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Myoelectric Pattern Measurement Based on Two-Dimensional Communication Technology

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Abstract: Last year, we proposed a new man-machine interface that detects myoelectric signals on a forearm. Since the myoelectric signals can be detected just before an actual motion, the system can predict motions of the fingers or related grasping forces. It is considered that a high-density electrode array is necessary for improving the accuracy of the motion estimation. In general, a large number of the sensor units require also a large number of wires for data transmission. Due to these annoying wires, the motions are constrained and the system is not suitable for daily use. In our previous work, we proposed "Two-Dimensional Communication (TDC)" technology as a substitution for the wires. In the TDC scheme, signals are transmitted within a two dimensional medium as well as an electric power. Therefore, not only the wires for signal transmission, but the batteries for individual sensors are not required. In this paper, we show how to send the data to a host machine in the TDC sheet. We adopt a time division multiplexing method for reducing interferences between the sensor units.

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

1. INTRODUCTION

Last year, we proposed a new man-machine interface that measures myoelectric signals on a forearm [1] as shown in Fig. 1. The myoelectric signal is the electrical potential that produces contraction of the muscle fibers. The signals can be detected by electrodes that touch on the skin surface. One of the remarkable aspects of the myoelectric signal is that the signal can be detected just before an actual motion occurs. Therefore, a precise observation of the myoelectric potentials enables one to predict the motion of the limbs.

When we focus on finger motions, it is known that almost all the muscles relating to the finger movements exist in the forearm. Muscle activities are conducted through tendons to the finger. As a result, if the two dimensional myoelectric signal patterns on the forearm are measured appropriately, the finger motion can be estimated without any constraints on the fingers even under the measurement.

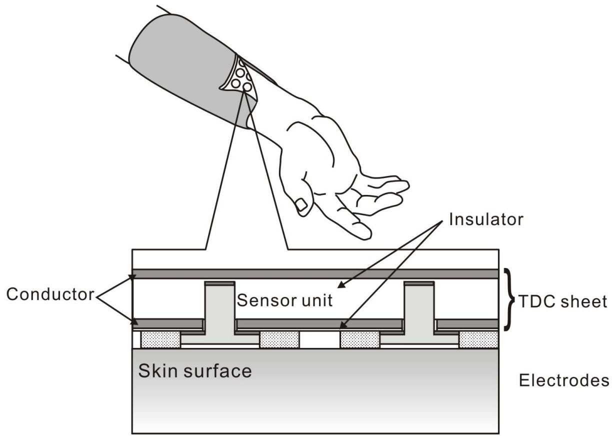

Fig. 1 Schematic diagram of the wristband-shaped electrode array for electromyography [1].

In order to improve the accuracy of the estimations, it is considered to be important to increase a number of measuring points. An increase of the number of the electrodes also causes an increase of the number of wires. Due to these annoying wires, the movement of the arm is restricted. There are several previous studies which measures dense 2D Electromyography (EMG) [2] [3], however, the studies assumed some special situations that make wearing complex devices allowable. Or in some other researches [4] [5], the myoelectric signals are obtained by a few sparse measurement points on the major muscles. They devoted most of their efforts to a pattern matching technique. Initial alignment of the electrodes is important for effective estimation.

In this paper, we aim to achieve EMG-based man-machine interface that can be applied for daily use. So as to achieve the objective, following three conditions are desirable.

1) There are no annoying wires for data collection so that the arm can move freely.
2) Precise alignment of the sensors is unnecessary.
3) Comfortably wearable.

One of the solutions we proposed last year is a "Two Dimensional Communication (TDC)" technology. In the TDC technology, signals are transmitted within a two dimensional medium (TDC sheet) as well as an electric power by microwave. The sensors attached onto the TDC sheet can communicate with each other without any wires. The electrical power is also supplied through the sheet. Therefore, the sheet can be used as substitutions for the individual wires. Note that this technology corresponds to the physical layer of the OSI reference model. Any communication protocols such as IEEE802.11a/b/g, Bluetooth and etc. are available for high speed communication. When the sheet is fabricated like a wrist-band shape as shown in Fig.1, the EMG data is obtained as two dimensional patterns. Consequently,

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the system requires no specific alignment for measurement.

One of the notable characteristics in the TDC is that the communication sheet can be realized with conductive flexible materials including conductive fabrics, conductive rubbers, and so on. It enables us to wear the measurement system comfortably. The stretchability also ensures the steady contact between the electrodes and the skin surface. The contact impedance between them can be decreased. Traditional wiring technologies can not realize such a high-density-sensor-embedding in a stretchable sheet.

Because of the features mentioned above, following two practical advantages are expected.

1) Intuitive data input by natural finger motions is possible.
2) Response delays are reduced (no irritations).

Thus, it is promised that following applications are achievable.

- 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.
- Recording behaviors of athletes by the myoelectric signals. The stored data are useful to know the motions and to teach the motions.

In our previous paper [6], we theoretically and experimentally showed that our sensing system could reduce common mode noises. Since the sensor units were connected to the TDC sheet without any electrical contacts, the unit can be driven being isolated from the ground potential.

In this paper, we show how to transmit data through the TDC sheet. We adopt a time division multiplexing (TDM) method. Note that the signal transmissions and the power transfer are realized with the same bandwidth in our system. The TDM is suitable for reducing the interferences between the data signals and the power transfer signals. There are two phases in our scheme. One is for the power supply and the other is for the signal transmissions. In the signal transmission phase, measured data is transferred by Pulse Width Modulation (PWM) method.

In the next section we show a principle of the "Two Dimensional Communication" technology. In section 3, we briefly show how to reduce common mode noises in this system. Then we show how to send data from the sensor units to a host machine simultaneously with small power consumption in section 4.

2. TWO-DIMENSIONAL COMMUNICATION

The idea of communication using two dimensional medium was originally proposed by some research groups [8], [9], [10] including us [7] at the early 2000s. In the researches [8], [9] and [10], 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.

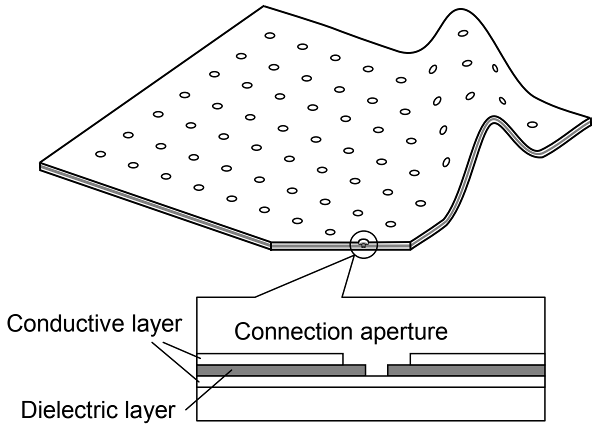

Fig. 2 Schematic illustration of the of the Two-Dimensional Communication descrived in [11]

"Two Dimensional Communication (TDC)" was reported by Makino et al. in [11] as a substitution for the annoying wires. Figure 2 shows the basic configuration for a TDC sheet. The sheet consists of three layers. Two conductive layers sandwiches the dielectric layer. An alternate voltage is impressed between the two layers through the connection aperture on the surface of it. We theoretically showed that a propagation mode exists in the sheet when the applied frequency is high enough so that the corresponding wave length λ is smaller than the sheet size. For example, 2.4 GHz microwave, whose wavelength λ is about 10 cm, (which is usually used in the wireless communication protocols) propagates within the dielectric layer if the sheet size is assumed to be 30 cm x 30cm. In this propagation mode, the energy is confined within the sheet. It does not interfere with outside devices. Since a higher power microwave can be applied without worrying about interferences, we can supply enough electric power to the sensor units with microwave as well as a signal transmission.

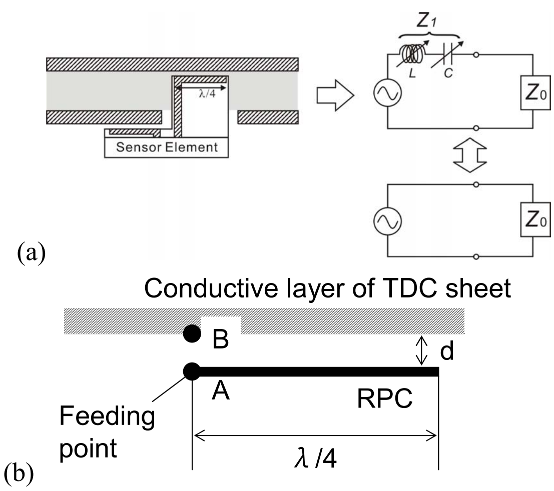

Fig. 3 Schematic illustration of the Resonant Proximity Connector (RPC) descrived in [12]. The equivalent circuit between A and B is a series resonant circuit. The resonant frequency weakly depend on the distance between the electrode and the TDC sheet. The length of the electrode is designed to be λ/4 of the carrier signal.

For effective coupling between the sensor and the sheet, we proposed a connector named “Resonant Proximity Connector (RPC)” last year [12]. As shown in Fig. 3, when the total length of the electrode is designed to be λ/4 of the microwave, the connection can be seen as a short owing to its resonance. A notable characteristic is that it requires no electrical contact between them. The connection apertures can be covered with a thin insulating material so as to prevent the conductive materials from oxidization. We also confirmed that the size of the RPC could be reduced down to about 3mm in diameter by curling its shape. This connector is suitable for realizing a high density sensor array. Moreover, when the electric power is supplied through the RPC, the common potential of the sensor unit can be isolated to the ground potential. This advantage is useful for reducing common mode noises as shown in next section.

Any materials with high conductivity are available as the conductive layers like conductive fabrics and conductive rubbers. The sheet is feasible for the wristband shaped man-machine interface.

3. MYOELECTRIC POTENTIAL MEASUREMENT

A myoelectric signal is the signal that produces muscle contraction. The signal is observed by electrodes attached on the skin surface with its voltage is order of several mV. As a result, reducing a common mode noise is one of the important issues for the EMG. However, if the measurement circuit is isolated from the ground potential, we are released from consideration about the common mode noise. In our TDC system, the sensor unit is connected to the sheet through a small capacitor (RPC) whose capacitance is as small as 1 pF. Thus, the connection to the ground potential is negligible.

Figure 4 shows an equivalent circuit of our proposed method. The point of the circuit is that the common potential of the measurement circuit $V_{a.}$ is isolated from the ground potential (weakly connected through the 1 pF capacitor). This makes the all the potential on the circuit float. The common mode noise can be reduced by instrumentation amplifier.

For comparison, Fig. 5 shows the circuit whose common potential is connected to the ground potential ($V_{a.} = 0$). An ordinary stabilized power supply is simulated by this equivalent circuit. In this case, the outer noise source V_n is connected through a capacitive coupling to the constant potential of the skin surface V_b. If the impedance $1/\omega C$ is much smaller than the contact impedance R, the signal is seriously influenced by the noise.

In our former paper, we demonstrated that the myoelectric signals can be detected by these two-electrodes based measurement system. Figure 6 and 7 show the results in [6]. Though Figure 7 shows the myoelectric signal when the noise source is attached on the skin, the signal can be seen clearly. We confirmed that our proposed method is useful for reducing the common mode noise.

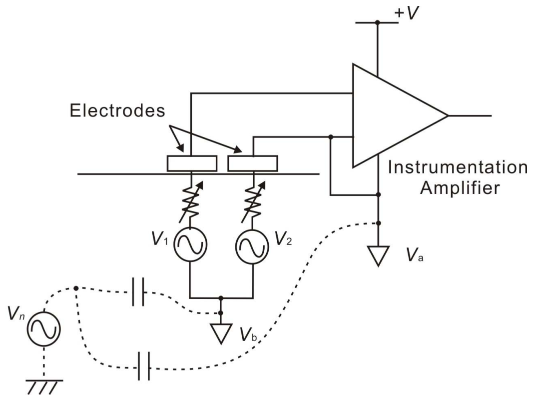

Fig. 4 Equivalent circuit of our proposed measurement system. Two electrodes are put on the skin surface. Myoelectric signals are modeled as voltage sources V_1 and V_2 to the constant potential of the skin surface V_b. The sources are connected to the instrumentation amplifier through the variable resistances. These resistances indicate contact impedance variations between the electrodes and the skin surface. All the potentials of the measurement circuit are isolated to the ground potential.

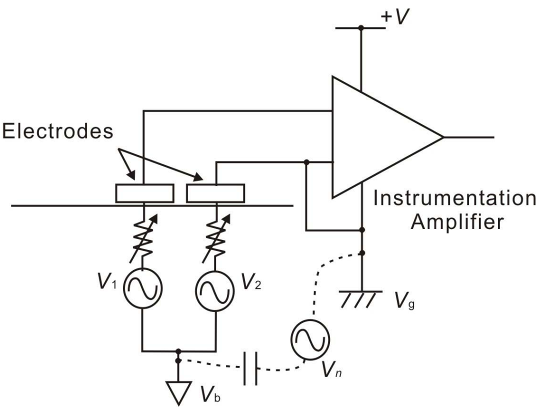

Fig. 5 Effect of the common mode noise $V_{n.}$ when the common potential of the circuit is connected to the ground potential

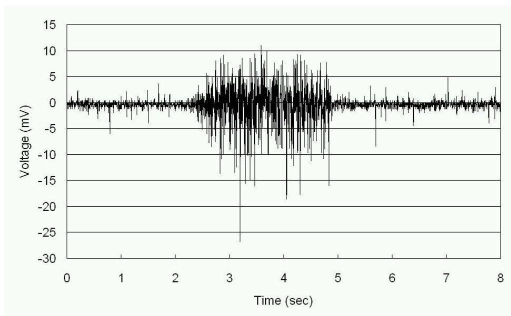

Fig. 6 Measured myoelectric signal without noise [6].

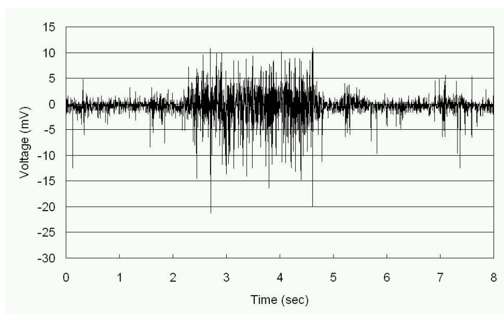

Fig. 7 Measured myoelectric signal under noisy condition [6].

4. DATA TRANSMISSION

In this paper, we adopt the time division multiplexing (TDM) method for achieving data transmission. Although there are many protocols that assure multi channel communication such as the frequency division multiplexing (FDM), the code division multiple access (CDMA) and etc., we adopted TDM from the easiness of implementation. Of course the other methods also can be used in this system.

There are two phases in our TDM method. One is for power supply to each sensor unit and the other is for data transmission. Figure 8 shows the time chart of our proposed method. After the power supply, each sensor sends data sequentially with PWM. The graph shows the envelope of the burst wave whose carrier frequency is supposed to be 2.4 GHz.

Figure 9 shows the one configuration for realizing the TDM. The circuit is composed of the passive components, the logic circuits and the analog switch. Therefore the circuit can be driven with low power consumption.

The behavior of the circuit is easily understood by Fig. 10 which shows the voltages at the points a~e in Fig. 9. (We use description V_i (i = a~e) as the voltage to the common potential at the point i.) When the power signal ends, the V_a also becomes low. However, a delay t_1 exists due to the resistance R_1 and capacitance C_1. Thus the rising edge of the V_b occurs t_1 second later than the falling edge of the power signal. The V_b is used to switch the state of the analog switch S. The switch S is connected to the measurement circuit during the V_b is low. On the other hand when the V_b becomes high, the point c is connected to the common potential through the resistance R_2. Then the V_c decreases with its time constant is R_2 C_2. The decay time t_2 is defined by the momentary voltage of the V_c at the exact moment when the V_b returns to high level. As a result, we obtain the PWM signal V_e. This signal is used as an "enable signal" of the 2.4 GHz oscillator. It is important that the time delay t_1 can readily be designed with different pairs of R_1 and C_1 so that the delays are different each other.

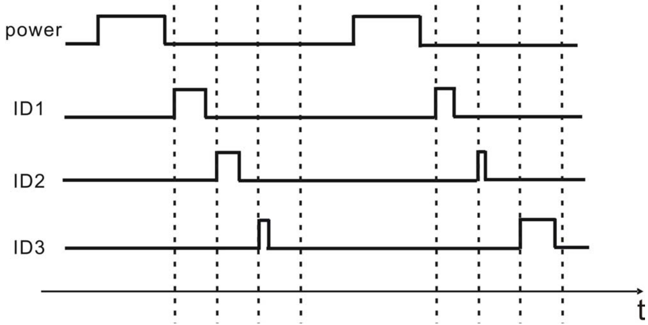

Fig. 8 Time diagram of the time division multiplexing method. The lateral axis indicates the time. Each sensor has a different delay to the falling edge of the power signal.

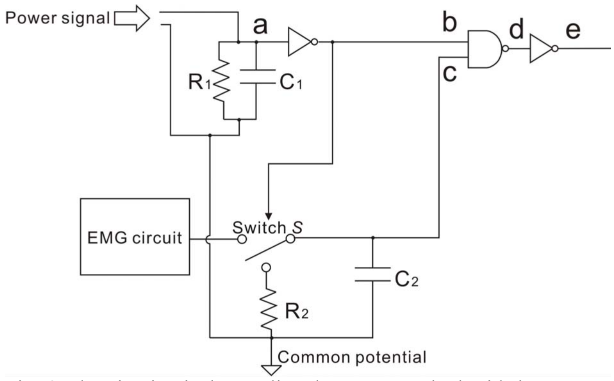

Fig. 9 Electric circuit that realize the TDM method with low power consumption.

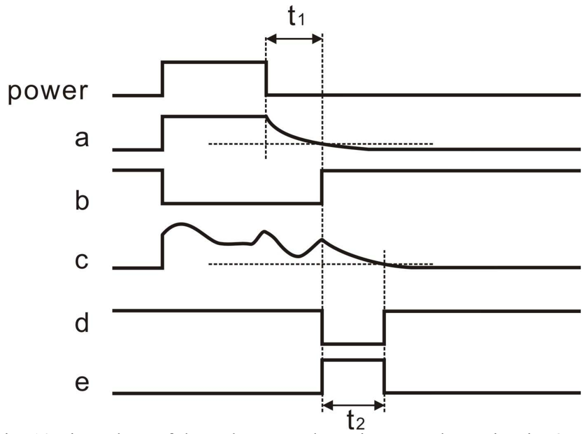

Fig. 10 Time chart of the voltages at the points a~e shown in Fig. 8.

The relationship between the voltage of the measurement circuit V_c and the pulse width t_2 can be calculated as follows. After the point c is connected to the common potential through the R_2, the transient profile of the V_c can be written as

$$V_c = V_{init} \exp(-t / R_2 C_2) \quad (1)$$

Here V_{init} is the momentary voltage of the V_c at the exact moment when the switch S was changed. If we assume that the low level threshold of the logic circuit is V_{th}, we obtain the following equation,

$$V_c = V_{init} \exp(-t_{th} / R_2 C_2) = V_{th} \quad (2)$$

Where the t_{th} represents the time of the falling edge of V_e. That means the t_{th} is equal to the pulse width t_2. Then the pulse width is given as

$$t_2 = R_2 C_2 (\log V_{init} - \log V_{th}) \quad (3)$$

Figure 11 plots the experimental results of the relationship between the voltage V_{init} and the pulse width t_2. Here, R_2=300Ω and C_2=0.1μF. The dashed line indicates the theoretical curve. Though there is constant difference (about 10 μs) between the experimental results and the theoretical values, a tendency of the curve is similar to each other. The difference is considered to be caused by the variation in V_{th} of the used IC.

Figure 12 shows the observed envelope of the signal at the side of the communication sheet with a single sensor unit. In this case, R_2 = 5.1 kΩ and C_2 = 0.1 μF. The horizontal axis indicates the time, and the vertical axis shows the amplified voltage. From 5 ms to 13 ms, the power signal is supplied. The PWM signal can be observed one millisecond after the falling edge of the power signal. Both the multi channel data transmission and the EMG data transmission with this system are our future work.

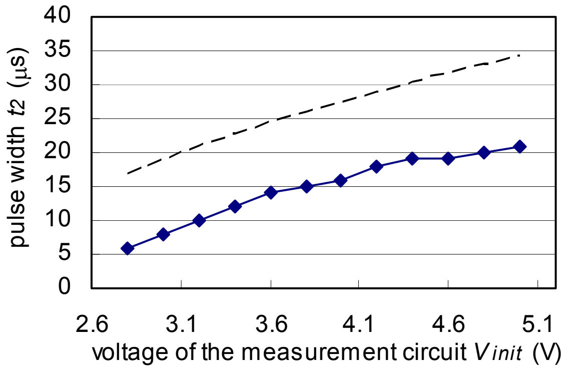

Fig. 11 The relationship between the voltage of the measurement circuit and the pulse width. The solid line with dots shows the experimental results when R_2 = 300 Ω and C_2 = 0.1 μF. The dashed line represents the theoretical values.

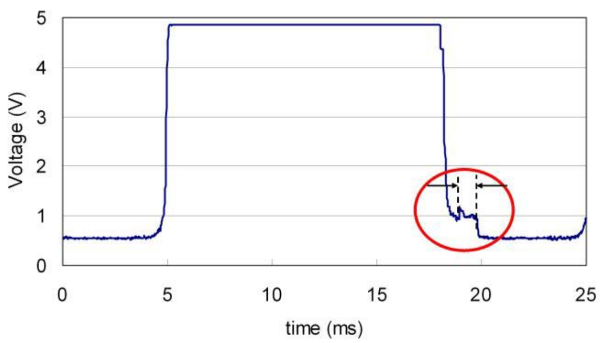

Fig. 12 Observed signal of a single sensor unit.

5. CONCLUSION

Last year, we proposed a new man-machine interface that detects myoelectric signals on a forearm. In the study, we showed one solution to reduce the number of wires named "Two-Dimensional Communication (TDC)" technology. Based on this technique, sensor units attached on the communication sheet can communicate with each other without individual wires. Moreover, an electric power is also supplied through the sheet by microwave. In our previous study, we demonstrated that a common mode noise could be reduced by using the TDC technology.

In this paper, we showed how to send the data to a host machine in the TDC sheet. We adopted a time division multiplexing (TDM) method for reducing interferences between the sensor units. In our method, there are two phases. One is for power supply to every sensor on the sheet; the other is the phase for sequential signal transmission. Measured data is transmitted by PWM method with low power consuming electric circuit. We confirmed that the PWM was achieved by our proposed circuit and that the signal could be received at the side of the sheet. Both the multi channel data transmission and the EMG data transmission with this system is our future work.

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