Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Development of the input equipment for a computer using surface EMG

○Keiichi Ando[†], Kentaro Nagata[†], Daisuke Kitagawa[†], Naoki Shibata[†]

Masafumi Yamada[‡], Kazushige Magatani[†]

†Department of Electrical and Electronic Engineering, University of Tokai, Japan,

‡Kanagawa Rehabilitation Institute, Japan

Abstract:
SEMG(Surface EMG) has many benefits, for example measuring SEMG is easy and a characteristic pattern of SEMG is obtained for each different movement. Therefore, SEMG that is generated by body movement is able to use as a control signal for some electric powered equipments. Our objective is the perfect control of the computer by using SEMG that is generated from forearms. In this paper, we will talk about our developed interface system that works as a keyboard of the computer.

Key Words: EMG, Multi Channel Electrode

I. OBJECTIVE

Recently, with the advance of information technology, the computer becomes an indispensable equipment in our human society. Normal person can receive benefit from these equipments. However, the disabled for example who has no forearm cannot use computer without some supporting equipments. Even if a disabled person cannot use his/her hands, in many cases, his/her remaining muscle can generate EMG. Therefore, they can use a computer, if the some kinds of EMG that are generated from remaining muscle are able to use as the discriminator for the instruction of a computer. So, our objective of this study is the development of a virtual system that works as the keyboard of a computer and is controlled by SEMG.

II. STRUCTURE OF OUR SYSTEM

A block diagram of our system is shown in Fig.1. This system consists of a SEMG measuring component and a personal computer. A SEMG measuring component measures and amplifies 96 channels SEMG that are led from 2 units of 48 channels multi-channel electrodes. A personal computer of the system analyzes measured multi-channel SEMG and generates instruction codes that control a computer as a keyboard.

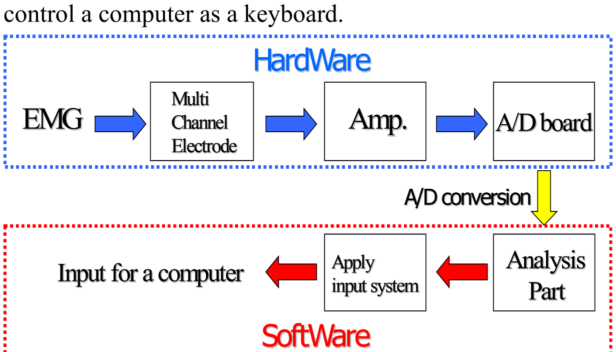


Fig.1 System Block Diagram

Fig.2 shows a block diagram of one channel SEMG amplifier. As shown in this figure, SEMG from an electrode is amplified about 4400 times and limited it's frequency band (from 10Hz to 1.5kHz) and removed hum noise. Fig3 (a) shows an unit of SEMG amplifiers. This unit includes 6 channels SEMG amplifiers. Fig.3 (b) shows a SEMG measurement system that includes 16 SEMG amplifier units. So, this system can amplifies 96 channels SEMG. Outputs of this system (amplified SEMG) are analog to digital converted (Sampling Frequency of 2kHz is used) in a personal computer and then are analyzed.

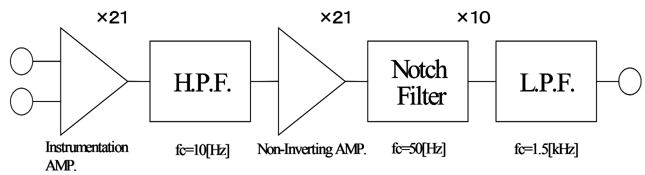
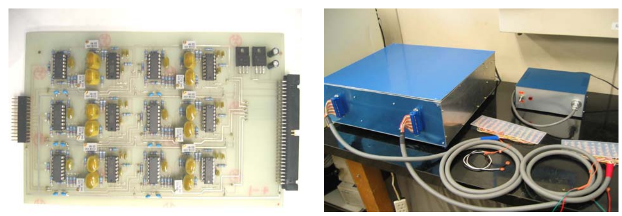


Fig.2 Block Diagram of 1chAMP.



(a) AMP. Board(2×3) (b) EMG AMP.(48ch×2)

Fig.3 EMG Measurement Sysytem

A structural chart of multi–channel SEMG electrode is shown in Fig.4. This multi-channel electrode is composed of 48 silver electrodes, and these electrodes are arranged 12 x 4 on the silicone rubber of 3mm in thickness. Each silver electrode is 1mm in the diameter. In our system, besides this multi-channel electrode, two ordinary Ag/AgCl electrodes are used for the measurement. One is for the common and the other is for reference. Fig.5 shows one pair of the multi-channel SEMG electrodes. In our system, these electrodes are put on the forearms. One is for left arm and the other is for right arm. An electrode on the forearm is fixed by using a supporter.

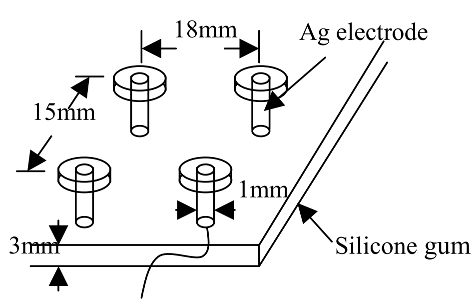
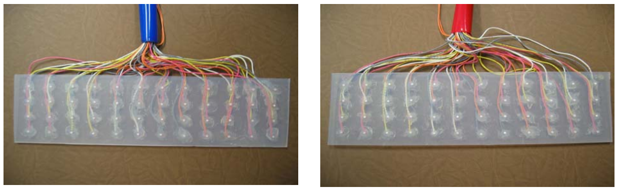


Fig.4 The illustration of multi channel electrode



(a) left arm (b) right arm

Fig.5 48 channel electrode

III. THEORY OF ANALYSIS

In our system, the movement of hand is recognized from forearm SEMG and each movement is assigned to one kind of key typing. So, we have to estimate a type of hand movement from measured forearm SEMG. In our system "Canonical Discriminant Analysis" is used for this purpose. And we do not use all channels of multi-channel electrode for the real time recognition. Because, SEMG analysis using all 96 channels of SEMG will be a heavy load for computer processing. In our multi-channel electrode, one line of electrode array includes 12 channels. And from early research, it is confirmed that high recognition rate is obtained by using about EMG of 12 channels. So, in this study, we used 12 channels EMG. However, we can select optimal 12 channels from 48 channels to recognize hand movement based on the characteristics of subject's independent SEMG pattern. In our system, the benefit of using a multi-channel electrode that includes 48 channels is this. In this part, we describe about "Canonical Discriminant Analysis of our system" and "how to select optimal 12 channels".

III-1. Canonical Discriminant Analysis

Now, each characteristic value of SEMG $X_i(i=1,2,\cdots 12)$ is defined by

$$X_i = c\sum_{i=1}^{Ti} | x_i(t) | \qquad (3.1.1)$$

Where c is the constant for normalizing patterns, $x_i(t)$ is the sampled SEMG value at time t and T_i is summation period. In our system T_i is set as 300ms. The discriminant function Z is defined by

$$Z = a'(X-\overline{X}) = \sum_{i=1}^{p} a_i(X_i - \overline{X}_i) \qquad (3.1.2)$$

Where p is the number of component. As shown in (3.1.2), Z is uniquely decided, if the coefficient vector a is obtained. The within-class covariance of Z is given by

$$S_w = \sum_{k=1}^{g}\sum_{\alpha=1}^{n_k}(Z_\alpha^{(k)} - \overline{Z}^{(k)})^2 /(n-g) = a'Wa \qquad (3.1.3)$$

And the between-class covariance of Z is given by

$$S_B = \sum_{k=1}^{g} n_k(\overline{Z}^{(k)} - \overline{Z})^2 /(g-1) = a'Ba \qquad (3.1.4)$$

And then, the coefficient vector a of discriminant function Z is obtained under the condition that maximized the ratio $\lambda = S_B / S_w$, that is

$$\lambda = \frac{S_B}{S_W} = \frac{a'Ba}{a'Wa} \Rightarrow \max \qquad (3.1.5)$$

From this condition,

$$(B - \lambda W)a = 0 \qquad (3.1.6)$$

is derived. The other solution of (3.1.6), excluding $a=0$ is given by next equation.

$$|W^{-1}B - \lambda E| = 0 \qquad (3.1.7)$$

Where E is the unit matrix. Therefore, we can obtain eigenvalues $\lambda_1 > \lambda_2 > \cdots > \lambda_m$ and eigenvectors $a_1, a_2, \cdots, a_m$ from equation (3.1.7). Where m is the minimum of $g-1$ or p. In order to discriminate SEMG patterns, the first 4 eigenvectors are chosen to form a discriminant space. We evaluated suitable number of eigenvector using a contribution rate. So, we used 4 eigenvectors whose accumulation contribution rate is up to 80%. Then, the group is classified by selecting a minimum Euclidian Distance or Maharanobis Distance.

III-2 How to select electrodes

In our system, 12 channels electrodes of a multi-channel electrode are used for recognition. Selecting 12 channels from 48 channels makes possible to select optimal electrodes in order to recognize hand motion for each subject's independent SEMG. In our system, 12 channels are selected the following procedure.

1) 1000 sets of 12 channel electrodes are generated randomly.
2) Mean value of recognition rate of hand movements are calculated for each sets of electrodes.
3) The set of electrodes that marks highest recognition rate is used.

This procedure is very simple and easy. However, this method works very good.

IV. KEYBOARD INTERFACE

In our system, 13 types of movements for each hands are recognized by using the method as mentioned earlier. So, 26 types of hand motion are used for our objective. However, there are about 100 keys in ordinary keyboard and this number is greater than 26. Therefore, in order to assign these motions to key typing, an interface system is necessary. In our system, a keyboard is separated into three parts. This concept of separated keyboard is shown in Fig.6. As shown in this figure, "Default Line" is from "A" key to "L" key. "Top Line" is from "Q" to "P". And "Bottom Line" is "Z" to "M". As the system default, selected key line is set to "Default Line". If a subject flex his/her finger in this condition, one character of "Default Line" is inputted. The relationship between the flexed finger and inputted character is shown in Fig.6. And pronation of right arm changes selected key line to "Top Line", supination of right arm changes selected key line to "Bottom Line". After input of one character of "Top" or "Bottom" line, selected line changes to "Default Line". For example, in "Default Line", flex of left index finger causes input of "F" key. In our system, some special key like "Shift","Ctrl", and so on, is assigned to the hand motion as shown in Fig.7.

	Left Finger					Right Finger				
mode	Little	Ring	Middle	Index	Thumb	Thumb	Index	Middle	Ring	Little
Top	Q	W	E	R	T	Y	U	I	O	P
Default	A	S	D	F	G	H	J	K	L	
Bottom			Z	X	C	V	B	N	M	

doing pronation of right arm

	Left Finger					Right Finger				
mode	Little	Ring	Middle	Index	Thumb	Thumb	Index	Middle	Ring	Little
Top	Q	W	E	R	T	Y	U	I	O	P
Default	A	S	D	F	G	H	J	K	L	
Bottom			Z	X	C	V	B	N	M	

doing supination of right arm

	Left Finger					Right Finger				
mode	Little	Ring	Middle	Index	Thumb	Thumb	Index	Middle	Ring	Little
Top	Q	W	E	R	T	Y	U	I	O	P
Default	A	S	D	F	G	H	J	K	L	
Bottom			Z	X	C	V	B	N	M	

Fig.6 Input system for the Alphabet

Left arm				Right arm	
Shift	Alt	Ctrl	backspace	Enter	Space
WRIST FLEXION	WRIST EXTENSION	ULNAR DEVIATION	GRASP	GRASP	RELEASE

Fig.7 Input system for the special key

V. EXPERIMENT

One normal male subject is tested in our system. Types of recognized hand motion are shown in Table1. At first, preliminary experiment was done in order to select 12 optimal electrodes for each hand. After this experiment, 4 eigenvectors are chosen to form a discriminant space as mentioned earlier. An example of the projection of this space to 2 dimension plane is shown in Fig.8. As shown in this figure, each hand motion is mapped different space each other, and each motion can be separated.

Using selected 12 channels for each hand, real time recognition experiment was done. In this experiment, Euclid Distance and Maharanobis Distance are used for the discrimination. Table 2 shows the recognition results of the right hand, and the results of the left hand is shown in Table 3.

Table1 13 Requested Movement

Wrist Flextion	Flextion of Thumb Finger
Wrist Extension	Flextion of Index Finger
Grasp	Flextion of Middle Finger
Release	Flextion of Ring Finger
Pronation	Flextion of Little Finger
Supination	
Radial Deviation	
Ulnar Deviation	

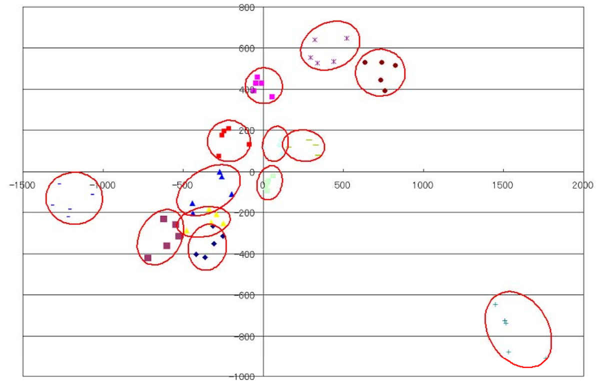


Fig.8 Two-dimensional map of 13 groups in the z1-z2

Table2 Recognition Rate of right arm

Euclid Distance		*Maharanobis Diatsance*	
Requested Movement	**Recognition Rate**	**Requested Movement**	**Recognition Rate**
Wrist Flextion	**80.0%**	Wrist Flextion	**100.0%**
Wrist Extension	**100.0%**	Wrist Extension	**70.0%**
Grasp	**100.0%**	Grasp	**100.0%**
Release	**90.0%**	Release	**60.0%**
Pronation	**90.0%**	Pronation	**100.0%**
Supination	**100.0%**	Supination	**90.0%**
Radial Deviation	**50. 0%**	Radial Deviation	**100.0%**
Ulnar Deviation	**90. 0%**	Ulnar Deviation	**100.0%**
Flextion of Thumb Finger	**100. 0%**	Flextion of Thumb Finger	**100.0%**
Flextion of Index Finger	**100. 0%**	Flextion of Index Finger	**80.0%**
Flextion of Middle Finger	**80. 0%**	Flextion of Middle Finger	**100.0%**
Flextion of Ring Finger	**100. 0%**	Flextion of Ring Finger	**100.0%**
Flextion of Little Finger	**90. 0%**	Flextion of Little Finger	**100.0%**
Average of Recognition Rate	**90. 0%**	**Average of Recognition Rate**	**92.3%**

Table3 Recognition Rate of left arm

Euclid Distance		*Maharanobis Distance*	
Requested Movement	**Recognition Rate**	**Requested Movement**	**Recognition Rate**
Wrist Flextion	**90.0%**	Wrist Flextion	**100.0%**
Wrist Extension	**100.0%**	Wrist Extension	**70.0%**
Grasp	**100.0%**	Grasp	**60.0%**
Release	**90.0%**	Release	**100.0%**
Pronation	**100.0%**	Pronation	**100.0%**
Supination	**70.0%**	Supination	**90.0%**
Radial Deviation	**100.0%**	Radial Deviation	**100.0%**
Ulnar Deviation	**90.0%**	Ulnar Deviation	**90.0%**
Flextion of Thumb Finger	**100.0%**	Flextion of Thumb Finger	**100.0%**
Flextion of Index Finger	**90.0%**	Flextion of Index Finger	**100.0%**
Flextion of Middle Finger	**90.0%**	Flextion of Middle Finger	**90.0%**
Flextion of Ring Finger	**100.0%**	Flextion of Ring Finger	**70.0%**
Flextion of Little Finger	**100.0%**	Flextion of Little Finger	**100.0%**
Average of Recognition Rate	**93.8%**	**Average of Recognition Rate**	**90.0%**

VI. CONCLUSION

In this paper, we describe about the our developed system that works as the keyboard of a computer and is controlled by SEMG. In order to recognize hand motion, optimal selected 12 channels SEMG of each arm are measured and analyzed, and canonical discriminant analysis is used. As shown in Fig.8, we can separate every groups of hand motions in canonical space. So, we think that both Euclid Distance and Maharanobis Distance are effective in discriminating. As shown in Tabel2 and Table 3, Maharanobis Distance is better than Euclid Distance for right arm in average recognition rate. On the contrary, Euclid is better than maharanobis for left arm. And the recognition rates that use both distance are more than 90 %. These rate are sufficient for our system.

And for keyboard interface system, this system worked very well. However, we think that there is better way to select key characters. In future, we need to create easy input method. Therefore, we've concluded that if some problems are improved, our system will be a very valuable one to support activities of amputees.

In our system, we don't pay attention to cross-talk between each channel of the multi-channel electrode. However, we think that there are some cross-talks between each channel. In future, we would like to check the influence of cross-talk. And we also will test our system by using more than ten subjects and evaluate our system.

REFERENCES

[1] Kentaro NAGATA, Keiichi ANDO, Masafumi YAMADA, Kazushige MAGATANI, "A Classification Method of Hand Movements Using Multi Channel Electrode", IEEE EMBC 2005:Proceedings of the 27th Annual International Conference of the IEEE

[2] Kentaro NAGATA, Masafumi YAMADA, Kazushige MAGATANI, "Recognition method for forearm movement based on multichannel EMG using Monte Carlo method for channel selection", Proceeding of the International Federation for Medical & Biological Engineering Vol.12(2005)

[3] Takara T. and Imai S., "Isolated Word Recognition Using DP-Matching and Maharanobis Distance" (in Japanese) Trans. IECE Japan, Vol.J66-A, No.1, pp.64-70(Jan 1983)