Hand Motor Function Evaluation by Integrating Multi-Tasks Using Home Rehabilitation Device

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***Abstract*—Many hemiplegic patients, especially those having paralysis at hand, need continuous rehabilitation after leaving hospitals. To support rehabilitation at home, we have developed a robotic device which provides automated rehabilitation and evaluation of hand motor function recovery. The device monitors the patient's finger movements during voluntary finger tasks. Our idea is to calculate the extent of recovery by asking a patient to perform a specific voluntary movement (task) and calculating the dissimilarity between a typical healthy person's movement and that measured by this device. In our previous studies, we only clarified the evaluation methods for a single task. This paper proposes the integration of these values into a single measurement value by using binary logistic regression. This integration provides the patient with a probability of being classified as a patient and a healthy subject. A home user should easily understand the value. The experimental results show that the integrated evaluation has higher performance over the single task evaluation.**

Keywords—hemiplegia, rehabilitation at home, finger, robot therapy, diagnosis

I. Introduction

Hemiplegia is known as one of the after-effects of cerebrovascular diseases. After developing hemiplegia, a patient undertakes rehabilitation to regain motor function in a hospital. However, because of the increasing number of hemiplegia patients in Japan, there are quite many cases where a patient is not allowed to receive enough rehabilitation at a hospital. Especially, the motor control of hand takes a long time to recover, and paralysis in hand tends to remain by this insufficiency of rehabilitation opportunities. Continuous voluntary rehabilitation should be carried out at home. However, rehabilitation at home is difficult without support from medical staffs, and an automated home rehabilitation support device for hand is desired [1].

In the research of hand rehabilitation device, many types of device are researched such as exoskeleton type [2, 3] and glove type [4, 5]. These devices have many good points specific to each type. However, these has common drawbacks such as high cost and difficulty to handle for elderly person, in the case of home use. Focusing on these drawbacks, the authors have been developing a finger rehabilitation device for home use [6] (Fig. 1 left). Like a human therapist, our device aims at (1) providing automated rehabilitation procedure, and (2) evaluating the extent of paralysis and informing it to the user. In previous reports, the authors have proposed two methods for the automated evaluation of recovery, which are based on a single finger movement [7] and the coordinated finger movement [8]. However, in these reports, the values of evaluations by these two methods are separately given. To provide a single measurement of the recovery of an entire hand motor function, these values should be integrated into a single measurement. In this study, we propose a novel automated evaluation method which integrates single finger movement and coordinated finger movement by using binary logistic regression.

II. Finger Rehabilitation Device and Measurement

A. Measurement Equipments and Overview of Evaluation

In our rehabilitation device, a patient is asked to perform various voluntary finger movements (*tasks*). During movement, the other finger's movements are monitored, which contain the information of the degree of unwanted or paralyzed movements. To monitor the movements, the device mounts pressure sensors at each finger [6]. Pressure sensors corresponding from index finger to little finger are located behind the keyboard (Fig. 1 top right). For the thumb, two pressor sensors are located at the fingertip and thenar (Fig. 1 bottom right).

We prepared two tasks: a single finger movement task and a coordinated finger movement task. In both tasks, the degree of a patient's performance of the finger movement is measured. Also, the tasks are carefully designed to measure whether a patient can suppress undesired movement such as reflex and compensation movement on fingers that are not indicated. We describe each evaluation task below.

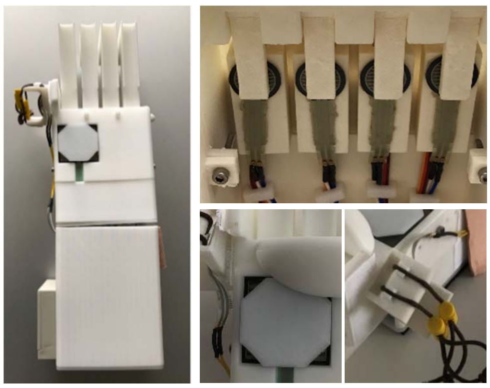

Fig. 1. The overview of the device and pressor sensors

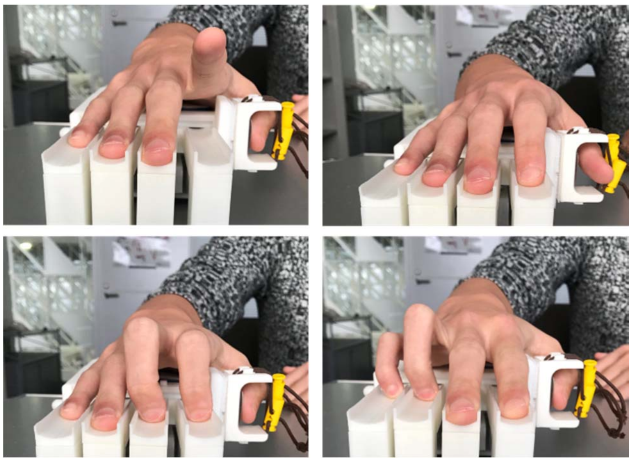

Fig. 2. Example of tasks (top left: *I task*, top right: *T task*, bottom left: *P3*, bottom right: *G2*)

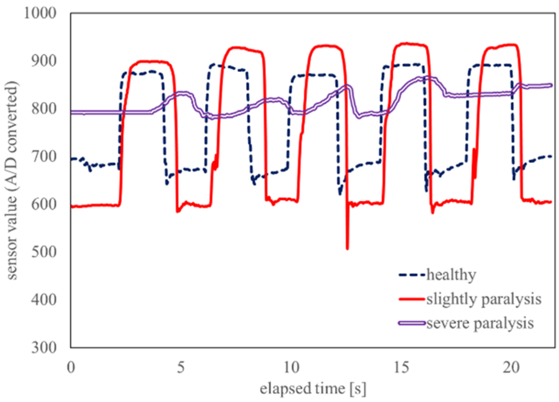

Fig. 3. Measured signals from a healthy subject and patients (index finger in *P2* task)

B. *Task 1: Single Finger Movement Task*

Single finger movement task consists of two small tasks: the task of the index finger and thumb (*I task* and *T task*). Single finger movement task aims at evaluating whether a patient can perform a single finger movement without undesired movements. In *I task* (Fig. 2 top left), a patient is asked to raise an index finger for 8 seconds. After 8 seconds, a patient moves down an index finger. In *T task* (Fig. 2 top right), a patient releases a thumb from the pressure sensor of a fingertip for 5 seconds. After 5 seconds, a patient touches the pressure sensor.

C. *Task 2: Coordinated Finger Movement Task*

Coordinated finger movement task has four small tasks: *P2* (pinch movement by index finger and the thumb), *P3* (Fig. 2 bottom left, pinch movement by index, middle finger and the thumb), *G2* (Fig. 2 bottom right, grasp movement by ring and little finger) and *G3* (grasp movement by middle, ring and little finger). Coordinated finger movement tasks aim at evaluating whether a patient can perform a coordinated finger movement, which appears in daily life. In all tasks, a patient performs assigned finger movements five times in every 2 seconds.

D. *Measured Signals and Hypothesis for Quantification of Hand Motor Function Recovery*

Fig. 3 shows the example of measured signals from a subject who has various extent of paralysis including healthy subject. In healthy subject, there is no disability on his/her hand to prevent finger movement. Therefore, the signal exhibits clear 5 cycles so that the signal reflects that a healthy subject can move correctly. On the other hand, the signal shapes of the patients who have slight paralysis and severe paralysis are different. Especially, the signal of a patient who has slight paralysis is similar to the healthy subject's signal. From this, we can hypothesize that the signal of a patient would become similar to a healthy subject's signal as paralysis recovers.

In addition, our hypothesis is based on not only the shape of a signal but also the clinical scale for evaluating hemiplegia which is called Brunnstrom Stage (Brs). Brs has 6 stages corresponding to the extent of recovery. Higher stage indicates that the paralysis is recovered more. Brs also indicates that a patient's behavior will become similar to a healthy subject if a patient has sufficient potential to recover and if the paralysis recovers ideally. From these discussions, we calculate dissimilarity between a patient's signal and a healthy subject's signal, and quantify the recovery of hand motor function by the dissimilarity.

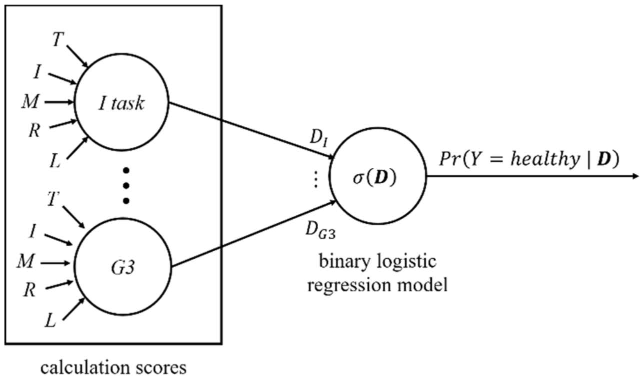

Fig. 4. Overview of the entire hand motor function evaluation

III. EVALUATION SYSTEM OF HAND MOTOR FUNCTION

A. *Overview of the Proposed Evaluation System*

Fig. 4 shows an overview of the proposed evaluation system. In this system, the input is the pressure signals of fingers in all tasks (T: thumb, I: index finger, M: middle finger, R: ring finger, L: little finger). The output is the probability of being labelled as a healthy subject. By showing this probability, a patient can quantitatively know his/her extent of recovery. This system consists of score calculation part and integration part. In score calculation part, as described in chapter II, the dissimilarity between the movement of a patient and healthy subjects is quantified.

B. *Score Calculation*

The score calculation part calculates dissimilarities between the fingers to move and other fingers across all tasks. At fingers to move, dissimilarity between the signal of a patient and a healthy subject is calculated. The dissimilarity is calculated by Dynamic Time Warping (DTW). At the rest of fingers, the absolute difference between RMS of a patient signal and RMS of a healthy subject is calculated. These two kinds of dissimilarities are summed up and the result is outputted as the final score of the score calculation part. For example, the final score of *I task* is D_I, and $\boldsymbol{D} = (D_I, D_T, D_{P2}, D_{P3}, D_{G2}, D_{G3})$ in Fig. 4 is provided as an input to the logistic regression model. By these procedures, the hand motor function is quantified as the following 6 types of scores (*I task, T task, P2, P3, G2,* and *G3*). Here, the

TABLE I. DATASET

	label (dummy variable)	number	total number
healthy	healthy (1)	30	30
Brs. VI	patient (0)	4	9
Brs. V		2	
Brs. IV		1	
Brs. III		2	

representative healthy subject signals and RMS, which are used as a template data, are selected from the pre-measured healthy subjects data in advance.

C. Score Integration

The score integration part aims at integrating all the tasks and evaluating the entire performance of hand motor function. By integrating 6 types of scores described above, the hand motor function is evaluated.

We use binary logistic regression model for the integration. To construct the model, we assign 1 to the set of scores belonging to healthy subjects and 0 to the set of scores belonging to patients. In addition, we applied L2 normalization when the model is constructed.

IV. EXPERIMENTS

A. Dataset and Experiental Procedure

Table I shows the dataset. At the single finger movement task, a subject carries out each task at five times. At coordinated finger movement tasks, a subject carries out each task at one time. After measuring the data across all subjects, scores are calculated and the logistic model is constructed. Template data and test data in the score calculation step are selected by dividing the healthy subjects data by cross-validation. In the model construction, cross-validation is applied to split the data for model construction and for testing. All the patients' data are used as test data.

We compared the performance of the proposed method with our previous study. The previous evaluation method is the one based on a single task [7, 8]. Instead, our new method is based on integrating all the tasks. In the former method, we assigned all finger dissimilarities (DTW dissimilarity and RMS) as input to the logistic model construction. In the latter method, as described in chapter III, all the scores (summed dissimilarities) in all tasks are used as input. The output in both methods is the probability that the input data is labelled as *healthy*.

Our system aims at outputting probability so that the degree of recovery is evaluated quantitatively. To validate the results, we checked the classification accuracy .

B. Experimental Results

Table II shows the experimental results. We compared the accuracy between the proposed method (all tasks integration) and the previous method (a single task evaluation). From Table II, the proposed integrated evaluation exhibits the highest accuracy. Therefore, it is suggested that the system based on the integration of the results of single finger movement tasks and coordinated finger movement tasks gives valid probability.

TABLE II. EXPERIMENTAL RESULTS (CLASSIFICATION ACCURACY)

I task	T task
0.815	0.747

P2	P3	G2	G3
0.793	0.904	0.880	0.840

integration
0.959

V. CONCLUSION

In this study, we proposed an automated evaluation system of hand motor function recovery for our finger rehabilitation device. During tasks, all finger movements are independently measured by pressure sensors as time-series signal. After the measurement, the dissimilarity with healthy subjects is quantified, and the probability of being categorized as a healthy subject is given. From the results, we expect that the proposed evaluation system has high validity.

ACKNOWLEDGMENT

This work was partially supported by JSPS KAKENHI Grant Numbers 18K12170, 18K12164.

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