EFFECT OF SURFACE ELECTRODE ORIENTATION ON INDEPENDENT COMPONENT ANALYSIS FOR FEATURE EXTRACTION OF SURFACE MOTOR UNIT ACTION POTENTIAL

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Abstract: Recently, application of Independent Component Analysis (ICA) has been reported for effective decomposition of surface electromyogram (SEMG) signals into a train of surface motor unit action potentials (SMUAPs) of a single motor unit (MU). Results of ICA were not always sufficient as the feature extraction of SMUAP at first dorsal interosseous muscle (FDI). The purpose of this study is to propose an effective method for feature extraction of SMUAP by simulation study of focusing on the effects of electrode orientation. SEMG signals were created with the model and application of ICA was applied to the signals. The present study showed that the useful and actual method of ICA application was to repeat measurement of SEMG signals with varying the electrode orientation, and then to select the better signals for the feature extraction by executing ICA algorithm.

1 INTRODUCTION

In the field of sports science and rehabilitation, electromyogram (EMG) observed with the surface electrode, rather than the invasive needle electrode, is often used to investigate behaviors of the motor units (MUs). Then the surface EMG (SEMG) could be decomposed into a train of surface motor unit action potential (SMUAP) of a single motor unit. Subsequently, such factors as waveform of the SMUAP, firing rates, recruitment, de-recruitment, territory of the MUs could be examined.

Recently a few researches have been reported: Xu, Xiao, and Chi (Xu et al., 2001) were proposed the method using the artificial neural network. Bonato, Erim, and Gonzalez-Cueto (Bonato et al., 2001) were proposed the method using the method in the area of time frequency. Recently, Independent Component Analysis (ICA) (Bonato et al., 2001) algorithm has been applied to the decomposition method for large muscles such as biceps brachii muscle by Maekawa, Arimoto, Kotani, and Fujiwara (Maekawa et al., 2002), Nakamura, Yoshida, Kotani, Akazawa, and Moritani (Nakamura et al., 2004), and Gonzalo, Okuno, and Akazawa (Gonzalo et al., 2005). While we applied to first dorsal interosseous muscle (FDI), results of ICA were not always sufficient as the feature extraction of SMUAP. It was difficult to separate SMUAPs because several types of SMUAPs appeared in the single ICA component.

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2 METHOD

2.1 Experimental Set-up

The subject put his hand on the desk horizontally where the thumb and the fingers were loosely fixed except the index finger. The isometric adductor torque of the index finger was measured with strain gauge. SEMG signals were obtained with eight-channel bipolar surface electrodes array shown in Fig. 1. The electrode was placed over the FDI. Each electrode was stainless wire of 1 mm diameter, a pair of electrodes was placed with inter-electrode spacing of 2.54 mm and each pair was placed in parallel with spacing 2.54 mm. The SEMG signal was amplified with the gain 60 -80 dB and the cut off frequency 800 Hz.

The subject was instructed to keep the constant force of 5% maximal voluntary contraction (MVC) by watching the force output displayed with bright lines on the oscilloscope. Both the isometric force and the eight-channel SEMGs were A/D converted at the 10 kHz sampling frequency. Informed consent was given to each subject.

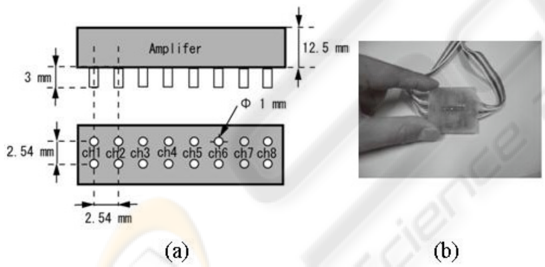


Figure 1: Eight-channel bipolar surface electrodes.

2.2 SEMG Model

Spatial information such as MU territory, muscle fiber and electrode, is shown in Fig. 2 (a). In the present study, Griep's tripole model (Griep et al., 1982) was used to calculate the action potential generated on the skin surface by the excitation of a single muscle fiber.

As shown in Fig. 2, the axis x is defined to be perpendicular to the skin surface, the axis z is the moving direction of excitation of the muscle fiber and the axis y is direction orthogonal to x and z. The distance between the electrode and the axis of muscle fiber is x_n in the x-axis, and y_n in the y-axis. The distance between the electrode and each point current source is z_{ni} (i = 1, MU, 3) in the z-axis at $t = 0$ (the time beginning of excitation of the muscle fiber) and $z_{ni} + v\ t$ at the time t, where v is the conduction velocity of excitation. The action potential of a single muscle fiber monitored at the electrode is given as

$$\Phi(x_n, y_n, z_{ni}, t) = \frac{1}{2\pi\sigma_M} \sum_{i=1}^{3} \frac{I_i}{\sqrt{{x_n}^2 + {y_n}^2 + (z_{ni} + vt)^2}} \quad (1)$$

where σ_M is conductivity of the volume conductor and I_i the strength of the point current source.

Assume that individual muscle fibers within the MU are all identical in their characteristics and different in their locations and the number of muscle fibers is N, the potential at the electrode is given by

$$\Phi_{MU}(x) = \sum_{n=1}^{N} \Phi_n(x_n, y_n, z_{ni}, t) \quad (2)$$

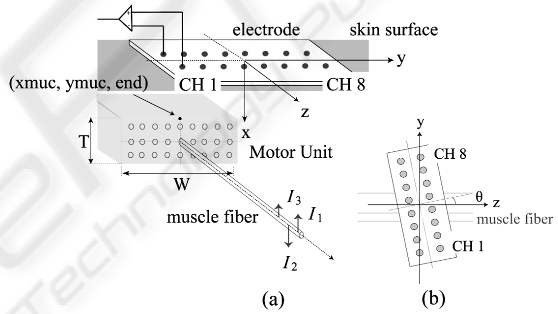


Figure 2: Illustration for the SEMG generation model. (a) Spatial relation between the electrode and the muscle fiber; (b) Electrode angle θ.

3 RESULTS

3.1 Simulation

<Parameters for tripole model> As to the tripole model, following parameters were used ; conductivity of the volume conductor was σ_M = $0.16\,(\Omega^{-1}m^{-1})$ (Disselhorst-klug et al., 1998), point current was $I_1 = 0.4\,(\mu A)$, $I_2 = -0.5\,(\mu A)$, and $I_3 = 0.1\,(\mu A)$ (Griep et al., 1982). The distance between I_1 and I_2 was 0.45 mm, and that between I_2 and I_3 was 1.8 mm (Griep et al., 1982). The conduction velocity v was 3.5 (m/s) (Disselhorst-klug et al., 1998).

<Location of MU> Because we estimated that territories of single MU of FDI were mostly square-

type (Akazawa et al., 2005), squared territory model is used here. As shown in Fig. 2 (a), *W* is the width, *T* is the thickness, *xmuc* is the distance from skin surface to the top of the MU, and *ymuc* is the center of the MU. For the simplicity only two groups of MU were used; the number of small-sized group was hundred and that of large-sized group was ten. Distribution of the size was Gaussian. Mean values of *W* and *T* were 10 mm, and 10 mm respectively for the large-sized MU, and 1 mm and 1 mm for the small-sized MU. The thickness of skin surface/fat tissues was assumed to be 2.0 mm and the width of FDI was 2.0 cm.

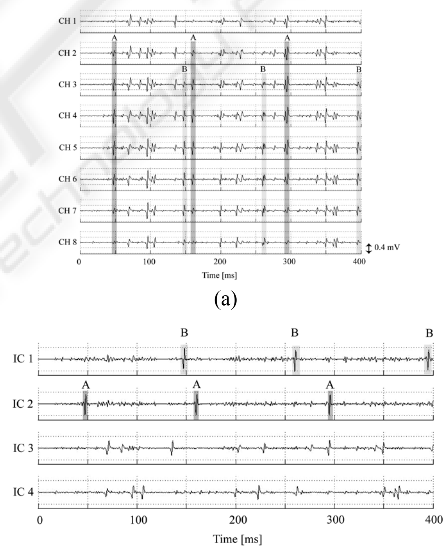
<*Firing Rates*> The firing rates of MUs in isometric contraction were examined statistically by Clamann (Clamann, 1969). His finding that the distribution was Gaussian was applied to the present model. Because the isometric contraction to be studied in the present study was approximately 5% MVC, the mean firing rate was assumed to be 7 Hz for all the MUs. It was showed that at the low force level of isometric contraction, firing of individual MUs is statistically independent (Kanosue et al., 1979). This results was applied to the present model concerning to the firing time of MUs.

<*Electrode* > The position of each electrode is fixed with the actually used electrode in Fig. 1. Simulation was executed with changing the electrode angle θ up to 40 degree. Orientation of only the one large-sized MU was changed from zero to certain value for understanding clearly the effect of electrode angle, while electrode angle of other MUs is zero.

<*Effects of Electrode Orientation on ICA* > Effects of changing the electrode angle were examined by simulation study; firstly eight-channel SEMG of 1 (s) duration were created by the model of SEMG generation, and then ICA was applied to the SEMG. Eight channel SEMG of the model with the electrode angle of 0 degree is shown in Fig. 3 (a). The output signals which are obtained by applying the ICA algorithm to the SEMG signals in Fig. 3 (a) are shown in Fig. 3 (b).

Clear signals (SMUAP-like signals) with almost the same waveform are apparently found on the first component IC 1, while very small amplitudes of signals are found in IC 1 component. Judging from the time of appearance, these SMUAP-like signals in IC 1 correspond to the SMUAP marked with B in Fig. 3 (a); MU corresponds to this SMUAP is referred to as MU (B). Furthermore, no SMUAP-like signals are found at the same time in other components IC 2, IC 3, and IC 4. These results mean that feature of MU (B) is extracted by ICA explicitly. Similarly the same type of SMUAP-like signals are also found in IC 2 in Fig. 3 (b), which correspond to MU (A) in Fig. 3 (a).

The effect of electrode angle was examined. Fig. 4 shows thus obtained component of ICA. SMUAP-like signals are found at the same time in IC 1 and IC 2. The angle between the electrode and the MU is 10 degree. On the other hand, clear SMUAP-like signal is found in IC 3, which corresponds to the MU of the electrode angle of 0 degree. When the electrode angle changes to 30 degrees, SMUAP-like signals appear in all the ICA components from IC 1 to IC 8. This result implies that SMUAP amplitude of the MU (A) in SEMG signal is so large that the SMUAP-like signal appears in two or more components of ICA. Executing these simulations, we found that as the electrode angle increased, the number of components in which SMUAP-like signals of the same MU appeared was increased, and the number of MUs the SMUAP-like signal of which appeared in one component was also increased.



(a)

(b)

Figure 3: SEMG and ICA. (a) SEMG signals. (b) The output signals obtained by applying ICA algorithm to SEMG signals.

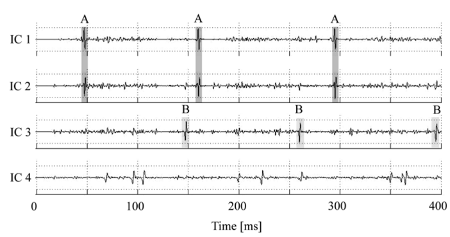


Figure 4: Results of ICA with electrode angle of 10 degree.

3.2 Result with Consideration of Electrode Orientation

Apart from insufficient, we tried to obtain better results with repeating measurement three times with changing the electrode orientation. Isometric contraction was at 5% MVC and the duration 15 (s). The result of ICA is shown in Fig. 5 (a) and the corresponding measured SEMG in Fig. 5 (b). In IC 1, SMUAP-like signals marked with × could be found clearly; briefly the corresponding MU is called MU 2. The larger amplitude signal marked with open circle ○ was also found in IC 1; the corresponding MU is called MU 1. In IC 3, a large amplitude SMUAP-like signal marked by ● was found. This MU might correspond to MU 1 because of appearance at the same time in both IC 1 and IC 3. Consequently the feature extraction of MU 2 was effectively sufficient in IC 1, and small amplitude signal corresponding to MU 3 was found in IC 2 as shown with triangle △. Focusing attention on IC 1 and IC 3, MUs marked by ● and ○ are the same MU 1. This conclusion could be supported by comparing the SEMG signal in Fig. 5 (b) with ICA in Fig. 5 (a). SMUAPs of MU 1 are clearly seen from CH 1 to CH 6 in Fig. (b) and those of MU 2 from CH 3 to CH 5. It should be noted that both SMUAPs of MU 1 and MU 2 in CH 5 are very similar in the shape, which means that decomposition of SMUAP is difficult in judging from only the SEMG signal.

4 CONCLUSIONS

In this study, effects of electrode orientation on the result of ICA was analyzed with simulation study and actual voluntary isometric contraction of FDI. Obtained results were as follows. When the long axis of the eight-channel electrode was perpendicular to the long axis of muscle fiber, the result of ICA was best in terms of the feature extraction of SMUAP; large amplitude of SMUAP-like signals of the single MUs appeared in one component of ICA. As the orientation of the electrode changed apart from this direction, unexpected results of ICA were obtained; i.e., large amplitude of SMUAP-like signals of the single MUs appeared almost at the same time in other components of ICA, and SMUAP-like signals of different MUs appeared in one component.

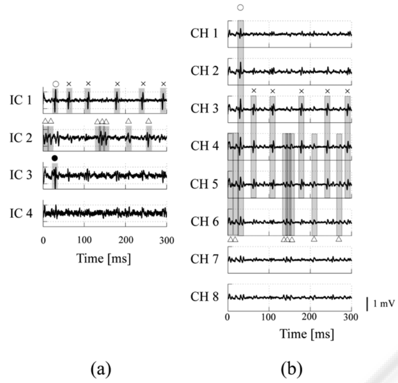


Figure 5: Result of ICA (a) and measured SEMG (b) at 5% MVC of isometric contraction.

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