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Basic Study on Combined Motion Estimation using Multichannel Surface EMG Signals

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Abstract— **To improve degree of freedom (DOF) of system control using surface electromyogram (SEMG), we made a basic study of the estimation of user's intended motion including combined motion which is performed by more than one basic motion simultaneously. Our developed system requested to obtain three SEMG characteristics of basic motion and one SEMG characteristics of rest state. This study defines the motion of grasp, supination and pronation as basic motion, and two combined motion which is "grasp +supination" and "grasp + pronation" are set. Our system investigates the possibility of combined motion estimation based on SEMG characteristics of basic motions. Estimation method which is utilizing optimal SEMG that are derived from multichannel SEMG signals is performed by canonical discriminant space and tendency of degree of similarity between combined motion and basic motion.**

In experimental results, we succeeded in estimation of combined motion although it was included an estimation of basic motions which were constructed elements of combined motion.

I. INTRODUCTION

RECENTY, an estimation of user's intended motion using surface electromyogram (SEMG) is a widely researched topic. Because SEMG activity is as changes in a time series signal that depend on instruction of motion from a brain, it is thought to include lots of information about user's intention of motion. Thus, many researchers have tried to estimate user's intended motion and apply as a control source for operating some systems (e.g. myoelectric prosthetic hand, etc)[1-3]. The goal of the system operation is to provide the same control feeling as human motion, but there are still many issues to realize such a control due to human's high degree of freedom (DOF) of motion.

To estimate user's intended motion using electrical signals from muscles, it is important how to process this biomedical signal. As for the general processing method, it is performed by employing an appropriate discriminant function after set a target motion which is decided optionally and each measured SEMG motion data is evaluated. Types of discriminant function, such as linear or nonlinear discriminant function, are various and lots of functions are proposed to apply as useful and powerful discriminant function [4-6]. However, the basic procedure to estimate an inputted unknown SEMG motion data is the same. This defines the relationship between type of target motion and the characteristics of measured SEMG data in accordance with the algorithm of their applied discriminant function. In this case, a problem occurs in estimate of user's intended motion, because the number of available target motion is limited to the number of classes which can be estimated clearly. Example of DOF in human motion is, about 10 to the 2th power at a joint level, about 10 to 3th power at a muscular level, about 10 to 14th power at a neuron level [7], quite high. This huge order causes difficulty in significant estimation of motion classes, and this is also an unrealistic way from aspects of quantity of learning requirement and computational complexity. Therefore, it is difficult to improve DOF by one-to-one connection between a control source and an estimate motion.

Against this back ground, this study does not tries this clustering problem to improve DOF, but attempts to estimate a combined motion utilizing multichannel surface SEMG signals. We consider human motion which is performed in daily life is constructed by some basic motions, such as grasp, pronation and extension, etc. Therefore we aim to estimate this combined motion from SEMG characteristics of the basic motions. We set the combined motion and basic motion as a motion related to a hand movement, and SEMG is measured from forearm. To evaluate a characteristics of generated SEMG while performing combined motion, we developed a 96-multichannel surface electrode (See II-A) to measure almost all SEMG information from the forearm. Because there is no useful procedure to find effective measurement location though SEMG measurement position is critical aspect for accurate estimation. We evaluate whole SEMG signals. In estimation experiment, we utilize a few effective channels for every user through evaluation of 96 SEMG signals, and to ascertain whether the combined motion is able to estimate with SEMG characteristics of basic motions included in combined motion.

II. METHOD AND MATERIALS

A. Measurement System of SEMG

To detect whole generated SEMG related with performed motion, we developed a matrix-type surface electrode which composed of 96 silver electrodes. Each silver electrode is 1mm in diameter and that is arranged with an electrode interval, 10mm long and 16mm wide. To fit a bodyline and

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wrap the multielectrode around user's forearm, flexible silicone gum is adopted as the base of 96 silver electrodes. The multielectrode is fixed by a support bandage. The structure of developed multielectrode is shown in Fig.1 and the attached placement on forearm is shown in Fig.2. We also designed the SEMG amplifier, which amplifies an SEMG signal about 3,000 times and the frequency band is limited from 10 Hz to 1,000 Hz. The amplified SEMG signals are sampled by a 16-bit A/D converter at a rate of 2,000 Hz. SEMG measurement and signal processing are performed on a computer by Microsoft Visual C++ language.

B. Combined Motion

There are lots of requirement to perform a combined motion in daily life. For example, in case open a door, hand needs to rotate with grasping a doorknob and it is thought that a grasp motion and pronation or supination are performed simultaneously. We think this is one example of combined motion, and this study defined the combined motion as motion which is performed by more than one basic motion simultaneously. As for the basic motion, we set as motion which is simple movement and easy to combine. From this point and performed frequency in usual days, we set three motions of "grasp", "pronation" and "supination" as a basic motion. As for the combined motion, to enable a combination of these three basic motions, it is set to two motions of "grasp + pronation" and "grasp + supination". Investigation of the SEMG characteristics of the two combined motions is key of this study; we examine the effects of different characteristics of SEMG by 10,000 combinations of the SEMG signals which measured from different location based on 96-ch multichannel surface electrode.

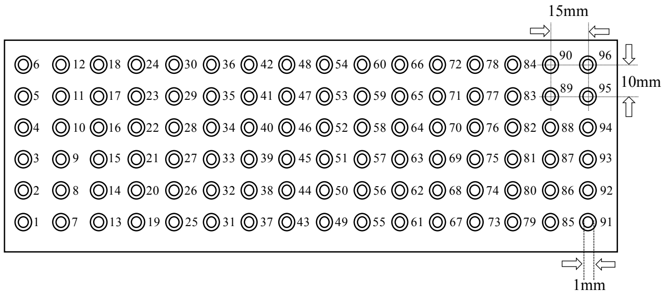
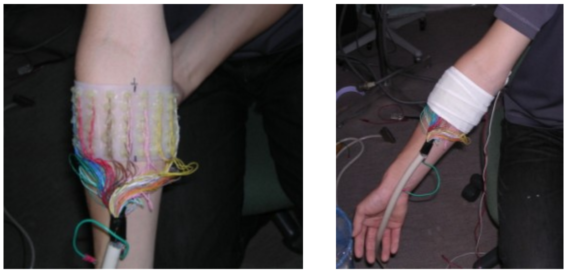


Fig.1 Structure of the 96-channel surface multielectrode. By the side of each electrode is shown the placement number from 1 to 96



(a) **(b)**

Fig.2 (a) Attached placement of multielectrode on forearm. (b) Overview of a fixed multielectrode by support bandage.

C. Signal Processing for Combined Motion Estimation

1) Measurement location of SEMG signals: Our developed system is able to acquire 96 SEMG signals; however, to use all signals makes two issues mainly. These are the loss of quick response and an obstruction of simplicity and ease of use. Therefore, we need to reduce the number of SEMG signals and it is necessary to select a few effective SEMG signals. But as mentioned before, selecting measurement electrode location is difficult due to SEMG characteristics changes that caused by individual differences. A characteristic of measured SEMG is greatly affected by the location, but there is no useful procedure to find effective measurement location. Almost all of the conventional method, there is no other way according to an anatomical knowledge. However, despite of the same measurement condition, measured SEMG signals show huge differences depending on the individual structure of the muscle and the diversity of personal factors. Example of this difference is shown in Fig.3 as a 4bit gradation display which made by SEMG amplitude of grasp motion. Thus, we utilize 10,000 configurations which generated by randomly selected number to evaluate various types of SEMG characteristics (i.e. Monte Carlo method is applied) and the property of measured SEMG is analyzed respectively without prejudice about anatomical knowledge.

2) Discriminant function: The Canonical Discriminant analysis (CDA) is applied as a discriminant analysis. This linear discriminant analysis is a dimension-reduction technique and that makes a small number of canonical variate to clearly indicate the difference between each group.

The SEMG feature extraction is performed by an integrated time and that is set to 300 ms. Now, each component of feature extraction X_i is denoted by

$$X_i = c\sum_{n=1}^{N}\left|x_i(n\Delta t)\right| \tag{1}$$

where c is the constant for normalizing patterns, $x_i(t)$ is the sampled SEMG value at time t of i channel, and Δt is sampling period. The discriminant function Z is defined by

$$Z = \mathbf{a'}(X - \overline{X}) = \sum_{i=1}^{r} a_i (X_i - \overline{X}_i) \tag{2}$$

where $\mathbf{a'}$ is the transpose vector of $\mathbf{a}$, r is the number of components. As shown in equation (2), canonical variate Z is uniquely decided depending on coefficient vector $\mathbf{a}$.

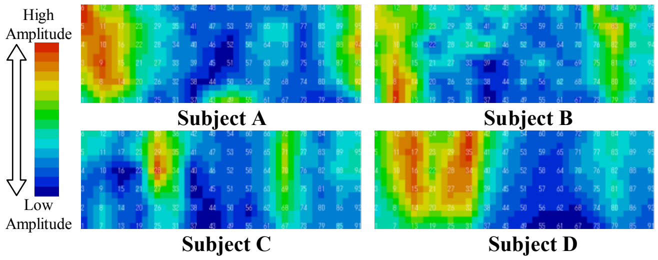


Fig.3 This figure is a SEMG distribution map of hand grasps for four subjects. Attached multielectrode position and measurement condition are the same among all subjects.

Eventually, we obtained the eigenvalue problem, and three canonical variate of Z_1, Z_2, Z_3 are obtained. These three variates construct a canonical discriminant space to estimate motion group and it is decided by selecting a minimum Euclidean distance based on this space.

3) Estimation Index: Our system needs estimation index for extracting SMEG characteristics of basic motion included in the combined motion. Thus, we first examine a characteristics change of combined motion on constructed the discriminant space as a pre-experiment. Pre-experiment are performed as follows.

a) Three basic motions and rest state are inputted into PC by each five trials. (i.e. Predefined motion for the estimation is four in total.)

b) Four electrodes configuration which is specific location for every subject is selected to achieve accurate estimation of these four target motions.

c) SEMG of two combined motions is recorded each 300 ms while combined motion is performed.

As for a way of performed motion, we didn't instruct the subject how to perform the basic motion. We requested to execute same way in their daily life. Fig.4 shows plot points of combined motion performance test on two-dimensional discriminant plane of four predefined motions. From Fig.4, a feature of combined motion was visually similar to predefined motion characteristics in this constructed discriminant plane. As for the Fig.4-(a) which shows a performance of “grasp + pronation”, plot point of combined motion (shown as blue diamond) was distributed in the vicinity of the predefined pronation group (shown as purple X mark) and the predefined grasp group (shown as green triangle). And it began a change from a predefined rest state group (shown as red square). In Fig.4-(b) which shows performance of “grasp + supination”, it is also distributed in the vicinity of the predefined supination group (shown as light blue asterisk) and the grasp group.

So, we evaluated the degree of similarity (DoS) between inputted combined motion characteristics and predefined motion characteristics. And the DoS was calculated by every three basic motions. The change of each the DoS during the combined motion performed was shown in Fig.5.

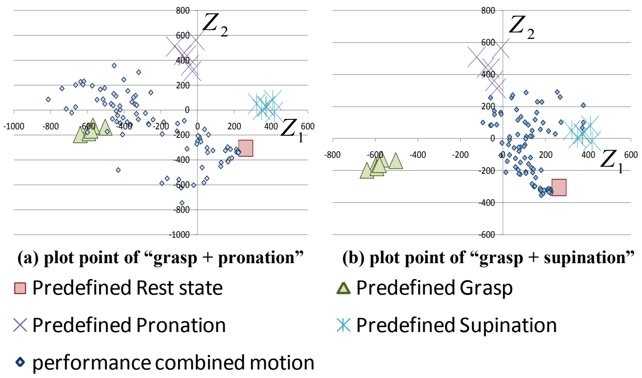


Fig.4 Plot point of combined motion on constructed discriminant plane

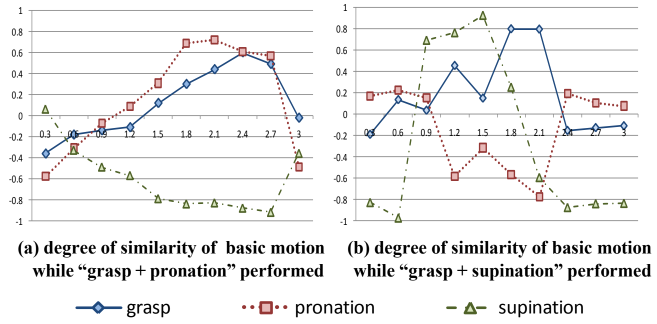


Fig.5 Degree of similarity of each basic motion in combined motion. Horizontal line shows time period and vertical line shows DoS value.

From Fig.5-(a), in case of “grasp + pronation” combined motion performed, we can see an upward tendency of DoS in grasp (shown as blue line) and pronation (shown as red line) along with motion performed. But a supination (shown as green line) which is not related to this combined motion shows downward tendency of the DoS. In the case of “grasp + supination” combined motion performed shown in Fig.5-(b), it is also confirmed the same tendency; the DoS of grasp and supination which are combined as a basic motion shows an upward tendency, but the other motion’s DoS shows a downward tendency. Furthermore, we consider the change of DoS exhibited signs of turn of combined motion. As for the Fig.5-(a), it was estimated that both motions were simultaneously performed. And in the case of Fig.5-(b), it was estimated that grasp was performed after supination was significantly performed. These estimation results were matched with hearing result to the subject after pre-experiment. Therefore, in this study, we adopted DoS as estimation index for extracting feature between combined motion and basic motion in addition to constructed canonical discriminant space. The constructed canonical discriminant space for four basic motion and detection of upward tendency of DoS try to accurate estimation of six motions including two combined motions.

III. ESTIMATION EXPERIMENT

To evaluate our system, we tested two normal subjects. Before an estimation experiment, each subject was decided own four electrodes configuration through a pre-experiment.

Estimation result of motion which combined grasp and pronation is shown in Fig.6, and the result of motion which combined grasp and supination is shown in Fig.7. As for Fig.6 and Fig.7, a horizontal line is time series in performance combined motion and a vertical line shows a type of estimated motion by our system. Decided the estimated motion during combined motion performance test is plotted beside the name of motions in time series, and plot points are shown as square in each 300 ms which is an integrated time length as SEMG feature extraction. In Fig.6 and Fig.7, the basic motions are shown as blue square and the combined motions are shown as red square respectively.

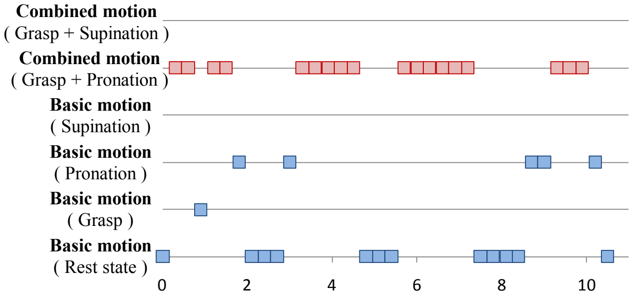


Fig.6 Estimated motion during combined motion. Performed combined motion is " grasp + pronation ".

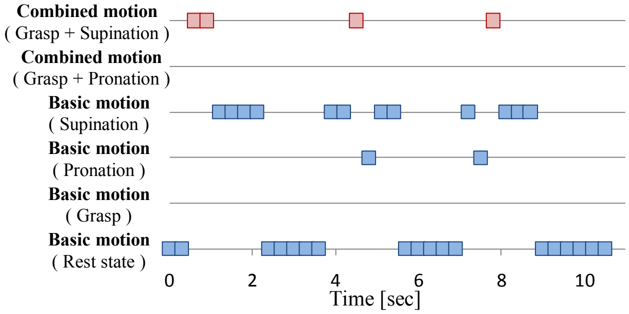


Fig.7 Estimated motion during combined motion. Performed combined motion is " grasp + supination ".

From Fig.6, we could see an accurate estimation of motion which combined grasp and pronation. Fig.6 also showed the estimation of grasp and pronation which were combined as basic motion. Since these basic motions were constructed elements of combined motion, and canonical discriminant space and DoS were calculated only using SEMG data of the basic motion, we thought the characteristics of basic motion significantly appeared even if subject intended to perform combined motion. However, there was no inaccurate recognition which means the motion that was not an element of combined motion appeared. We also utilized hearing result from subject to evaluate an estimation of combined motion. The subject in this case performed four trials of combined motion, and Fig.6 showed the same consequence. Estimated motion were changed from rest state to "grasp + pronation" combined motion, but at the moment of start to move and end of motion showed some constructed basic motion. It was thought that the cause was turn of the constructed basic motion even if they intended to perform these basic motions simultaneously.

From Fig.7, we could see an estimation of motion which combined grasp and supination. Constructed elements of basic motions are also estimated, but there was some incorrect estimation. In this experiment, though we requested subject to perform combined motion of grasp and supination, pronation was appeared. Since constructed canonical discriminant space and DoS based on basic motions were not corresponded to estimate combined motion, we need to brush up our system and improve estimation method.

IV. CONCLUSION

This study tried to estimate combined motion only using SEMG characteristics of basic motion. To calculate canonical discriminant space and DoS, we utilized four optimal electrodes configuration from multichannel SEMG for each subject, and it suggested a possibility of combined motion estimation.

As for an estimation experiment, we succeeded in estimation of "grasp and pronation" combined motion, however, combined motion of "grasp and supination" did not obtain accurate estimation. One of these reasons is constructed discriminant space which is not able to discriminate basic motions clearly. This experiment evaluated 10,000 sets of configurations and we decided the one which showed the best estimation accuracy. Thus, we obtained clearly significant accuracy of combined motion in compared with worst configuration used. But, it needs more research whether it is most suitable and useful for the estimation of combined motion. In this study, since an adopting canonical discriminant space and DoS showed one of usefulness, we'd like to investigate more effective estimation method.

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