Quantification Method of Motor Function Recovery of Fingers by Using the Device for Home Rehabilitation

Yuta Furudate, Kazuki Yamamoto, Kaori Chiba, Yuji Ishida, and Sadayoshi. Mikami, Member, IEEE

Abstract—After leaving hospital, patients can carry out rehabilitation by using rehabilitation devices. However, they cannot evaluate the recovery by themselves. For this problem, a device which can both carry out the rehabilitation and evaluation of the degree of recovery is required. This paper proposes the method that quantifies the recovery of the paralysis of fingers in order to evaluate a patient automatically. A finger movement is measured by a pressure sensor on the rehabilitation device we have developed. A measured data is used as a time-series signal, and the recovery of the paralysis is quantified by calculating the dissimilarity between a healthy subject’s signal and the patient’s signal. The results of those dissimilarities are integrated over all finger to be used as a quantitative scale of recovery. From the experiment conducted with hemiplegia patients and healthy subjects, we could show that the proposed method gives the scale value which matches well with a traditional clinical scale.

I. INTRODUCTION

Hemiplegia, which develops after having brain infarction, exists as one of the typical after-effects of this disease. Such patient tries to regain motor function during hospitalization. However, in Japan, a patient is regarded that a disability is recovered after 180 days pass from developing diseases. From this, the cases where a patient must leave a hospital without recovering motor function are increasing. Therefore, the device used by a patient to carry out rehabilitation is extremely required. It is known that many devices assisted rehabilitations show significant efficiency [1,2] and many types of rehabilitation robots are researched. Typical examples are the exoskeleton robot [3,4] and the globe type devices [6,7]. However, if a patient can carry out the rehabilitation by devices, he/she cannot evaluate the recovery of motor function by oneself. Normally, during hospitalization, a patient is evaluated clinical scale based on medical evidence observed by medical staffs. After leaving hospital, a patient cannot rely on a therapist to know the stages of recovery.

In order to evaluate patient, it is necessary for the device to recognize the human movement. Currently, a lot of methods measuring human movement with external devices are researched [8,9]. According to [8,9], a lot of information can be obtained accurately. However, the combination of the rehabilitation device and an external device tend to be expensive. In addition, complicated devices are difficult to operate for a patient. Hence, a device, which is possible not only to carry out the rehabilitation but also to evaluate the recovery, is required. The mechanical simplicity and low cost are also important points to realize these devices placed at home.

To this end, we are trying to develop an automated home rehabilitation device that aims at performing finger rehabilitation procedure. In the finger rehabilitation by a therapist, the procedure starts with asking a patient to lift his/her forefinger. If the lift is insufficient, the therapist may assist to move up the finger. During this process, the therapist carefully observes the behavior of the other fingers. By the degree of involuntary movements observed on the other fingers, the therapist will evaluate the degree of recovery from his/her experiences.

To automate this evaluation process by a device at home, we have to find the way to numerically calculate the degree of recovery from simple sensory time series signals of finger movements. However, there is no method proposed for this purpose.

In this paper, we propose the quantification method of the paralysis to evaluate patients on the prototype developed by our study. Our idea is to compute the differences of the sensory time series of finger movements between the patient and the average of healthy persons, and bind them into a single value. Since the sensor data should easily be obtained by a device at home, we measure a force signal of each finger that pushes down a simple lever (keyboard) (Fig. 2).

This paper is organized as follows. Section 2 describes our hardware to measure the finger movements. Section 3 discusses the correspondence between a force signal obtained by the prototype and clinical scale. The proposed method is described in section 4. Experimental setup, experimental result and discussions are described in section 5. Finally, conclusions and future works are discussed in section 6.

II. HARDWARE OF THE PROTOTYPE FINGER REHABILITATION DEVICE

In this research, the quantification method is proposed by using the simple device we developed [10]. Fig. 1 shows the outline of the device and Fig. 2 shows the placement of pressure sensors to measure the force on keyboards (levers). All fingers are measured by film-type pressure sensors located

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at the back of the keyboard. A motor is associated with the keyboard for a forefinger, which assists the finger to lift if necessary and measures the height of lift by pushing the keyboard until it stops.

### III. **RELATIONSHIP BETWEEN CLINICAL SCALE AND THE FORCE SIGNAL**

**A. Measurement of Finger Movement by Pressure Sensors**

In this section, we describe the procedure of the measurement of 4 finger movements (from index finger to little finger) by using our device. Firstly, a patient places his/her hand on the device and stays still during 5 seconds. Secondly, he/she is asked to raise an index finger as high as possible. Then, the keyboard lifts and measures height. After measuring height, the keyboard goes down and he/she lowers index finger. Finally, he/she stays still for 5 seconds.

**B. Correspondence of Force Signal with Clinical Scale**

Brunnstrom stages (Brs) [11] are known as one of the clinical scales to evaluate the level of paralysis of a patient. Table I shows the Brs for fingers. Brs are defined as 6 different stages, each corresponding to a group of patients having certain behaviors of paralysis. From Table I, a patient of higher Brs is recovered more.

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**TABLE I. BRUNNSTROM STAGE (FINGER) [11]**

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<tr>
<th>Brs</th>
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</tr>
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<tbody>
<tr>
<td>I</td>
<td>Flaccid paralysis</td>
</tr>
<tr>
<td>II</td>
<td>Slight finger flexion or no voluntary finger flexion</td>
</tr>
<tr>
<td>III</td>
<td>No voluntary finger extension simultaneously</td>
</tr>
<tr>
<td>IV</td>
<td>Lateral pinch, slight voluntary finger extension</td>
</tr>
<tr>
<td>V</td>
<td>Facing pinch, cylinder pinch, all finger extension simultaneously</td>
</tr>
<tr>
<td>VI</td>
<td>Voluntary finger movement, independent finger movement</td>
</tr>
</tbody>
</table>

**III. **

**B. Correspondence of Force Signal with Clinical Scale**

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**IV. ESTIMATION OF RECOVERY BY USING TIME SERIES MATCHING OF FINGER FORCE DATA**

**A. Overview**

Fig. 4 shows the overview of the proposed method. Based on the hypothesis, we propose the quantification method by calculating the dissimilarity between a signal (time series of

![Figure 1. The prototype of finger rehabilitation device](image1)

![Figure 2. Pressure sensors location.](image2)

![Figure 3. Signals of movements (force) by healthy subjects and patients.](image3)

![Figure 4. Overview of the proposed quantification method.](image4)
finger force) of a healthy reference subject and that of the patient. In this method, firstly, a reference data set of signals are gathered from a large number of healthy collaborators. This data set is used to choose some representative signals of healthy subjects, which should be compared with the patient’s signal. We refer to these representative signals as template signals. Then, the dissimilarity of signals is evaluated on each finger basis. By integrating each finger’s dissimilarity, the method calculates the degree of recovery of paralysis of a patient.

The points are, how we choose good signals of healthy reference subject (template signal), and how we derive dissimilarities of signals having different values and time scales.

B. Calculation of Dissimilarity of Each Finger

At the measurement phase, the device simultaneously measures force data of index, middle, ring, and little fingers of a patient as force signals. In this method, in order to compare the movement between a healthy subject and a patient, we must select signals that represent all healthy subjects. Here, for this reason, is to eliminate an individual difference.

An arbitrary signal is chosen from a dataset of healthy subjects as a candidate signal. The dissimilarities are calculated between the candidate signal and all the other signals. Here, in order to calculate a dissimilarity, we adopt Dynamic Time Warping (DTW) [12]. By using DTW, a dissimilarity between signals of different length can be calculated. After calculating dissimilarities for a candidate signal, an average for a candidate signal is calculated. This procedure is carried out until selecting all signals are selected as a candidate signal (calculation by duplicate combinations are skip). Finally, 5 signals are selected in order from health signals with the smallest average, as template signals. It should be noted that the number of templates was experimentally chosen as 5.

Once the template signals are prepared, the dissimilarity between input signals (force data of the patient) and template signals is calculated. In the proposed method, we aim to compare with a movement of a healthy subject and a patient. In order to this, it is necessary to compare the shape of 2 signals. For this, input signals and template signals are both normalized as having the maximum amplitude to 1. Then, the method calculates the dissimilarity on each finger by applying DTW to the template signals and the input signals corresponding to that finger.

C. Integrating Dissimilarities of All Fingers

Once the dissimilarities are calculated on each finger, an entire hand movement will be evaluated by integrating those. We adopt multi regression analysis on the 4 dissimilarities from index finger to little finger. In this step, firstly, the dataset that will be used for constructing a regression model is prepared by gathering from a variety of patients and healthy subjects who collaborated with our research.

We add some fine-level values that are considered as corresponding to the degree of paralysis of the patient to the above mentioned coarse objective variable. This procedure is described in detail as follows:

\[ Y(j) = C(j) + 1/4(S_1(j) + S_M(j) + S_R(j) + S_L(j)) \]  \hspace{1cm} (2)

By using \( D' = \{ (D_1(j), D_M(j), D_R(j), D_L(j), Y(j)) | j = 1 ... n \} \), we can derive the regression model as follows:

\[ Y = \beta_0 + \beta_1 X_1 + \beta_M X_M + \beta_R X_R + \beta_L X_L \]  \hspace{1cm} (3)

where \( \beta_0 \) is a constant and \( \beta_i \) is the regression coefficient for the dissimilarity \( X_i \) of the finger \( i \).

When a patient to be evaluated measures the finger force time series (signal), the dissimilarity values \( X_i \) for each finger is calculated from the signal by DTW. The values are given into the equation (3), and the measurement of the recovery will be given in \( Y \).

V. VERIFICATION OF THE METHOD BY EXPERIMENTS

A. Evaluation by Cross Validation

To verify the proposed method, we applied 5-fold cross-validation over the dataset gathered from our collaborators. Firstly, the template signals are chosen from the entire dataset. Then, the dissimilarities are calculated for all data in the dataset. From this, we adopt 5-fold cross validation to create reference data and evaluation data.

At each fold, a regression model is constructed from the reference data. Each element \( j \) of the evaluation data is used to calculate the objective value \( Y(j) \) score from the model. The score for the element \( j \) is taken average over the group \( k(j) \in \{ \text{healthy, slight, severe} \} \). We denote the average score for the group \( k \) as \( A_k(f) \), where \( f \) corresponds to the \( f \)-th fold. Finally, \( A_k(f) \) is taken average over \( f \), which we denote \( A_k \).
B. Experiments with Hemiplegia Patients and Healthy Subjects

Table II shows the dataset of the experiments in this study. Signals of healthy subjects were measured from 50 students, and signals of patients were measured from 14 hemiplegia patients in the neurosurgical hospital in Hokkaido, JAPAN. Each of them agreed on the collaboration with our experiments in advance. Fig. 5 shows a typical situation of measuring the finger force signals by a hemiplegia patient. Healthy subjects and patients carried out the evaluation movement 10 times. The patients involved in these experiments are the persons whose cognitive functions were normal and who were able to carry out the extension movement voluntarily. Thus, the stages of these patients are from Brs. III to VI.

C. Result

Table III shows the result of the experiments. As seen in this table, the patient having lighter paralysis gained smaller score. This means that the output score from the quantification system indicates the recovery of the paralysis. Therefore, the proposed method would effectively be used for the automatic measurement of the paralysis from time series of finger force signals.

VI. CONCLUSIONS

This paper proposed the quantification method of the paralysis on a finger rehabilitation device at home. Evaluating the recovery of paralysis is difficult for a patient who is after leaving a hospital. Therefore, the rehabilitation device that can give an automatic feedback of the level of recovery to a patient is necessary. In our method, the quantity of recovery of a paralysis is given by calculating the dissimilarity between a signal of healthy subject and a signal of the patient. By integrating these dissimilarities over all fingers, the proposed method quantifies the level of recovery in terms of an entire hand movement. In future, we plan to quantify the recovery of motor function more precisely by using force data and other sensory data such as the amount of lift of fingers.

### TABLE II. DATASET

<table>
<thead>
<tr>
<th>Group</th>
<th>Age</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>18–22</td>
<td>50</td>
</tr>
<tr>
<td>Brs.VI</td>
<td>---</td>
<td>1</td>
</tr>
<tr>
<td>Brs.V</td>
<td>62–86</td>
<td>6</td>
</tr>
<tr>
<td>Brs.IV</td>
<td>---</td>
<td>4</td>
</tr>
<tr>
<td>Brs.III</td>
<td>41, 55 (one person unknown)</td>
<td>3</td>
</tr>
</tbody>
</table>

### TABLE III. RESULT OF THE EXPERIMENT

<table>
<thead>
<tr>
<th>Group</th>
<th>$k = $Severe</th>
<th>$k = $Slight</th>
<th>$k = $Healthy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average score $A_k$</td>
<td>0.234</td>
<td>0.192</td>
<td>0.124</td>
</tr>
</tbody>
</table>

ACKNOWLEDGMENT

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REFERENCES


