenience[a]	Do you think the proposed device is convenient for patients?
Independence[a]	Do you think patients can use the proposed device on their own without specialists?
Effectiveness[a]	How much does the proposed device assist in rehabilitation training?
Effectiveness[a, b]	Do you think the patient-driven mode assists in rehabilitation training compared with the passive mode and active mode in this device?
Acceptability	If this proposed device is commercialized, do you think that patients can purchase it and train at home?
Satisfaction	How satisfied are you with the proposed device?
Suggestions for improvement & Comments	What are the factors that need improvement? Do you have any other comments or suggestions?

a. Questions for usability.

b. Questions for the patient-driven mode.

B. Interview Data Analysis

In the usability category, there were three types question: convenience, independence, and effectiveness. The key opinion related to convenience was that the proposed device is convenient overall. There were opinions about the independent usability including that "it would be better to include a scenario related to ADL" and "patients need the assistance of therapists at the beginning of the training, but they can use this device independently once they become accustomed to it". For the effectiveness question, there were two significant opinions: "This rehabilitation device provides assistance in training but the handle movement velocity must be adjusted according to the patient's condition" and "the handle of the device should be more comfortable". Furthermore, responses for the effectiveness of the patient-driven mode were obtained. The therapists stated that "it is very effective because the patient is more motivated during grasping training" and "the training in the patient-driven mode is more useful than that of a wrong trajectory or an excessively active movement". This response stems from some stroke patients with deficits attempting excessive movements of the affected part using other physical compensation acts, e.g. whole body movements. Another therapist's opinion was that "this devices assists patients who are not able to spontaneously grasp even thought their effort.

However, just active movement training is appropriate rehabilitation for the patients who are able to do grasping movements with a half ROM". The response to the acceptability question was that a reasonable cost would be an important issue for the diffusion of the proposed device.

However, there was an opinion from a stroke patient that he prefer therapist's guidance more than self-training. The responses to the satisfaction question were primarily affirmative and positive. For the improvement and general comments questions, some valuable feedback was received. If the proposed device includes grasping training and extension training functions, then it will be a better hand rehabilitation device. Furthermore, there were some opinions on the need for the ability to adjust the speed and strength so that patients can use it for adaptive training.

Taken together, the responses to the interviews indicated that a target group who will be able to effectively use the proposed device exists. Furthermore, the patient-driven mode may be useful because it helps users training with motivation and prevents a compensational strategy. However, an improvement of the handle is required in order to give more comfortable feeling to the patients, and the force and velocity must be adjustable in order to be appropriate for each patient's needs. Moreover, it is expected that more patients will use the proposed device if an extension movement is added.

V. Conclusion

In this paper, a robotic rehabilitation device that assists stroke patients for recovering their grasping functions was proposed. Also, a novel patient-driven mode based on the patient's movement intention detected using pressure sensors was proposed in order to directly engage in neuroplasticity. In the user study conducted with therapists and a stroke patient, it was found that the proposed device with the patient-driven approach could be useful for hand rehabilitation. Our proposed device has several limitations. It is needed to adopt adaptive control strategies for each patient's capabilities. Further research focused on investigating the rehabilitation effect of the proposed device will be undertaken through working with stroke patients and constructing solid evidence of the proposed device's benefits using functional neuroimaging devices such as fMRI and EEG.

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