Home Robotic Device for Rehabilitation of Finger Movement of Hemiplegia Patients

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Abstract—In current health care system, it is difficult to have sufficiently long period of rehabilitation in hospital. Therefore, an automated rehabilitation support at home is needed. To this end, we developed a simple robotic device that will support index finger rehabilitation for patients who suffer from aftereffects of hemiplegia. The purpose of the device is to foster voluntary movement of index finger. It has pressure sensors for all fingers, and a power assisted index finger lift mechanism. The power assist lift supports to lift the patient's finger if the lift by voluntary movement is insufficient. The pressure sensors are used to monitor the simultaneous movement of all fingers. By this, the system checks if undesirable movements such as synergetic movements are found. The information is integrated to provide a quantitative measure of recovery. Patients are able to monitor his/her condition and continue rehabilitation as needed. Our device is simple and compact so that it should be placed on a desk at home. The device is used by placing the patient's hand on keyboards. This allows the patients to see his/her fingers during rehabilitation and is expected to enhance the effect of rehabilitation by seeing the result of voluntary movement at his/her real fingers. This paper shows these concepts and the hardware design of this device in detail. This paper also discusses the results of the measurement of hemiplegia patients and the healthy subjects by this device. The results show that the explicit difference was seen between the patients and the healthy subjects, which shows the effectiveness of this design.

I. INTRODUCTION

In Japan, the number of patients of the cerebrovascular disease (CVD) is increasing year by year. By this, the number of persons who suffer aftereffects of this disease is also increasing. It is known that hemiplegia is one of the most common aftereffects. A patient suffering from hemiplegia is not able to perform voluntary movements by the paralysis of one side of his/her body, which causes serious troubles in his/her daily life.

At early stages after onset of hemiplegia, a patient will receive sufficient rehabilitation in a hospital. However, because of the lack of the number of medical institutions, the patient is usually not allowed to be treated in a hospital for a sufficiently long period. Therefore, it is expected that the patient and his/her family, who would not have sufficient medical knowledge, should be able to carry out proper rehabilitation at home by themselves.

To this end, we are developing an automated home rehabilitation support device, which is designed to be simple and easy to use [1].

In this device, we aim at the rehabilitation of fingers. One reason of selecting finger rehabilitation is that the device is to be made compact. Usually, devices designed for finger are small and are easily put on a desk at home.

Another reason is its simplicity. Finger rehabilitation is done by hand assistance at each finger, which is just moving a finger by applying a small amount of force. Therefore, the device does not require large and high-powered actuators.

The last reason is the effectiveness of finger rehabilitation over upper limb functionality recovery. In our previous report [1], it was shown that the training for a finger to get a new movement or skill contributes to acquire a similar skill at an upper limb of that finger. Therefore, the rehabilitation of a finger is also expected to contribute to the upper limb functionality recovery.

In recent years, many types of hand rehabilitation support devices have been proposed[2, 3]. Typical examples are the exoskeleton type devices such as [4, 5, 6]. However, the problem of an exoskeleton type device with joints is its difficulty of properly aligning its joints with the finger joints of a patient. Some globe type soft actuator devices [7, 8] do not need to care about positioning. But the problem of wearing complex device onto a patient’s hand still needs some skills.

The other problem of the exoskeleton and glove devices are that the device cover the entire hand so that the patient cannot see his/her real hand movements.

A patient tries to voluntarily move his/her finger during rehabilitation. If his/her finger looks different from the actual finger, he/she could not feel the reality of trying to move his/her own finger. The importance of seeing an actual body during rehabilitation is known as a visual feedback. It is used in many rehabilitations for hemiplegia patients with hemiparesis [9].

From these points, we have designed our device as a simple set of levers. A patient is only requested to place his/her fingers onto the levers. The lever lifts a finger as a rehabilitation process. It also measures pressure of each finger applied on it during his/her trial of voluntary movement. The time series of these measured pressures contain many information of the patient such as the degree of separation of finger movements and the existence of synkinesis. In our previous research, it is expected to measure the level of recovery from this information [10].
In this paper, we describe the detail of the mechanical design of our finger rehabilitation device. We show that the simple lever (keyboard) mechanism realizes a compact hardware which gives information of the patient’s level of recovery and performs power assistance for finger lift when it is necessary in part of the finger rehabilitation at home.

II. HEMIPLEGIA CAUSED BY CVD

A. Recovery Process of Patients

Recovery of finger movements of a hemiplegic patient consists of three stages. First, a patient suffers flaccid paralysis. At this stage, patients cannot move their fingers at all. Second, the patient exhibits synkinesis and associative reaction. At this stage, when he/she tries to move a finger, other parts of body such as different fingers or hand will move involuntarily. Finally, the patient will be able to perform synergic movement at his/her fingers. This is the stage where voluntary movement at finger is established, and the patient should be regarded as mostly approaching to the normal state [11].

The target of our rehabilitation device is the second stage of the recovery, and the purpose of the device is to help recovery from synergic movement by fostering his/her voluntary movement of a finger. A widely used medical scale for a patient suffering from hemiplegia at a hand is the Brunstrom stage (Brs) [12]. In terms of Brs, we are targeting the stage III to VI. A patient of these stages is usually treated at home and goes to the hospital for periodic treatment. This is the reason for our home use design.

Also, we focus on index finger rehabilitation since it is most frequently used part in fingers in daily life.

B. Detection of Synergic Movement (Positive Sign)

Synergic movement (a positive sign) of fingers is a sign that a patient unintentionally moves fingers other than the finger he/she tries to move. The degree of this positive sign indicates the separation of voluntary movement of their finger, which is usually monitored by a therapist. Therefore, the device we developed has pressure sensors that monitor pressures of every finger to detect synergetic movement and measure its degree.

C. Effect of Visual Feedback

Visual feedback, where a patient looks at his/her fingers during voluntary movements, is known to enhance the effect of rehabilitation [9]. For this, we made our device constructed by simple keyboards where a patient puts his/her fingers onto plates. Fig. 1 shows an overview of the keyboard by CAD drawing. Fig. 2 shows the actual use by a patient. As seen from this figure, the patient easily recognizes his/her fingers.

III. DESIGN OF THE DEVICE

A. Rehabilitation Process by Using the Device

We mount four keyboards (Fig.1) on the rehabilitation device to place a patient’s fingers. The device has a motor to lift the keyboard for an index finger (Fig. 3). By this, we design the rehabilitation process of the device as follows (Fig. 4):

i. The device instructs the patient to raise an index finger.

ii. If the patient can raise the index finger, the device instructs him/her to keep raising the finger for 5 seconds. If not, the keyboard of the index finger assists to raise the patient’s finger by a motor.

iii. After 5 seconds, the device instructs the patient to put back the finger onto keyboard and judges the degree of the recovery. The measured degree of recovery is presented to the patient or his/her family, so that they are expected to keep motivation to continue rehabilitation at home.
B. Hand and Finger Positions

Fig. 2 and 5 show the hand position. Fig. 6 and 7 show a thumb pressure sensor unit. A thumb has a different movement from other four fingers because it has opposition movement [13]. Therefore, the position of thumb largely differs to each person. To fit to the position of the thumb for each patient, we made a thumb sensor unit being affixed by a Velcro tape (Fig. 7).

C. Finger Lift Assistance

The finger lift mechanism can move the keyboard by a geared motor. Fig. 7 shows the lift mechanism. This mechanism uses the 1/128 geared motor operated by DC 6V (HS-GM21-DLW, Fig. 8).

D. Finger Pressure Sensing

The rehabilitation device developed in this study senses finger pressure to judge positive sign and the patient’s recovery. To make the device compact, we use the flexible flat pressure sensors (FSR-402, Fig. 9). As in Fig. 10, we place these sensors on the back of each keyboard. When a patient’s finger presses a keyboard, a small bump pushes the flat pressure sensor (Fig. 11). A thumb pressure sensing unit contains a pressure sensor which is directly pushed by the patient’s thumb (Fig. 12). Additionally, we also place a pressure sensor on a position of a patient’s thenar eminence (Fig. 13).
E. Finger Pressure Sensing During Lift Assistance

In the rehabilitation by this device, a patient is asked to raise his/her index finger. During this period, the index finger pressure is monitored by the flat pressure sensor. If some pressure value is observed, it is regarded that the lift was insufficient, and the index finger lift is assisted by the motor. Monitoring the force to lift the finger is important to measure the level of the voluntary movement for the index finger. However, the keyboard does not touch on the pressure sensor during raising (Fig. 14). To this end, the device has a load cell (strain gauges on an aluminum block) on the finger lift mechanism to sense the finger lift pressure (Fig. 15). Fig. 16 shows an image of sensing the finger pressure during lift assistance.

Figure 9. A flat pressure sensor (FSR-402).

Figure 10. Positions of pressure sensors (from back of the keyboard).

Figure 11. The mechanism of pressure sensor.

Figure 12. Pressure sensor on position of patient’s thumb.

Figure 13. Pressure sensor on position of patient’s thenar eminence.

Figure 14. The keyboard cannot touch on a pressure sensor.

Figure 15. Index finger pressure sensing by a load cell (strain gauge).

Figure 16. An image of finger pressure sensing by strain gauge.
Another important value of determining a degree of recovery is to measure the height of the index finger when the patient is asked to voluntarily lift the finger. This is measured by lifting the keyboard for index finger with a weak power and holding it when it touches on the finger. The motor for lifting the keyboard is associated with a rotary encoder. The encoder measures the angle (the height) of the index finger (POLOLU-2590, Fig. 17, 18). Fig. 19 shows an image of the finger angle sensing by the rotary encoder.

**F. Finger Angle Sensing**

Fig. 17. A rotary encoder (POLOLU-2590).

Fig. 18. Its position.

Fig. 19. Finger angle sensing by rotary encoder.

**IV. EXPERIMENTAL RESULTS**

Fig. 20 shows the entire view of the finger rehabilitation device. The system is fabricated by a 3D printer with ABS resin, and is controlled by a Raspberry Pi 3 with an Arduino microcontroller. Hence the system is inexpensive so that the patients would be able to afford to use at home. The user interface is simple. The user only needs to follow the instructions displayed on LCD and push some buttons. The degree of recovery will also be displayed on the LCD, but this functionality is under construction.

Fig. 20. The prototype.

Fig. 21 and 22 show the profiles of sensory signals measured by the pressure sensors of this device during performing the rehabilitation procedures in Fig. 4. These signals are normalized as having the maximum amplitude to 1. Fig. 21 is by healthy subject and Fig. 22 is by a patient with light hemiplegia. As seen in these figures, there is an explicit difference between two profiles. In Fig. 22, it is shown that the patient is able to lift the index finger since the index finger pressure signal drops down at the time when the instruction to lift was given. However, in Fig. 22, the pressure signals of the thumb (both at the fingertips and thenar) largely changed after the patient tried to raise the index finger. This is a typical synergetic movement which represents that the patient still suffers from hemiplegia aftereffect. The device is able to detect this diagnostic information.
Although index finger is the most used part than the other fingers, there are some cases where severe paralysis is found on other fingers. In that case, the device should be able to change the power assisted keyboard to a different finger position. At this moment, this is only realized at the time of assembling. Another point is the support for patients with severe contracture at finger. The keyboard is designed to fit for a natural posture of hand. But for the patients with highly contracting finger, it is not easy to measure the pressure. To this end, we are considering another type of keyboard that has a fixed joint in the middle.

In future, we would like to carry out long term experiments for evaluation of this rehabilitation device.

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REFERENCES


