Development and Evaluation of a Wireless Interface for Inputting Characters Using Laplacian EMG

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Abstract—We developed a compact wireless electrode containing an amplifier, a filter and a transmitter to measure the Laplacian electromyogram (Laplacian EMG) using the source derivation method. We made a character input system by connecting a circuit converting Laplacian EMG signals to clicks, with a personal computer in which a software for scanning character input was installed. We evaluated the system by comparing two integrated EMGs (IEMGs) measured with a conventional amplifier: one measured when the Laplacian EMG was used as an input signal to the system during a character inputting task, and the other measured when the conventional EMG was used. The IEMG was smaller in all of five subjects when the Laplacian EMG was used as the input signal than when the conventional EMG was used.

I. Introduction

Recently, information and communications technology such as the internet and e-mail, are rapidly progressing and spreading around the world. As a consequence, the digital divide has been extended between persons able to easily use information technology and the rest, especially persons with physical disabilities. Therefore, it is essential to develop some interfaces that enable persons with physical disabilities to operate a pointing device and/or a character input device more easily.

While a variety of switches and sensors are tried for the human-computer interfaces, biosignals also provide a potential for the interfaces. In particular, electromyogram (EMG) signals have often been used as control signals for a prosthesis hand [1], a manipulator [2] and a pointing device [3], because EMG signals contain useful information such as intended motion, muscle force, and muscle impedance. However, conventional interface employing wired electrodes and amplifiers narrowed the range within which persons with physical disabilities can use computers, and, in some cases, even prevented the use of computers. For example, it is difficult for persons disabled physically by cerebral palsy to use wired interfaces because involuntary limb movements often occur while using.

In this paper, we developed a compact wireless electrode containing an amplifier, a filter and a transmitter to measure the Laplacian electromyogram (Laplacian EMG). Then we made a character input system by connecting a circuit converting the Laplacian EMG signals to clicks, with a personal computer in which software for scanning character inputs was installed.

II. Theoretical Basis of Body Surface Laplacians

The use of the body surface Laplacian has been first proposed by Hjorth in electroencephalogram in 1975 [4] and by He and Cohen in electrocardiogram in 1992 [5], but not in electromyogram until now. Considering a local orthogonal coordinate system (x, y, z) with origin at a point on the body surface where the z axis is orthogonal to the body surface, the Laplacian EMG, L_S, is defined by applying a Laplacian operator to the body surface potential ϕ as follows:

$$L_S = -\nabla_{xy}^2 \phi \equiv -\nabla_{xy} \cdot \nabla_{xy} \phi \equiv -\left(\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} \right). \qquad (1)$$

If the body is assumed to be a linear, isotropic and piecewise homogeneous conductor, the gradient of the electrical potential ϕ is proportional to the electric field:

$$-\nabla \phi = E . \qquad (2)$$

On the other hand, Ohm's law requires

$$E = \frac{1}{\sigma} J \qquad (3)$$

where J is the current density and σ is the electrical conductivity.
Combining Eqs.(1-3) gives

$$L_S = \nabla_{xy} \cdot E_{xy} = \frac{1}{\sigma} \nabla_{xy} \cdot J_{xy} = \frac{1}{\sigma} \left(\frac{\partial J_x}{\partial x} + \frac{\partial J_y}{\partial y} \right). \qquad (4)$$

The following equation describes that the divergence of the total current vanishes under quasi-static conditions:

$$\nabla \cdot J = \frac{\partial J_x}{\partial x} + \frac{\partial J_y}{\partial y} + \frac{\partial J_z}{\partial z} = 0 \qquad (5)$$

where $\nabla\cdot$ is the divergence operator. By substituting Eq. (5) into Eq.(4), L_S can be expressed as

$$L_S = \frac{1}{\sigma}\left(-\frac{\partial J_z}{\partial z}\right) = -\left(\frac{1}{\sigma}\right)\frac{\partial J_z}{\partial z}. \tag{6}$$

Thus the Laplacian EMG signal is negatively proportional to the normal derivative of the normal component of the current density at the body surface [5]. Therefore, Laplacian EMG is supposed to be sensitive to the firing of the muscle right under the site at the measurement. Accordingly, the signal is potentially useful as an input for human interfaces, because it is less susceptible to the interferences caused by the activity of approximal muscles than the conventional EMG signal.

III. Wireless Interface for Character Input

Fig.1 shows the block diagram of the developed wireless interface for inputting characters. In the first stage, the Laplacian EMG is measured with the developed wireless electrode, and transmitted to a receiver over a low-intensity radio wave with 300 MHz. In the second stage, the received signal is rectified and integrated, then converted into pulses by analog circuits. Then, pulses are converted to click signals of a mouse connected to a personal computer (PC). In the PC, where a scanning software for inputting characters is pre-installed, horizontal cursor scanning is stopped and changed to vertical scanning by a first click signal, and a character is selected and displayed on the screen after a second click.
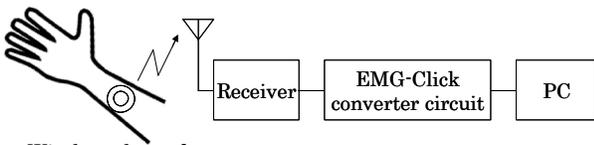
Fig. 1. Block diagram of the developed wireless interface for inputting characters.

A. Compact Wireless Electrode for Laplacian EMG Measurement

Fig.2 shows the diagram of a part of the circuit measuring the Laplacian EMG in the compact wireless electrode. The circuit is composed of measuring electrodes, an instrumentation amplifier, a high-pass filter, and a noninverting amplifier. The amplification factor of the instrumentation amplifier is set to 1. The input impedance is set to 200 MΩ by connecting resistors in parallel with the input of the instrumentation amplifier. The input impedance is selected to be much larger than the contact impedance between the electrode and skin, generally assumed to be 10 kΩ, so as to remove conductive adhesive gel or paste. The time constant of the high-pass filter is set to 1.0 s, i.e., cutoff frequency 0.16 Hz. The amplification factor of a noninverting amplifier can be changed from 2000 to 4000 (from 66dB to 72dB) by a variable resistor. Fig.3 shows the appearance of the assembled wireless electrode.
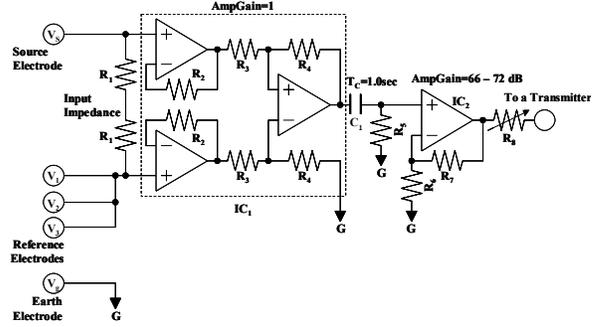

Fig. 2. Circuit diagram of EMG measuring part with filtering and amplification circuitry.

Fig. 3. An Image of the developed wireless electrode for Laplacian EMG measurement. The left is top view and the right is bottom view.

B. EMG-click Converter Circuit

Fig.4 shows the block diagram of the developed circuit converting the EMG to click signals used for a mouse. The circuit is composed of a voltage follower, a high-pass filter, an inverting amplifier, a full-wave rectifier, a voltage integrator, a comparator, an inverting amplifier, a relay and a mouse controller. In the first stage, the high-pass filter with a cutoff frequency of 100 Hz rejects the low frequency component of the EMG to reduce the baseline fluctuation. In the second stage, the filtered signal is amplified by 10, rectified by a full-wave rectifier to produce the absolute value and then integrated. The comparator and the inverting amplifier generate a pulse, when the integrated signal exceeds a threshold in the comparator, which has a hysteresis to prevent chattering. The threshold can be altered by a variable resistor in the comparator. When a "high" signal is input to the relay circuit, two terminals of a mouse controller are short-circuited, and then a click signal is generated by the controller. The click signal transmits a user's intention to the scanning software.
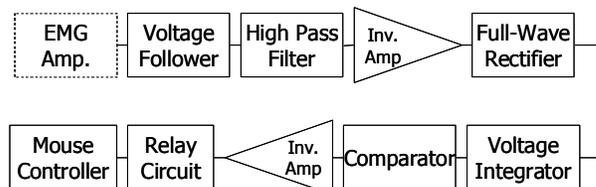

Fig. 4. Block diagram of the developed EMG-click converter circuit.

C. Scanning Software for Character Input

This section outlines the scanning software. Fig.5 shows an

example of the execution screen in the scanning software. The software was originally developed to accelerate the character selection by conventional scanning. The user interface is based on the standard matrix design used in many commercially available communication aids in Japan. The most distinctive feature of this software is the use of multiple cursors. A user first selects the column containing the desired character with the cursors moving from the left to the right, and then selects the row with the top-to-bottom cursors. As the cursors move synchronously on the matrix, multiple characters are simultaneously selected. To solve this ambiguity, the software estimates the most probable sequence of characters using the n-gram model of Japanese syllabic characters [6] and then determines one character. Simulation results showed that almost 95% of determined characters were correct when two cursors and the 4-gram model were used. Because the width of the Japanese syllabary is inherently larger than the height (nearly two times), the selection of a character at the right-hand side of the matrix used to be very time-consuming. The use of two cursors reduced by half the time required for the column selection. Theoretical analyses showed that the two cursor method decreased the time for input operation by 29.6% with the character correct rate of 95% [7].

Characters are determined in this scanning software only by clicks. Therefore, the character input is realizable using the Laplacian EMG, the wireless electrode and the interface circuitry described before.

Fig. 5. An execution screen of the scanning communication system.

IV. EVALUATION OF THE DEVELOPED SYSTEM

A. Comparison between the Laplacian and Conventional EMGs

The Laplacian and conventional EMGs were simultaneously measured from a normal subject. The compact wireless electrode was attached on the flexor carpi ulnaris muscle of the right forearm of the subject to measure the Laplacian EMG. For the conventional EMG measurement, two electrodes with leads were attached on the both sides of the wireless electrode along the muscle fiber, and a reference electrode was attached on the distal end of the radius of the same forearm. Fig.6 shows EMGs recorded when each of four fingers of the right hand was bent 10 times to mimic click motions. The top recording exhibits the Laplacian EMG, and

the bottom the conventional EMG. Dotted lines divide the recordings into four sections one of which is the EMG recorded at each finger. In the conventional EMGs nearly the same amplitude was observed for all bent fingers, while in the Laplacian EMGs the amplitude was clearly different among them. Therefore the Laplacian EMG is expected to discriminate among the finger which is bent more accurately than the conventional EMG.
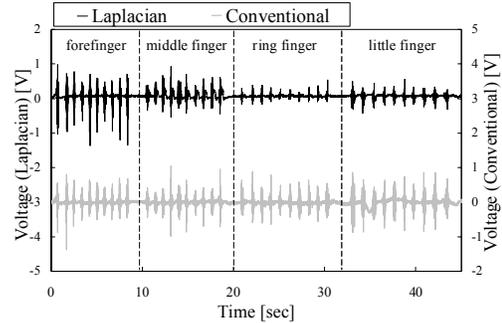

Fig. 6. Recordings of Laplacian (top) and conventional (bottom) EMGs.

B. Character Input using Finger Motion

The compact wireless electrode was attached on the same site of the same subject described in the section IV-A. The subject was instructed to mimic clicking motion by the forefinger, and the Laplacian EMG and the output signal of the EMG-click converting circuit were simultaneously recorded while he was mimicking. Fig.7 shows typical recordings of the Laplacian EMG (top) and pulses (bottom) generated by the circuit. Fig.7 illustrates that the pulses corresponding to muscular contractions are successfully generated. The subject reported that characters could be input just as he intended.
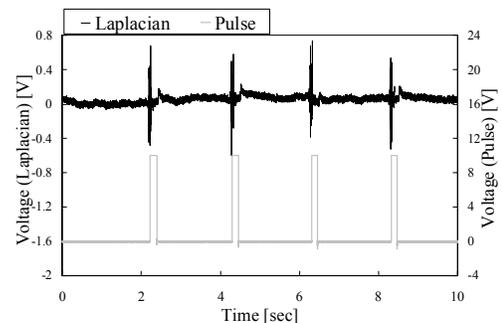

Fig. 7. Recordings of Laplacian EMG and generated pulses from the EMG-click converter circuit.

C. Character Input by Various Parts of the Body

Experiments were conducted to confirm whether or not characters can be input using the Laplacian EMG measured at other parts of the body. The Laplacian EMG was measured at (a) the flexor carpi ulnaris muscle of right forearm bending the wrist with the hand grasped, (b) the anterior tibial muscle of the right leg lowering the tiptoe, or (c) the trapezius muscle of the neck raising the head. Fig.8 shows the EMGs measured

at the three parts and the generated pulses. It demonstrates that the pulses were generated when the bursts were observed in the EMGs, and hence that characters can be input by the motion of various parts of the body.
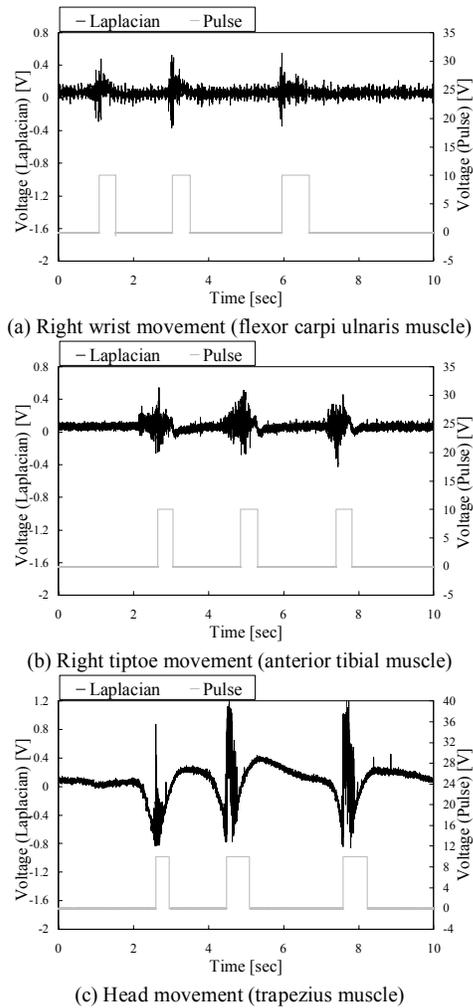

(a) Right wrist movement (flexor carpi ulnaris muscle)

(b) Right tiptoe movement (anterior tibial muscle)

(c) Head movement (trapezius muscle)

Fig. 8. Recordings of Laplacian EMG from various sites and generated pulses

D. Comparison between the IEMGs when the Laplacian or Conventional EMG was Used as an Input Signal

Experiments of inputting characters were conducted on five normal subjects. The wireless electrode was attached on the same site as described in the section IV-A. Electrodes with leads and a reference electrode were also attached to measure the conventional EMG in the same manner written in the section IV-A. The subjects were instructed to input a sentence consisting of 115 characters using the developed system by flexing the forefinger or the middle finger. Each subjects repeated the input of the sentence 5 times. The Laplacian or Conventional EMG was used as the input signal to the EMG-click converter, and the conventional EMG was recorded during the experiment for evaluation of the system. The conventional EMGs were integrated and then averaged when the conventional EMG was used as the input signal and

also when the Laplacian EMG was used (Fig.9). The reason why the conventional EMG was always integrated when the two different deriving methods were used is to eliminate any effects originating from the deriving methods. Four of the five subjects produced significantly smaller amounts of the integrated EMGs at a p value of less than 0.01, when the Laplacian EMG was used as the input signal than when the conventional EMG was used (Fig.9). This result suggests that on the activity of the muscle used for inputting is lower when the Laplacian EMG is used than when the conventional EMG is used.
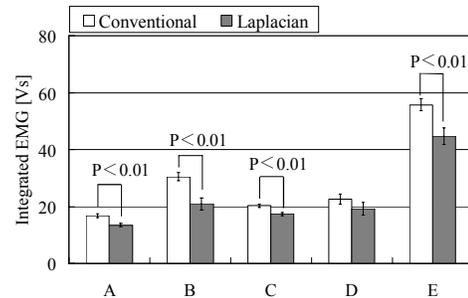

Fig. 9. Mean IEMGs when conventional EMG was inputted and Laplacian EMG was inputted.

V. Conclusion

We used the source derivation method to measure the Laplacian EMG, and developed the compact wireless electrode containing the amplifier, the filter and the transmitter. We made the character input system by connecting the circuit converting the Laplacian EMG signals to clicks, with a personal computer in which software for scanning character inputs was installed. The experiment of inputting 115 characters suggests that on the activity of the muscle used for inputting is lower when the Laplacian EMG is used as the input signal to the interface than when the conventional EMG is used.

References

[1] S. C. Jacobson, D. F. Knutti, R. T. Johnson, and H. H. Sears, "Development of the Utah artificial arm," *IEEE Trans. Biomed. Eng.*, vol.BME-29, pp.249-269, Apr. 1982.

[2] O. Fukuda, T. Tsuji, M. Kaneko and A. Otsuka, "A Human-Assisting Manipulator Teleoperated by EMG Signals and Arm Motions," *IEEE Transactions on Robotics and Automation*, Vol.19, No.2, pp.210-222, April 2003.

[3] H. Ogino, J. Arita, and T. Tsuji, "Wearable Pointing Device using EMG Signals," *Journal of Robotics and Mechatronics*, Vol. 17, No. 2, pp. 173-180, 2005.

[4] B. Hjorth, "An on-line transformation of EEG scalp potentials into orthogonal source derivations," *Electroenceph. Clin. Neurophysiol.*, vol.39, pp.526–530, 1975.

[5] B. He and R. J. Cohen, "Body Surface Laplacian ECG Mapping," *IEEE Trans. Biomed. Eng.,* vol.39, no.11, pp.1179-1191, November 1992.

[6] Mori, H.; Aso, H.; Makino, S., 1997. Robust n-gram model of Japanese character and its application to document recognition. IEICE Trans. Inf. & Syst., E79-D(5), 471-476.

[7] Mori, H.; Iwabuchi, S.; Kasuya, H., 2003. A fast scanning input method based on multiple cursors. Trans. Human Interface Soc., 5(1), 135-141.