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Measuring Myoelectric Potential Patterns Based on Two-Dimensional Signal Transmission Technology

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Abstract: In this paper, we propose a new man-machine interface which measures two-dimensional patterns of myoelectric potentials from a surface of a forearm. Measuring high density 2D patterns of the myoelectric signals makes it possible to predict the movements of one's fingers and forearm before a limb actually moves. The key issue is the wiring to each electrode for realizing such a device that covers whole area of the forearm with high density electrode array. The wires also constrain the motion of the forearm. To solve this problem, we adopt a Two Dimensional Communication (TDC) sheet as a substitution for the individual wires. Electrical power is also supplied through the TDC sheet to each sensor by microwave as well as the signal. Based on this technology, we show that small sensing units without electrical contacts to the TDC sheet can measure the EMG signal free from the common mode noise.

Keywords: Man-Machine Interface, Electromyography (EMG), Two Dimensional Communication .

1. INTRODUCTION

In current information tools including mobile phones and PDA, the interaction between a man and a machine is mainly based on several typical interface devices as keyboards, mouse, and touch-panels. One problem of the current interface devices is that they have their own minimal sizes for operation, which means a limitation of down-sizing exists.

One possible form of future interfaces is a device that measures myoelectric signals for inputting data from people. The myoelectric signal is an electrical impulse that produces contraction of muscle fibres in the body. The signals can be detected by electrodes that touch the skin surface. A remarkable aspect of the electromyography (EMG) is that the signals are detected before a limb actually moves. Therefore, the signal can even predict the user's motion.

In this paper, we propose a comfortably wearable EMG interface system that is a wristband-shaped electrode array covering one's whole forearm as shown in Fig.1. High density electrodes are arrayed inside the wristband. The EMG data is obtained as two dimensional patterns. The system requires no specific alignment for measurement since the myoelectric signals are detected as cylindrical 2D patterns. A pattern-recognition-based processing enables measurement without initial adjustment of the wristband location. The device is worn at the forearm with the finger and hand free. The EMG signals can be used for multiple purposes without switching the physical interfaces. The possible applications to be expected currently are summarized as follows.

- An input interface for small devices such as mobile phones or PDAs.
- Operating artificial limbs.
- Inputting commands by one's behaviors for video games and etc.

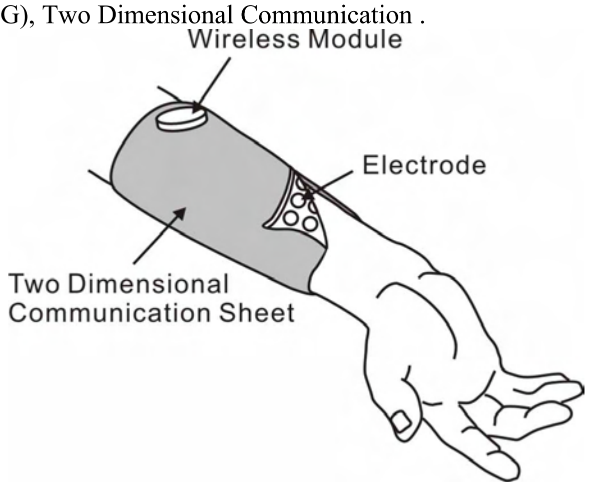


Fig. 1 Schematic diagram of the wristband-shaped electrode array for electromyography.

- Recording behaviors of athletes by the myoelectric signals. The stored data are useful to know the forces in motions and to teach the motions.
- Reducing response delays for remote operating systems since the myoelectric signals are obtained just before the actual motions.

There are several previous studies which deal with usages of the EMG as interfaces. Kawamoto et al. [1] use the myoelectric signals as an input for a power assist system. In that system, the signals are used for detecting an onset of the movement of legs. Based on those signals, the system infers the movement of the operator and assists him/her immediately. Other papers such as [2], [3] are also discussing the possibility for using EMG as the interface. In these researches, the myoelectric signals are obtained by several measurement points for major muscles. Researches which deal with a pattern matching for estimating the motion using such a small number of data are also conducted [4]. A data acquisition through a two dimensional electrode array is also studied [5], [6]. In [5], a high density electrode array on a plate is developed which contains 130 channels of electrodes within 45 mm x 60 mm area. These previous studies, however, assumed some special situations that make wearing complex devices allowable. The device proposed here enables the use of EMG for human interfaces in daily lives.

The following sections in this paper describe the feasibility of the device. There are two important issues to be solved for realizing it. The first one is the wiring problem. We have to embed a large number of measurement units on a flexible sheet. The stretch property of the sheet is especially important to obtain the comfortability and to avoid the interference with hand movement. The stretchability also ensures the steady contact between the electrodes and the skin surface. Traditional wiring technologies can not realize such a high-density-sensor-embedding in a stretchable sheet.

To solve this problem, we adopt a "Two Dimensional Communication (TDC)" sheet as a substitution for the traditional wires. The TDC technology is the technology that uses electromagnetic signals propagating in a two dimensional medium [7]. Communicatory LSI chips on the sheet can communicate with each other using microwave without individual wires. In addition, they are supplied with the electrical power by microwave without electrical contact between the sensor unit and the TDC sheet. Figure 2 shows the schematic illustration of our proposed system. Sensor units are embedded into the two dimensional medium without any wires to the sheet. In our previous paper [8], we showed that a small spiral electrode on a sensor unit whose total length was quarter of the wavelength was useful for stable non-contact connection. Since we need no rigid connection to the sheet, a stretchable and durable communication sheet is feasible. Details of TDC technology is described in Appendix.

The other important issue is how to measure the myoelectric data by small sensor units. In this paper, we show two-electrode-based myoelectric signal measurement. A feature in our proposed method is that the measurement circuit is electrically isolated from the sheet. Then it is free from the common mode noise. In the next section, we show the detail of the measurement.

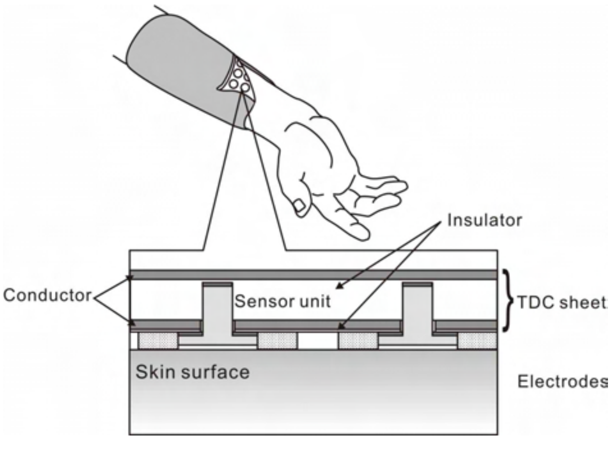


Fig. 2 Sensor units are embedded in the two dimensional medium without electrical contact to the conductive layer of the TDC sheet.

2. MYOELECTRIC MEASUREMENT

Figure 3 shows the equivalent circuit of our proposed method. The circuit represents a situation that only two electrodes are put on the skin surface. Myoelectric signals are modeled as voltage sources V_1 and V_2 with internal resistances R_1 and R_2. These resistances include contact impedance between the electrodes and the skin surface. The resistance is modeled as 100 kΩ in [10]. Common potential of the measurement circuit is represented as V_a The feature of this system is that the common potential V_a is isolated from the ground potential. By reducing the coupling capacitor C, we can reduce the common mode noise.

One of the important issues to be discussed is the distance between two electrodes. For myoelectric potential, it is known that the conduction velocity is about 3~6 m/s. The frequency range is about 5~500 Hz whose peak is around 50~100 Hz. Thus the main wavelengths of the signal are estimated about 50~100 mm. Taking the spatial Nyquist frequency into account, it is preferable that the inter electrode distance is as small as several millimeters for accurate measurement. In [5], they realized two dimensional electrode array whose interval was 5 mm. In this paper, we also assume that the inter electrode distance of our system is 5 mm. It is also a preferable value to obtain high S/N ratio.

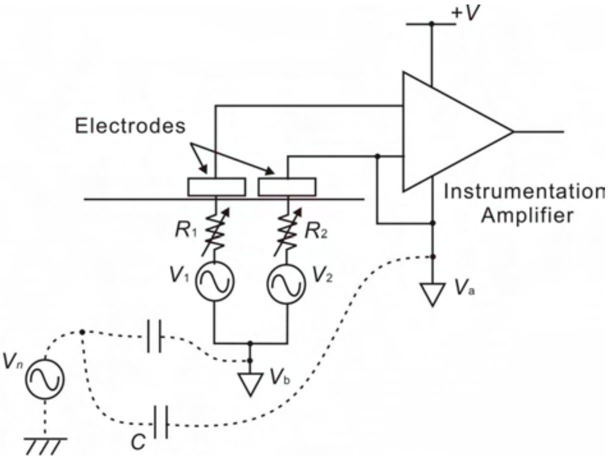


Fig. 3 Equivalent circuit of our proposed measurement system. The measurement circuit is isolated from the ground potential.

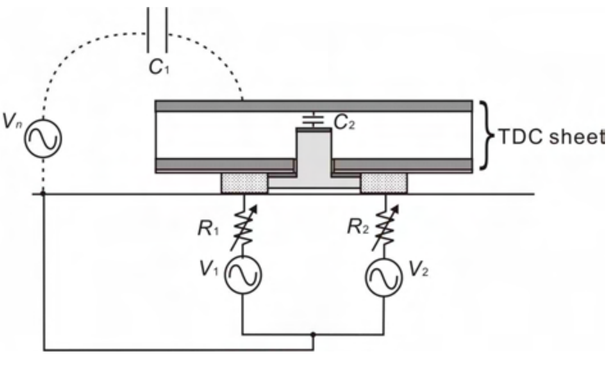


Fig. 4 Equivalent circuit when the noise source is held by the hand

Next we quantitatively evaluate the effect of the noise. The first noise source for EMG measurement is supposed to be a carrier signal for communication and power supply within a TDC sheet. However, the frequency of the carrier signal is several GHz in TDC (see appendix), while the frequency range of the myoelectric signal is 1 kHz at most. The noise related to the carrier signal can be easily reduced by a simple low-pass filter. The second possible noise source is a power source held by hand such as an information tool, typically. The equivalent circuit is shown in Fig. 4. The noise source is connected to the measurement circuit mainly through the capacitive couplings C_1 and C_2. Here C_1 is the coupling between the noise source and the TDC sheet while C_2 is the coupling between the sheet and the sensor unit. The differential noise voltage observed by the two electrodes is given as

$$|v| = \frac{R_2}{\left|\frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} + R_2\right|} V_n < \frac{R_2}{\left|\frac{1}{j\omega C_2} + R_2\right|} V_n$$

In our system, C_2 is as small as 1 pF using Resonant Proximity Connector (see Appendix). In this case, the impedance of $1/\omega C_2$ at 1 kHz is about 100 MΩ while the resistance R_2 is estimated as 100 kΩ [10]. Then the noise voltage for 10 mV noise source is v = 10 μV, for example, that is smaller than the EMG signal.

For reference, we will explain the common mode noise and the typical noise cancellation method. The equivalent circuit of usual two electrode measurement is shown in Fig. 5. In this case the common potential of the measurement circuit is connected to the ground potential (V_a = 0). Then the outer noise source V_n is connected to V_b by unignorable capacitive coupling C', which causes the differential voltage between the two electrodes. This is called common mode noise.

So as to lessen the noise, typical method is to introduce a reference electrode as shown in Fig. 6. The reference electrode is attached to the skin surface where the electric potential is constant such as elbow. A possible noise is caused by an unbalance of the capacitive couplings from the noise source to the electrodes. Also in our system, the SN ratio improves more when the TDC sheet is connected to the skin surface by a reference electrode.

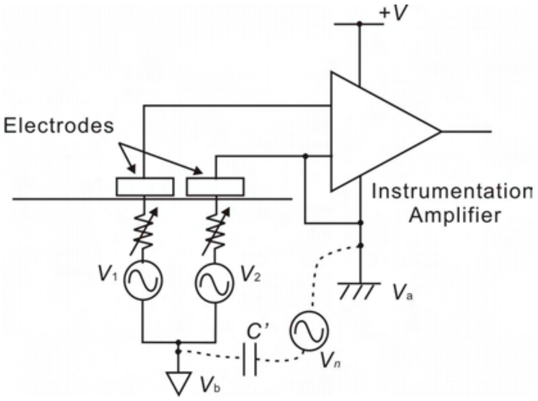


Fig. 5 Explanation of common mode noise when the common potential of the circuit is connected to the ground potential

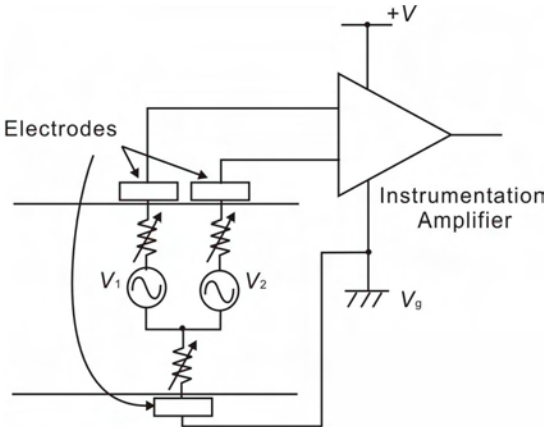


Fig. 6 Equivalent circuit of the measurement system using three electrodes for reducing common mode noise.

3. EXPERIMENT

In the following experiments, we confirmed the feasibility of the two-electrode-based measurement. As the first fundamental experiment, we used battery as floated power source instead of the power supply through the TDC sheet. Figure 7 shows the result of two-electrode based measurement using battery. Two commercially available wet electrodes were set on the inner forearm whose distance is about 50 mm. In order to avoid connection to the ground potential through the oscilloscope's probe, we measured the myoelectric signals keeping the oscilloscope floated. The figure shows the signals when the wrist was moved. It is clear that the myoelectric signals were obtained by two-electrode-based measurement.

Figure 8 shows the measured signals with a noise source attached on the skin surface. The noise source was a DC motor that was held by the other hand. Figure 8 (a) shows the result of our proposed method. Though the noise level is larger than the former one, the signals are clearly seen. On the other hand, Fig. 8 (b) shows the result using an ordinary stabilized power supply following the circuit in Fig. 4. Observed noise level is apparently larger than Fig. 8 (a).

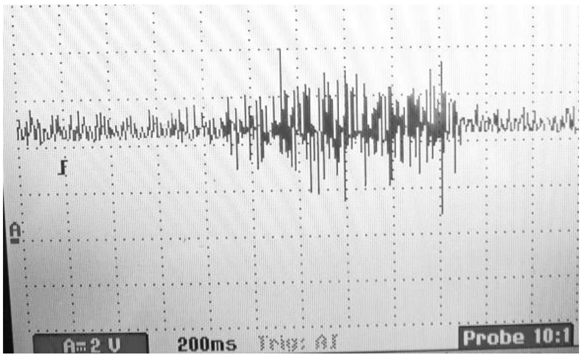
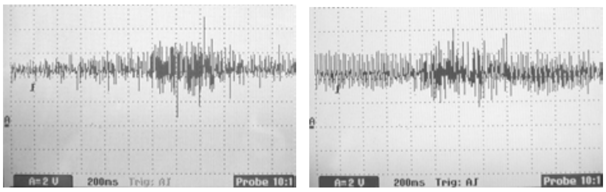


Fig. 7 Observed myoelectric signals using two electrodes with battery.



(a) (b)

Fig. 8 Measured signals with noise source on the other hand. (a): Using battery. (b): Using ordinary stabilized power supply.

We also carried out a basic experiment of TDC-based measurement. Figure 9 shows the block diagram of the prototype. An alternate voltage was supplied to the sensor unit through a TDC sheet. We confirmed the EMG signal detection with a voltage source by a rectification circuit. In this experiment, however, the sensor unit was electrically connected to the TDC sheet, and the power supply frequency was set at a low frequency 1.5 MHz.

Figure 10 shows the received signals by the prototype. Sufficient amplitude of the myoelectric signals was observed. EMG measurement without electrical connection between the sheet and the sensor unit is our future work.

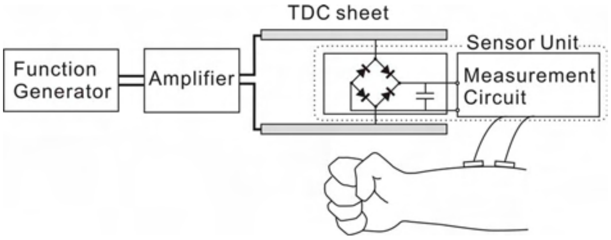


Fig. 9 Block diagram of the experiment for confirming the signal detection with a voltage source by a rectification circuit.

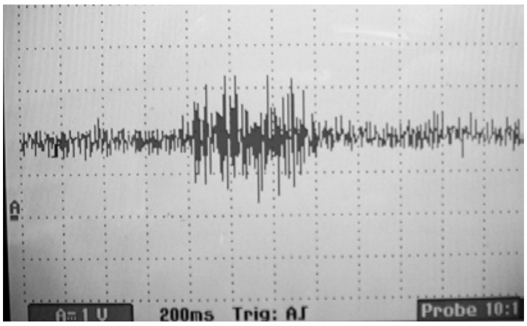


Fig. 10 Observed signal by the prototype

4. CONCLUSION

In this paper, we proposed a new man-machine interface which measures two-dimensional patterns of myoelectric potentials from a surface of a forearm.

Measuring high density 2D patterns of the myoelectric signals makes it possible to predict the movements of one's fingers and forearm before a limb actually moves. On the key issued to realize such a device is the stretchable wiring to each electrode that covers whole area of the forearm with high density electrode arrays. To solve this problem, we adopt a Two Dimensional Communication (TDC) sheet as a substitution for the wires. Electrically isolated sensing units measure the differential EMG signal. Signal transmission and power supply are also carried out by microwaves without electrical connection to the TDC sheet. The other key issue is the measurement method by the isolated sensing units. We analyzed the noise by the proposed simple two-electrode circuit, and showed EMG sensing is feasible. A basic experiment showed EMG signal was detectable by the proposed method.

APPENDIX

A.1 Two Dimensional Communication

"Two Dimensional Communication (TDC)" was proposed by Makino et al. in [7]. Fig. A-1 shows the one configuration for a TDC sheet. The sheet consists of three layers. Two conductive layers are set to sandwich the dielectric layer. The sheet has the connection apertures on the surface of it for inputting and receiving signals. When an alternate voltage between the conductive layers is impressed through the aperture, there exists a propagation mode of the electromagnetic wave signal within the dielectric layer. This electromagnetic wave is used for signal transmission between each communication node attached on the aperture.

Any materials with high conductivity are available as the conductive layers like conductive fabrics and conductive rubbers. In the previous paper, the TDC sheet composed of stretchable conductive fabrics were fabricated. Using the prototype system, they realized stable communications through the sheet using the IEEE 802.11b protocol. An achieved throughput between two PCs connected to the stretchable communication sheet was 11 Mbps which is a limit of the protocol. The theoretical and experimental details of signal transmission are described in [7].

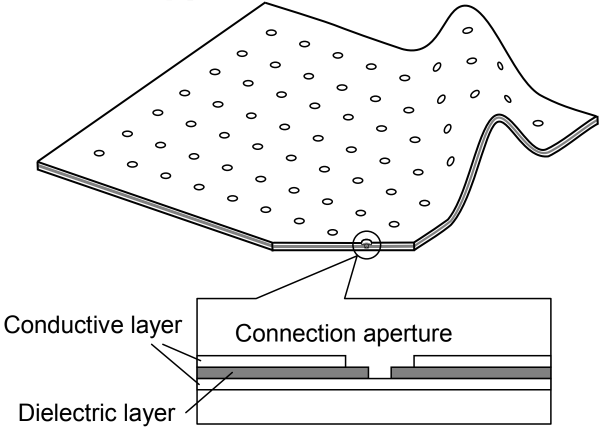


Fig. A-1. Schematic illustration of the of the Two-Dimensional Communication descrived in [7]

A.2 Power Transmission Using Resonant Proximity Connector

When the sensor units are arranged within a TDC sheet, the most primitive method for connecting the sensor units to the TDC sheet is to connect them with solid conductor such like a solder. However, hard conductor within a soft sheet can cause fatigue due to stress concentration around the rigid connection. Moreover, production process becomes complex. No electrical contact between the sensor units and the TDC sheet is desirable.

In our previous study [8] we proposed “Resonant Proximity Connector (RPC)” for realizing stable connection to the sheet without electrical contact. Figure A-2(a) shows the schematic illustration of the RPC. The connector is an electrode whose length is a quarter of the wavelength λ of the carrier signal. When we apply voltage between the points A and B (Fig. A-2(b)), the produced electric field is vertical to the layer. The electric field and the current are the minimum and the maximum, respectively, at the left end of the electrode, which means the impedance Z_1 between A and B becomes zero ideally even though there is no electrical contact between them.

An important thing is that the resonant condition only depends on the length of the electrode. There is little dependence on the gap *d* between the connector and the sheet. Therefore, it was presented that a curved electrode also could be useful for minimize the size of the RPC. The diameter of them was as small as 2.8 mm when the carrier frequency was assumed to be 2.4 GHz and the relative permittivity of the dielectric layer was 4.9. The size of the connector is appropriate for our system.

We confirmed that electrical power could be received by rectifying the alternate voltages. In our prototype, 20 mW was received through the sheet when the microwave of 110 mW at 2.4 GHz was inputted [9].

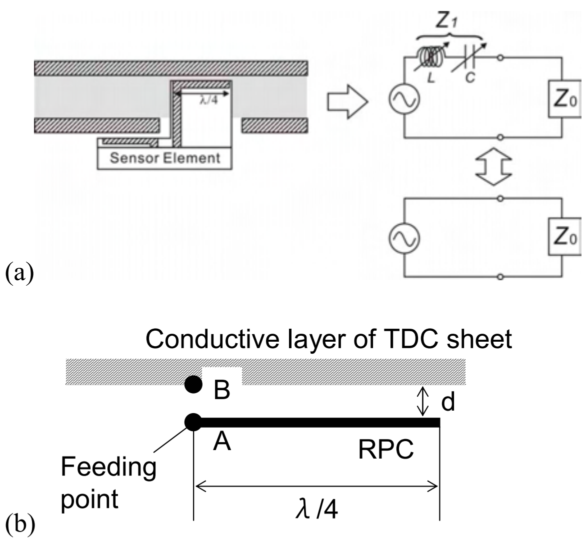


Fig. A-2. Schematic illustration of the Resonant Proximity Connector (RPC) descrived in [8]. The equivalent circuit between A and B is a series resonant circuit. The resonant frequency weakly depend on the distance between the electrode and the TDC sheet. The length of the electrode is designed to be λ/4 of the carrier signal.

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