An active electrode with a built-in transmitter (a wireless electrode) is developed, which derives surface EMG without skin preparation and conductive paste due to high input impedance. In addition, a reference electrode becomes needless by a built-in stabilized reference circuit. Subjects are less restricted with the present wireless electrode compared with the conventional telemetry system because of no connecting wires between electrodes and the transmitter, and no reference electrode. Moreover, it is not affected by the noise caused by the movement of lead wires. Since the FM transmitter is used in the FM radio band, we can use a commercially available FM radio receiver. The wireless electrode was found to be operated for 29 hours in changes of temperature and with a mechanical shock on the landing moment. Legal license is not required in Japan due to the low transmission power.

**Keywords:** EMG for athletes, Telemetry system, Active electrode, Built-in transmitter

1. Introduction

Electromyography is used for the study of human movement, which reflects muscle action potentials due to its contraction. Today, a wireless electromyograph used for EMG measurement becomes popular because of the advance of IC technology. For example, the 8ch multi-telemeter (NIHON KOHDEN Co., Ltd.) becomes smaller and lighter (130×85×30 (mm), 250 g), which makes less restriction of subjects. But an electrode is connected to a transmitter with lead wires. In the multi-channel measurement and hard movement such as in athletic science, the connecting wires limit subjects' movement. Those give trouble in the measurement of physiological phenomena to both subjects and observers. In addition, a conventional electromyograph needs a reference electrode, as shown in Fig. 1(a) (1)(2).

In this paper, to resolve such a drawback, an active electrode with a built-in transmitter and a built-in stabilized reference circuit for surface EMG (a wireless electrode) is described as depicted in Fig. 1(b). Then, the performance, e.g. frequency characteristics, the internal noise, the transmission distance, operating time, transmission characteristics, etc. is examined.

2. Structure of The Wireless Electrode

Presenting wireless electrode is composed of electrode terminals, an amplifier, a high-pass filter, a stabilized reference circuit, a transmitter and a power supply. Figure 2 depicts the block diagram of the present electromyograph. The block with the thick line shows a wireless electrode. The electrodes derive surface potentials, which are amplified, high-pass filter, and then transmitted with FM manner. The reference voltages of the input signal and of the amplifier are made common by the stabilized reference circuit. Electric power is supplied to the amplifier, the transmitter and the stabilized reference circuit. The modulated signal is received and demodulated with an FM receiver, and amplified. Then, the signal is fed to a computer through an A/D converter for recording and processing.

Figure 3 shows the implementation of the wireless electrode. That is composed of two layers, i.e. the power supply, and the circuit layers. Disposable electrodes are connected to snaps. The size is 22.5×49×14.5 (m-
Fig. 2. The block diagram of the present electromyogram.

m). Total weight is 15 g with button battery cells. The external appearance of the wireless electrode attached on human skin is shown in Fig. 4. Ag/AgCl disposable electrodes (MEDICOTEST, blue sensor type R) are used that are mounted on the snaps and easily attached on skin surface, as shown in Fig. 4. Surface potentials are measured bipolare.

The instrumentation amplifier (Burr-Brown Corp., INA118B, SO Package, 5 x 4 x 1.75 (mm) ) is used. That operates as a differential amplifier and an impedance transformer due to the high input impedance of 10GΩ compared with human skin resistance and very low output impedance (3). In the first stage of the instrumentation amplifier, the resistor R and the capacitor C composes a primary high-pass filter to remove contact potentials and its drifts by chemical interaction between human skin and an electrode surface, as depicted in Fig. 5

In the conventional electromyograph even with an active electrode, a reference electrode is necessary, because the reference voltages of the input signal and of the amplifier are not common. The small EMG signal (nominally several millivolts) is contaminated with ham noise, which is the common mode. The common mode noise can be rejected by using a differential amplifier with very high common mode rejection ratio (CMRR). But, if there is no reference electrode, the voltage exceeding the power supply voltage is often inputted to the amplifier (operational amplifier).

Once the voltage exceeds the common mode input range of the amplifier, the operational amplifier latches up, CMRR decreases, and in consequence the common mode noise is no more rejected. Thus the output contains ham noise whose voltage is much higher than the voltage of EMG signal. Hence, the reference voltages of the input signal and of the amplifier must be common. In our wireless electrode a reference electrode is eliminated, and their reference voltages are made common by the circuit depicted in Fig. 6. The voltage of the power supply is divided equally by the resistors, and its central voltage follower, where the operational amplifi
er NJU7051 (New Japan Radio Co., Ltd., SO Package) is used. Its special features are very low active supply voltage and current, which is 1V and 0.015mA, respectively. Because of the usage of the voltage follower to the reference terminal of the instrumentation amplifier in the Fig. 6, does not affect the reference voltage, and the stable reference voltage, and the reference volt-

Fig. 3. Implementation of the wireless electrode.

Fig. 4. The view of the wireless electrode attached to human skin.

Fig. 5. Top view of first layer

Top view of second layer

Side view

Bottom view

Stabilized reference circuit

On/Off switch

Power Supply

Amplifier

Transmitter

First layer

Second layer

Disposable electrodes

Snaps

22.5

14.5

49

5 x 4 x 1.75 (mm)
Fig. 5. The electric circuit of the amplifier.

Fig. 6. The electric circuit of the stabilized reference.

Fig. 7. The electric circuit of the transmitter.

Three button battery cells are used for the power supply. One is oxidized silver cell for the transmitter (SR44, 1.55 V, 160 mAh, φ11.6, t 5.4), and the others are lithium cells for the amplifier (CR1220, 3.0 V x 2, 35mAh, φ12.5, t 2.0).

3. Performances

Figure 8 shows the total frequency characteristics of the wireless electrode, the receiver and the amplifier. The gain is 47 dB, and the low cut-off frequency is 22.5 Hz. The frequency band to analyze EGM is sufficiently flat, which is ranging from 30 Hz to 1 kHz.

The internal noise of the wireless electrode with shunt inputs is measured and found to be 3.7 mVrms from 0.5 Hz to 5 kHz, which is small enough in the EGM measurement. It is almost white noise.

Figure 9 shows the relationship between the transmission distance and SN ratio. The measurement site is an open space, and there are no obstacles within a radius of 15 m. The wireless electrode was placed on the polystyrene foam, 60 cm high from the ground. The gain remained very high. The drops of gain shown at 20 and 27 m are due to the interference of the direct wave and the reflection wave from the ground.

The wireless electrode has no voltage regulator nor crystal oscillator. To assure the transmission frequency stability against temperature, the wireless electrode was put in a styrene foam box and the temperature was varied from 25 to 40 °C for one hour. And no frequency change was observed.

We also examined transmission frequency stability against the power supply voltage. The environment temperature was 24 °C. It was confirmed that the wireless electrode operated for 29 hour operation, the increase of the transmission frequency with the decrease of the voltage was observed.

The consuming current in the amplifier with the stabilized reference circuit of the wireless electrode is 0.38 mA. The consuming power in the transmitter is 6.35 mW. The output power is less than 6.35 mW.

Figure 10 shows the EMG waveforms of gastrocnemius muscles on both side, and the right tibialis anterior muscle derived by three wireless electrodes on jumping
movement. Triangles in the figure show the take-off and the landing moment. Three-channel EMGs could be recorded with no ham noise by giving various frequencies to each wireless electrode though they do not have reference electrodes. And it was seen that EMG was recorded with a shock on the landing interval because of no shaking about their zero line and of their spectra.

4. Discussion

Active electrodes with a built-in transmitter, in addition, with no reference electrode were presented. The conventional telemetry systems are easily affected by the movement of their lead wires, while the present system does not have such a drawback.

Since the input impedance of the present electrode is high, biopotential signals are not affected by skin resistance. In fact, the surface potential was derived without skin preparation and conductive paste though disposable wet electrodes were used, because of the ease of setting on the skin. The derived EMG is varied by the electrode distance. Though the interval of snaps is fixed, it can be varied by using electrodes which have connectors at the edge (MEDICOTEST, Blue Sensor type R). The electrode distance should be decided according to the measurement purpose.

The present system has no wires electrode and a transmitter, and moreover, it has no reference electrode, which reduces the burden of both observers and subjects. This system with a commercially available FM radio receiver is suited to not only the human movement analysis using an EMG signal, but the physiological measurement. But, it must be noticed that the frequency characteristics of the recorded signal are also affected by the frequency characteristics of a receiver and an amplifier. Since the output power of the transmitter is very low, the legal license is not required in Japan.

Though three-channel EMGs was shown in this paper, fifteen-channel EMGs can be recorded, when the frequencies of transmitters apart 1 MHz to each other. Telemetry system has a problem of fading by many reflections. Actually, it was seen that this system was under the influence of fading about the measurement at the corridor. To settle that, it is necessary to provide several antennas of a receiver, and to select measurement places.

The effective transmission distance was 18 m by the transmission characteristic measurement in the open space, but it depends on the circumstance condition. Thus, before EMG measurement using the present system, a preliminary measurement to determine the effective transmission distance is necessary. And the drop of the gain and SN ratio can be avoided by the shorter interval of received antennas.

We believe that the wireless electrode becomes smaller, thinner and lighter by the IC technology advancement. This system can be applied widely, for example, the measurement for ECG, EEG, etc. We expect that the measurement of physiological phenomena becomes much easier, and that it will be used in various studies and experiments.

5. Conclusion

We proposed a wireless electrode that has an active electrode, a built-in transmitter, and a built-in stabilized reference. It has the following advantages and performances:

(i) Due to no wires connected with electrodes and a transmitter, and no reference electrode, the burden of both observers and subjects is reduced.
(ii) This system is not influenced by the movement of subjects because it has no lead wire.
(iii) Skin preparation and conductive paste are needless.
(iv) A commercially available FM radio can be used as a receiver.
(v) Legal license is not required in Japan due to the low output power of the transmitter.
(vi) Eighteen meters effective transmission distance, and the operating time are available.
(vii) We ensured the performance of the electrodes of 3 channels. The number of channels of simultaneous use should be certified.
Fig. 10 EMG waveforms derived by wireless electrodes on jumping
(a) right gastrocnemius muscle, (b) left one,
(c) right tibialis anterior muscle.

(viii) The power consumption was measured to be
less than 6 mW per channel. The multichannel
use increases the power consumption, which is
regal but may raise the clinical problem. Thus, the
low power circuits should be designed.
(ix) The present experiments were carried out in an
open space. Further experiments in small rooms
or corridors should be carried out, and the ar-
rangement of receiving antennas to get rid of the
interference should be designed.

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