Comfortable Wristband Interface Measuring Myoelectric Pattern

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Abstract

In this paper, we propose a new haptic interface based on measurement of two-dimensional patterns of myoelectric potentials on a surface of a forearm. A myoelectric signal is an electrical impulse that produces contraction of muscle fibres in the body. Measuring high density 2D patterns of the myoelectric signals enables us to predict the movements of one's fingers and to estimate the related force. The key issue for realizing such a device that covers whole area of the forearm with high density electrode array is the wiring to each sensor element. 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 a small sensing unit without electrical contacts to the TDC sheet can measure the EMG signal without the significant influence of the common mode noise.

1. Introduction

The purpose of this study is to obtain haptic information related to grasping forces without any constraints on the movement of fingers and the hand. Myoelectric signal measurement on a forearm can be one of the solutions for this objective. A myoelectric signal is an electrical impulse that produces contraction of muscle fibres in the body. The signals can be detected by electrodes attached on the skin surface. A remarkable aspect of the electromyography (EMG) is that the signals are detected before fingers actually move. The signal patterns on the forearm therefore can predict the user's finger/hand motion. Moreover, it is known that the activity of the muscles is roughly proportional to the amplitude of the myoelectric signal. A grasping force is also expected to be estimated by measuring the myoelectric signals. Since the signal patterns are measured on the forearm, one can move one's fingers and hand freely even under the measurement.

There are several previous studies which use EMG in 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. Other papers [2], [3] also discuss the possibility of EMG as the interface. In those researches, the myoelectric signals are obtained by several measurement points on the major muscles. Temporal pattern matching for motion estimation using such a small number of measurement points is conducted [4]. Initial alignment of the electrodes is important for effective estimation. 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 force wearing such complex devices. In many cases, the movement of the arm is restricted due to annoying wires.

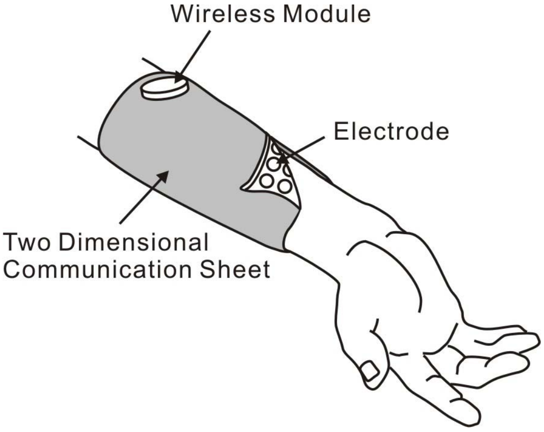

Fig. 1 Schematic diagram of the wristband-shaped electrode array for electromyography [8].

In our previous study [8], we proposed a comfortably wearable EMG interface system that was 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 realizes measurement without initial adjustment of the wristband location. The device is worn at the forearm with the fingers and hand free since few wires are required. The possible applications are summarized as follows.

- Haptic interface that estimates a grasping force of the hand.
- Measurement of muscle fatigue.
- An input interface for small devices such as mobile phones or PDAs.
- Operating artificial limbs.
- Inputting commands by one's behaviors for video games.
- 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 before the actual motions.

The following in this paper describes the feasibility of the device. There are two important issues to be solved for realization. The first one is the wiring problem. We have to embed a large number of measurement units in a flexible sheet. The stretchable 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 to use 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 in 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. The stretchable conductive layers can be realized by knitted conductive fabrics. Since no rigid bonding between the sensor chip and the TDC sheet are necessary, the device with a large number of sensor chips can keep elasticity, without fragility that ascribes to the stress concentration to the bonding. Details of TDC technology is described in Appendix.

The other important issue is how to measure the myoelectric data by a small sensor unit. 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.

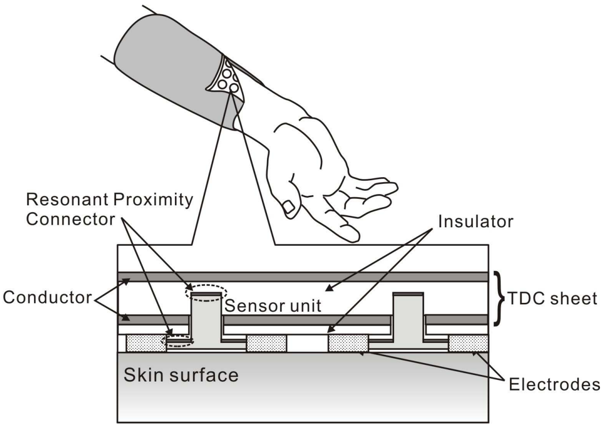

Fig. 2 Sensor units are embedded in the two dimensional medium without electrical contact to the conductive layer of the TDC sheet.

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.

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 v 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.

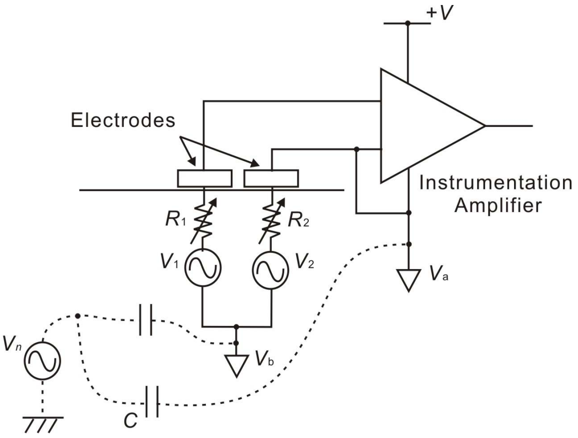

Fig. 3 Equivalent circuit of our proposed measurement system. The measurement circuit is isolated from the ground potential.

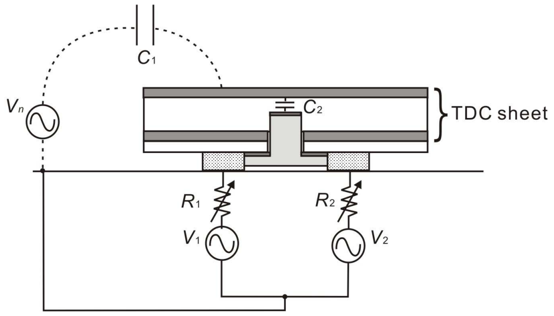

Fig. 4 Equivalent circuit when the noise source is attached on the hand

One of the important issues to be discussed is the distance between two electrodes. It is known that the conduction velocity of myoelectric potential is about 3~6 m/s. The frequency range is about 5~500 Hz whose peak is around 50~100 Hz. Thus the main spatial wavelength of the signal are estimated at 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 assume that the inter electrode distance of our system is about 10 mm. It is also a preferable value to obtain high S/N ratio.

3. Prototype

We confirmed the feasibility of the two-electrode-based measurement. Figure 5 shows the block diagram of the prototype. An alternate voltage was supplied to the TDC sheet at 2.4 GHz. Supplied voltage was received by RPC. RPC (Resonant Proximity Connector) is a non-contact connector between a sensor chip and a TDC sheet. The detailed information is summarized in Appendix A.2. In this experiment, we only confirmed whether the isolated two-electrode-based measurement was possible or not. Therefore, the obtained data was not transmitted through the sheet, but received by a cable through photo-coupling. So as to isolate the circuit from the ground potential, the output signal was isolated by photo coupler. We also kept the battery-driven oscilloscope isolated from the electrical ground.

Figure 6 shows the photograph of the prototype system. The measurement circuit was realized within 20mm x 30 mm. The electrodes were made of cupper whose diameter was 10 mm and the center-to-center spacing was 15 mm. The sheet was made of aluminum foil as conductive layers and poly olefin sheet as dielectric layer whose shape was like a horn so as to lessen the reflection of the microwave at the feeding point. The RPC with a rectification circuit was embedded in the TDC sheet. The diameter of the RPC was 7.2 mm. The distance between the RPC and the TDC sheet was about 0.5 mm. Thus the capacitance C_2 was roughly estimated as 3.5 pF.

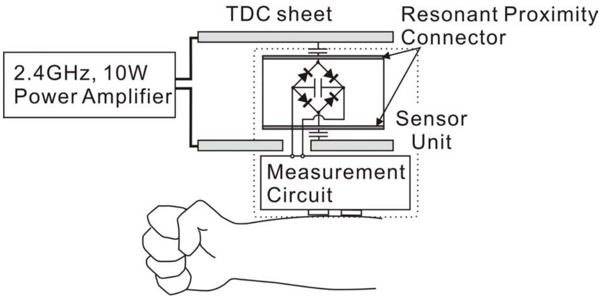

Fig. 5 Block diagram of the experiment.

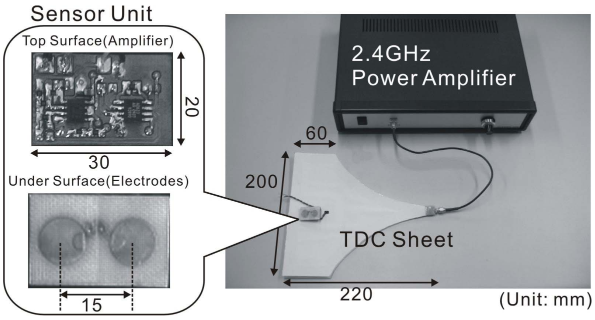

Fig. 6 Photograph of the measurement system.

4. Experiment

In the experiments, the single sensor unit was put on the inner forearm. The position was determined to sense cocking motion of the wrist. Figure 7 and 8 shows the measured myoelectric signals. The horizontal axis denotes the time and the vertical axis indicates the observed voltage. These signals were measured under following procedures.

1) The subject's hand was lightly grasped in a relax manner.
2) After 2.5 seconds passed, the wrist was cocked tightly for 2.5 seconds.
3) The wrist was replaced to the original position.

Figure 7 shows the result of the measurement under the low noise condition. The averaged voltage during the motion (3 - 4 seconds) is about 3.52 mV, while it is 0.48 mV without motion (0 - 1 second). The S/N ratio is 17.2 dB.

Figure 8 shows the result under noisy condition. An activated handy-size drill was touched on the measured hand as a noise source. The condition simulated the discussed model shown in Fig. 4. Though the noise level seems to be larger than the former situation, the myoelectric signal is clearly observed. The averaged voltage during the motion (3 - 4 seconds) is about 3.20 mV, while the noise is 0.81 mV (0-1 second). In this situation, the S/N ratio is 11.9 dB.

For comparison, we also measured the signal without TDC sheet and RPC. A stabilized power supply was directly connected to the measurement circuit. In this situation, the signal was hidden by the noise. We confirmed that the proposed method efficiently reduced the common mode noise although it required only two electrodes.

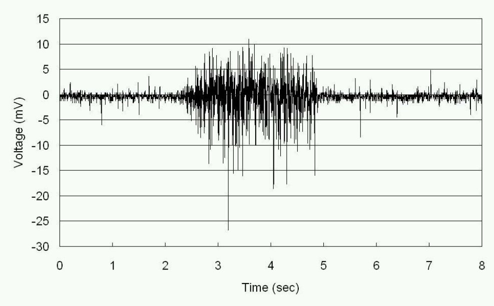

Fig. 7 Measured myoelectric signal under low noise condition.

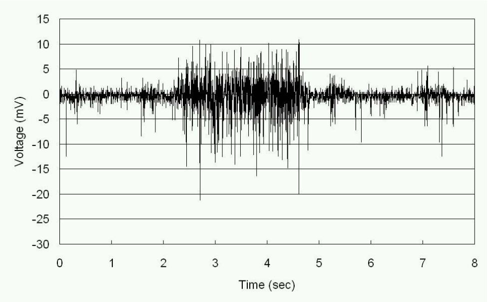

Fig. 8 Measured myoelectric signal under noisy condition.

5. Conclusion

In this paper, we proposed a haptic interface which measures two-dimensional patterns of myoelectric potentials from a surface of a forearm. Since an activity of muscles can be observed by the measurement, grasping forces are supposed to be estimated by the system.

We pointed out two key issues in realizing such a device. One 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. It enables us to measure the myoelectric signals without the significant influence of the common mode noise. This paper dealt with this issue mainly. We fabricated prototype measurement system for analyzing the noise. It was confirmed that our proposed method could reduce the common mode noise efficiently although the system required only two electrodes. Achieved S/N ratio was 17.2 dB under low noise condition and was 11.9 dB under noisy condition.

Appendix

A.1 Two Dimensional Communication

The idea of communication using two dimensional medium was originally proposed by us [11] and some other groups [12], [13], [14] at the early 2000s. In the researches [12], [13] and [14], however, high speed communication through the medium was out of consideration. In addition, mechanical and electrical contacts of elements to the conductive layers were necessary. “Two Dimensional Communication (TDC)” by microwave was reported 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 communication nodes attached on the apertures.

Any materials with high conductivity are available as the conductive layers like conductive fabrics. 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 the limit of the protocol. The theoretical and experimental details of signal transmission are described in [7].

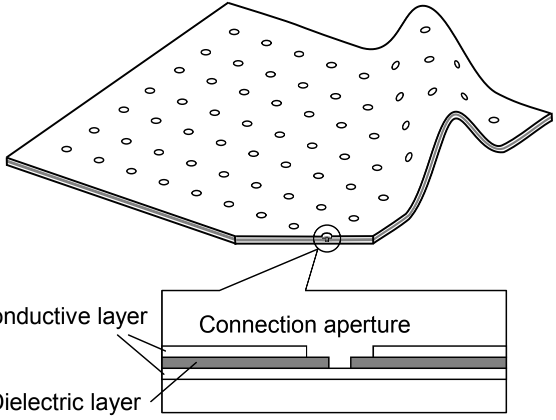

Fig. A-1. Schematic illustration of the of the Two-Dimensional Communication descrived in [7]

A.2 Resonant Proximity Connector and Power Transmission with Microwave

Non-contact connection between sensor chips and a TDC sheet is desirable. Excluding bonding between them makes fabrication process easy. Since non-contact connection allows the relative displacement of the sensor chip on the TDC sheet, the sheet can keep flexibility with a large number of sensor chips. The device also becomes durable since it is free from stress concentration around the sensor chip bonding.

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 total 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 feature 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 was usable for minimizing 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 [9] we realized the RPC whose diameter was 7.2 mm. When the microwave of 110 mW at 2.4 GHz was inputted, 20 mW was received through the TDC sheet with the identical specification to that of Fig. 6. The detail of the theoretical limit in power transmission is described in [8].

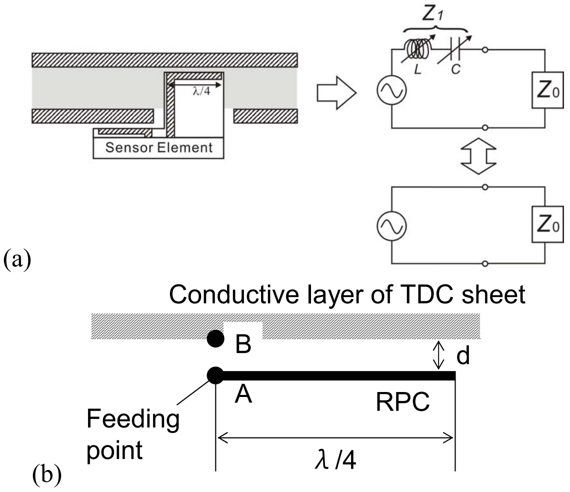

Fig. A-2. Schematic illustration of the Resonant Proximity Connector (RPC) described in [8]. The equivalent circuit between A and B is a series resonant circuit. The resonant frequency weakly depend on the distance between the electrode and the TDC sheet. The length of the electrode is designed to be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

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