Automated Evaluation of Coordinated Movement of Fingers Using Home Rehabilitation Device

Yuta Furudate
Graduate School of Systems Information Science
Future University Hakodate
Hakodate, Hokkaido, Japan
g3118006@fun.ac.jp

Nanami Onuki
Graduate School of Systems Information Science
Future University Hakodate
Hakodate, Hokkaido, Japan
g2118010@fun.ac.jp

Kaori Chiba
Hakodate Medical Association Hospital
Hakodate, Hokkaido, Japan
k-chiba@outlook.com

Yuji Ishida
Faculty of Human Science
Hokkaido Bunkyo University
Eniwa, Hokkaido, Japan
yishida@do-bunkyodai.ac.jp

Sadayoshi MIKAMI
Department of Complex and Intelligent Systems
Future University Hakodate
Hakodate, Hokkaido, Japan
s_mikami@fun.ac.jp

***Abstract*—Home rehabilitation is much in need in ageing societies. Especially, for hemiplegia patients who have paralysis at fingers, it is known that long continuous rehabilitation is effective for recovery. To automate home rehabilitation without the help of a medical specialist, it is desirable not only to provide a rehabilitation procedure but also to give the condition of the paralysis of the patient. In our previous studies, we proposed a robotic device to foster separative voluntary finger lift movement. The device mounts pressure sensors at each finger to monitor the degree of unwanted finger movements. However, it is not clear which is an effective way to measure the condition of paralysis by these finger pressure time series data. In this paper, we propose a new measurement method that is based on the "coordinated movement" of fingers. A patient is asked to perform 4 tasks: pinch2 (pinch movement by index finger and thumb), pinch3 (pinch movement by index, middle and thumb), grasp2 (grasp movement by the ring and little finger), and grasp3 (grasp movement by the middle, ring, and little finger). All pressure time series of finger movements are quantified their dissimilarities with data of standard healthy subjects. We found that the grasp3 has the largest correspondence relation with the degree of paralysis.**

***Keywords*—hemiplegia, rehabilitation robotics, evaluation, hand motor function**

I. Introduction

After developing cerebrovascular diseases, a patient often loses the motor function. Hemiplegia is one of the after-effects and the paralysis appears either the left side or right side of the body if a patient develops hemiplegia. A patient who develops hemiplegia tries to regain the motor function in the hospital. However, many patients leave a hospital without sufficient recovery and the paralysis of hand tends to remain. Although a patient requires home rehabilitation, it is quite difficult to rehabilitate by oneself. For this problem, a lot of hand rehabilitation devices are researched such as exoskeleton type[1] and glove type[2,3]. However, many sensors, actuators, and complicated device prevent introducing to home because of the high cost and difficult to use. Therefore, we have developed a finger rehabilitation device for home rehabilitation as the concept of low cost, simple mechanism and easy to use (Fig. 1) [4]. One of the functionalities of the device is to quantify the condition of the paralysis by using pressure sensors mounted at each finger. In our previous study, we proposed an evaluation method that monitors unwanted

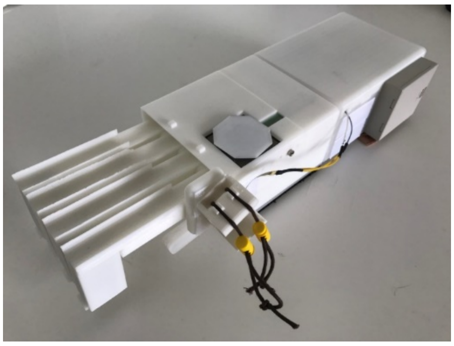

Fig. 1 Home finger rehabilitation device [4].

movements of fingers during voluntary index finger lift exercise. The results showed reasonable correlation with the degree of recovery measured by the clinical scale (Brunnstrom stages). However, this method only assumes a simple one finger movement (lift), which is far from complex daily activities. In this paper, we propose a new measurement method that uses coordinated movement of fingers and quantify the motor function. Our results show that the three fingers movement provides better correlation with the clinical scale of paralysis recovery.

II. Measurement by Finger Rehabilitation Device

A. Sensors in Finger Rehabilitation Device

Fig. 1 shows the device we have developed for home rehabilitation of finger [4]. The device mounts pressure sensors to measure each finger movement. Pressure sensors from index finger to little finger are located behind the keyboard. For the thumb, two pressure sensors are located at thenar part and the fingertip. Self-rehabilitation is performed by lifting index finger, while the insufficient lift is assisted by a motor [4]. We do not describe further into the rehabilitation process and the mechanism. We focus on the evaluation by these sensors in this paper.

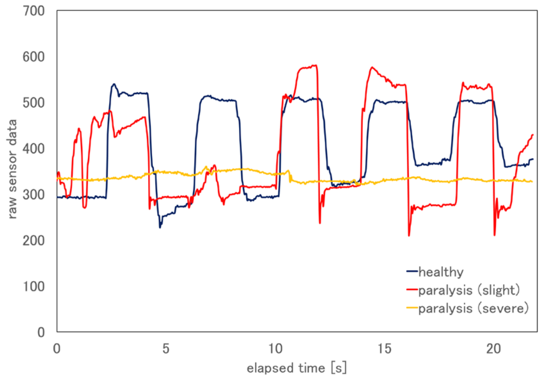

Fig. 2 The thumb signals of each subject (*pinch2)*

B. New Measurement Method by Coordinated Movement of Fingers

As simple and straightforward finger movements that use multiple fingers in coordinated way and that are sensible by our hardware, we propose the following two and three finger movements: *pinch2* (pinch movement by index finger and the thumb), *pinch3* (pinch movement by index, middle finger and the thumb), *grasp2* (grasp movement by ring, little finger) and *grasp3* (grasp movement by middle, ring, little finger). A patient performs each movement (task) five times in every two seconds. During the movemement, finger pressure sensors record the time series of all fingers, by which the degree of recovery is measured as described in the next chapter.

III. AUTOMATED EVALUATION OF MOTOR FUNCTION IMPROVEMENT

A. Overview of the Evaluation System

We assume that the difference between a healthy subject and a patient becomes smaller if the paralysis recovers more (Fig. 2). From this, the system calculates the dissimilarity with the healthy subject at each finger. The input of the system is all finger signals, and the output of the system is the integrated dissimilarity. The evaluation consists of preprocessing and quantification steps. Preprocessing step extracts a single movement and normalize the amplitude. Quantification step calculates the dissimilarities and integrates into a degree of recovery. The details of each step are as follows.

B. Preprocessing Step

This step extracts standardized pressure signals for one cycle of the movement (pinch or grasp). The most stable cycle is extracted by the cross-correlation between a rectangular pulse of the duration of movement and the signal. The amplitude of each signal is normalized by Z standardization.

C. Quantification Step

The dissimilarities with a typical healthy subject are calculated at each finger. Dynamic Time Warping (DTW) is used to calculate the dissimilarity between a healthy subject's signal (template signal) and the patient's signal. The template signal is selected from a set of healthy subject's signals collected in advance. After calculating dissimilarities at each finger, all dissimilarities are added. This integrated dissimilarity is expected to represent the degree of recovery.

Table. 1 Dataset

	group	each number	total
health	health	30	30
Brs. VI	slight	7	15
Brs. V		5	
Brs. IV		3	
Brs. III	severe	3	7
Brs II		4	

Table. 2 Experimental results

	pinch2			pinch3		
	health	slight	severe	health	slight	severe
ave±std	1.014±0.265	1.312±0.306	1.749±0.352	0.873±0.239	1.157±0.312	1.674±0.411
η^2	0.403			0.427		
	grasp2			grasp3		
	health	slight	severe	health	slight	severe
ave±std	1.049±0.268	1.428±0.367	1.892±0.280	0.856±0.205	1.216±0.327	1.855±0.401
η^2	0.438			0.536		

IV. EXPERIMENTS

Table. 1 shows the dataset. The patients are classified into healthy, slightly paralyzed, and severely paralyzed groups according to the clinical scale (Brunnstrom Stage (Brs)). As the evaluation of the automated quantification, the average, standard deviation of the integrated dissimilarity, and correlation ratio are derived from checking whether the integrated dissimilarity has the correspondence with each group. Table. 2 shows that the integrated dissimilarity shows the tendency of becoming smaller as the paralysis recovers. In addition, the correlation ratio of *grasp3* shows the highest value. From these, *grasp3* is the best way to evaluate the motor function by a simple home use device.

V. CONCLUSION

We proposed a new way of automated evaluation for the motor function by using a simple finger sensing device. The method is based on the finger coordinated movements, which are simple but well represent the finger use in daily activities. All finger movements are measured as time-series pressure signals while performing these movements. The evaluation is done by calculating the dissimilarity with the healthy subject's signal. As a result, *grasp3* has the best correspondence with the degree of recovery. From the experimental results, it is supposed that the device can reasonably evaluate the improvement of the hand motor function.

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