Evaluation of Forearm Muscular Function of Hemiplegic Patients Using Displacement MMG

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***Abstract*— To realise an automated self-rehabilitation at home, it is necessary to provide proper feedback on the status of the recovery of the patient. In a simple finger rehabilitation, a fingertip force monitor is used to detect undesired and paralyzed movement, which is used to determine the degree of recovery. In contrast to the fingertip force, the balance of flexion and extension of finger muscles is another essential feature of the paralysis. However, simultaneous monitoring of flexor and extensor is impossible by using a single fingertip pressure sensor. Usually, EMG is used to monitor individual muscular activity. However, inexperienced home user will not be able to deal with electrodes properly. In this paper, we propose a device to monitor flexion and extension by a unit which is easy to handle. Also, we propose a method to derive a degree of recovery using the signals collected from this device. The results by data collected from healthy and stroke patients show the potential effectiveness of our method.**

Keywords*— *Hemiplegia, Rehabilitation, Muscular movement, Evaluation

I. Introduction

Hemiplegia is one of the sequelae of stroke and cerebral infarction. When hemiplegia develops, paralysis appears on either the left or right limbs of the body. Fingers are gripped due to abnormal muscle tone. However, finger rehabilitation is particularly difficult to recover, and rehabilitation takes time. As a result, a patient often forced to leave a hospital without enough care. The need for self-rehabilitation at home is increasing.

Under such circumstances, devices for self-rehabilitation at home have been developed [1] (Fig. 1). This device assists an automated rehabilitation of each finger and measures the degree of paralysis [2]. The method is based on a neuro-rehabilitation. Each finger is associated with a keyboard. During the rehabilitation process, the keyboard is lifted by a DC motor to show a patient's desired finger movement. Also, a pressure sensor at each keyboard measures the movement of each finger so that the undesired movement or degree of paralysis will be detected. However, sensing pressure is insufficient to distinguish between complete relaxation and simultaneous contraction, which is one of the important key features of hemiplegic patients.

In this study, we propose an optical sensing method to measure the flexor and extensor muscle activities at the same time during rehabilitation. This paper shows detection hardware, which is easy to use by a home user. Also, this paper proposes a method to derive the degree of paralysis from simultaneous muscular activity sensing. The evaluation is based on the comparison of time-series signals of flexors and extensors with finger movements in healthy subjects and patients.

Fig1. The rehabilitation device

II. Related works

Muscle sound is a technique for measuring muscle activity by measuring minute vibrations or deformations on the skin surface. The degree of muscle sound reflects muscle contraction activity as well as myoelectricity, and its validity and usefulness have been verified, such as Berry [3] and Ito [4]. Also, Oka [5] clarified a method for measuring the amount of deformation of the skin surface using a photo reflector. It was shown that the photo reflector is useful to measure muscle activity during movement, which was difficult to measure with an accelerometer. Measurement with a photo reflector is called *displacement MMG* because it acquires skin surface displacement due to muscle contraction or muscle relaxation.

III. Displacement MMG(dMMG) sensor

A. Simultaneous Measurement of Multiple Muscles

As a method for sensing muscle activity, myoelectricity is famous. However, it cannot be easily used by a home user because treatment of electrode is difficult, and the results largely vary with the choice of places to apply. Therefore, in this study, we measure the flexor and extensor muscle activities during finger rehabilitation using displacement MMG, which can be measured only with optical sensors.

For each measured signal, we propose a muscle function evaluation for hemiplegic patients by calculating the degree of difference between the time series of the muscular activities given by healthy subjects and the patient.

B. *The Sensors*

Fig. 2 shows the sensors developed in this study (Fig. 2). We used photo reflectors (Sparkfun QRE1130), which have a linear distance-voltage relationship around 3 ± 0.5 [mm]. Photosensors are located beneath a 3 [mm] thick rubber sheet. To maintain tolerance against the displacement of targeting muscles, we arranged five photosensors as in Fig. 2(left). An elastic rubber band was used to wrap the sensor with forearm. Also, as the behavior of this sensor, when the muscle contracts, the distance between the skin surface and the sensor gets closer and the output value decreases. Conversely, when the muscle relaxes, the output value increases because the distance to the sensor increases. Fig. 3 shows an image when the muscle contracts.

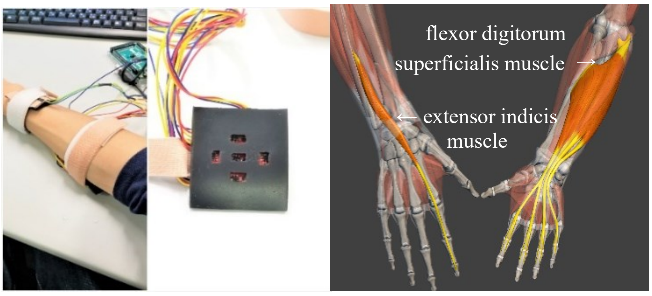

Fig2. dMMG sensor and target muscle (right pictures taken form the *Anatomy-3D Atlas* application).

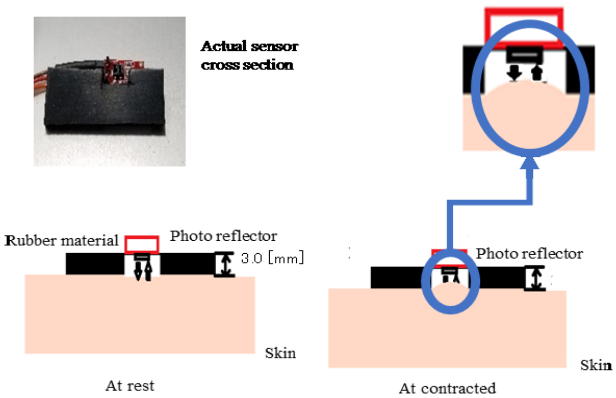

Fig 3. Cross-sectional view of the sensor.

C. *Evaluation of Paralysis by Calculating Differences*

Fig. 3 shows the MMG signal of the extensor indicis muscle during index finger extension. From these signals, as the paralysis becomes mild, the signals resemble those of healthy subjects. The degree of dissimilarity becomes smaller with mild paralysis than that with severe paralysis. Therefore, the degree of recovery will be quantified by the dissimilarity of a patient with a typical healthy subject. From our experiments, it was confirmed that the calculated difference corresponds to the clinical paralysis stage of a patient.

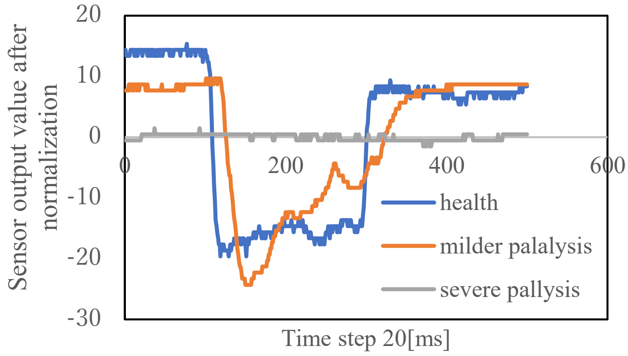

Fig. 4 The signal of extensor indicis

IV. Method of Evaluating Muscular Function

Dynamic Time Warping (DTW) is used to calculate the difference between healthy subjects and patients. Suppose the signal $T_k(k \in \{f, e\})$ (*f*: flexor muscle, *e*: extensor muscle) be one period of a healthy person's dMMG signal, and the signal $X_k(k \in \{f, e\})$ be that of a patient. Calculating the degree of difference of dMMGs between healthy subject and the patient at flexors and extensors as $D_k = DTW(\boldsymbol{T_k}, \boldsymbol{X_k})$, it gives the value of how close the patient's muscular activity is to the healthy condition.

V. Experiments

A. *Evaluation Tasks*

We asked patients to perform (1) all finger flexion/extension movements, and (2) index finger extension movements, which are known as one of the rehabilitation procedures for fingers.

B. *Selection of Reference Healthy Subject Data and DTW Calculation*

Subjects for the experiment were 20 healthy adults (university students) and 11 hemiplegic patients at a neurosurgery hospital. In order to calculate the degree of difference from the patient, it is necessary to choose one reference signal (template signal) for healthy subjects. We created this template of a healthy person in one cycle using leave-one-out cross-validation. The difference is calculated by comparing the template signal of a healthy person with the signal of a patient. The remaining healthy data and patient data were used as input.

C. *Results of Experiments*

TABLE I shows the results of the calculated difference between healthy subjects and patients. Here, *digit* represents the extension movement of the index finger, *af* represents the all-finger flexion/extension action, and *raf* represents the continuous all-finger flexion/extension action. The suffix *(f)* represents the flexor and *(e)* represents the extensor. As a result, the difference between healthy person and patient became smaller as the paralysis of the patient became mild.

TABLE I. RESULT OF DTW CALCULATION OF EACH TASK

	digit(f)	digit(e)	af(f)	af(e)	raf(f)	raf(e)
Healthy	0.394	0.137	0.236	0.235	0.267	0.173
Mild paralysis	1.239	0.575	0.654	1.142	0.703	1.082
Severe paralysis	3.311	3.182	2.630	2.713	3.109	3.455

VI. Conclusion

In this paper, we proposed a method for evaluating the function of flexor and extensor muscles of hemiplegic patients using displacement MMG. As a result, it was suggested that the degree of paralysis could be evaluated by the difference between time-series signals of healthy subjects and patients.

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