Noise Evaluation System for Biosignal Sensors Using Pseudo-Skin and Helmholtz Coil

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Abstract*—A test equipment that can evaluate the contact resistance and amount of noise of biosignal sensors is proposed in this study. Biosignals such as EEG are easily masked by the noise derived from contact resistance, because of their feebleness. To realize a low-noise measurement, the contact resistance and the amount of noise of biosignal sensors need to be investigated accurately prior to measuring the biosignal. A pseudo-skin made of conductive rubber was employed in this study to evaluate the performance of the sensors objectively and efficiently, similar to actual working conditions. The proposed device is composed of the pseudo-skin, signal-generating circuits to imitate EEG signals and pseudo hum noise on a minute scale, and a coil to emit the pseudo hum noise into the test space. The contact resistance of the pseudo-skin can be compared to that of human foreheads. The experimental results indicated that the standard deviation of the contact resistance of the pseudo-skin is 1.70, which is smaller than that of the human foreheads, which is 6.64. This result demonstrated that the pseudo-skin is suitable for contact resistance evaluation of the biosignal sensors. In addition, the correlation between contact resistance and the amount of noise was evaluated to assess the validity of the system. The amount of noise obtained was 597.37 μVrms, 1063.09 μVrms, and 1694.04 μVrms for the conductive gels with contact resistances of 32.65 kΩ, 85.17 kΩ, and 405 kΩ, respectively. An increase in the amount of noise with the increasing contact resistance was observed from the results. Further improvement of the device and an intensive study of the evaluation method of noise are required in future, in order to establish an efficient evaluation method for biosignal sensors.

***Keywords*—noise evaluation, biosignal measurement, contact resistance.**

I. Introduction

Biosignal sensors have been attracting attention in the recent years. Therefore, this study focuses on the contact resistance of the electrodes of biosignal sensors and proposes a test equipment to quantitatively evaluate the contact resistance and amount of noise.

An epidermal contact type electrode that can be attached to human forehead to obtain the electroencephalogram (EEG) [1], and an implantable electrode that can produce Electrocorticogram (ECoG) by contacting or penetrating the cerebral cortex of rats [2] have been widely used in studies of biosignal sensors. The research on implantable electrodes that can be embedded in the brain of common marmosets to obtain the ECoG [3] can be cited as an example of implantable electrodes for animals with complicated brain structures. In the case of brain implant devices, numerous initial work-ups are required, such as pathological analysis of brain diseases [4] and the brain functions themselves [5].

However, the biosignals are generally feeble and are very susceptible to noise. The voltage amplitude range of EEG is from 10 μV to 200 μV [6]. Their amplitude range is from 0.1 mV to 5 mV [6] even with electromyogram (EMG) and electrocardiogram (ECG). Therefore, the noise immunity of the sensor and measurement system is a key factor in actual measurement.

Contact resistance between the living body and the electrode used for measurement is one of the major factors that increases the noise. Contact resistance is an electric resistance existing in the vicinity of the interface of two conductors, when they are brought into contact and current flows. A higher contact resistance degrades the noise contamination of the measured biosignal. It is necessary to evaluate the contact resistance and the amount of noise of the biosignal sensors to realize low-noise measurement and to improve the material and structure of the device and arrangement on the living body. However, only a few researches have been focused on the objective performance evaluation of the measurement devices.

The influence of changes on contact resistance caused by differences in device material and push pressure [7], and *in vivo* contact resistance measurement [8] have already been

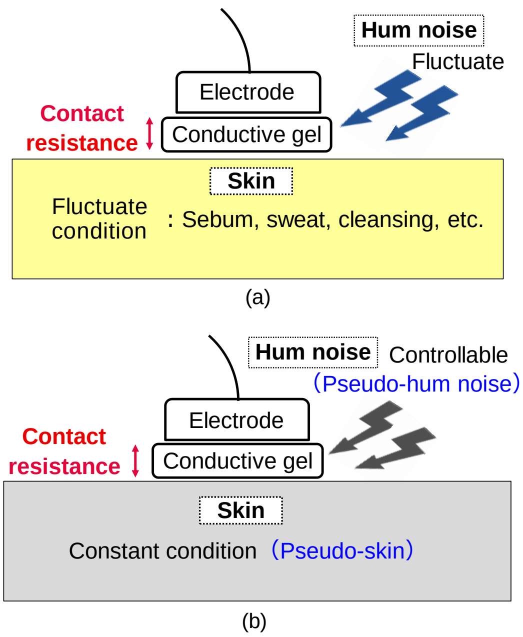

Fig. 1. (a) Schematic diagram of contact resistance generated during biosignal measurement, and (b) Proposed noise evaluation condition using pseudo-skin.

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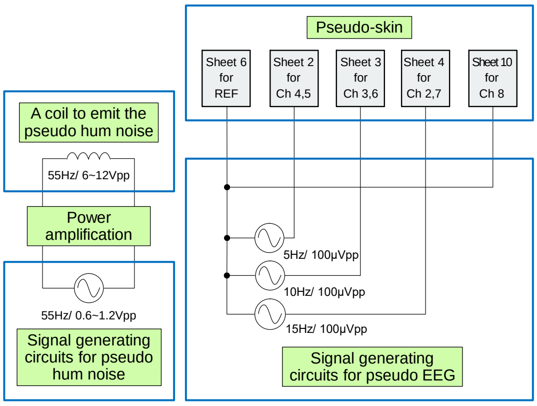


Fig. 2. Block diagram of the proposed system.

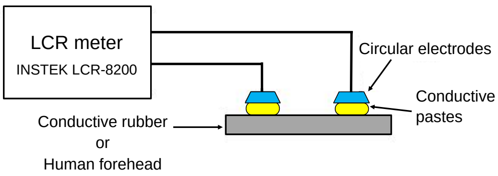


Fig. 3. Impedance measurement set up using LCR meter.

discussed in previous works. In addition, several other studies on artificial skin have been focused on using various materials such as suspensions and elastomers as substitutes for human skin [9–10]. However, no study has established the amount of noise derived from the contact resistance when using the artificial skin.

In this research, therefore, we propose a test equipment to evaluate the noise immunity of biosignal sensors. Using the pseudo-skin made of conductive rubber, the proposed system can evaluate the contact resistance and the amount of noise of the biosignal sensors, similar to actual biological measurement. Furthermore, the applicability of the pseudo-skin and the correlation between the contact resistance and the amount of noise are evaluated to determine the utility of the proposed system.

II. Proposed Test Equipment

It is clear from Fig. 1(a) that the evaluation of contact resistance and the amount of noise with high reproducibility and stability is difficult in actuality because of the variations of the living body's conditions and the hum noise amount.

The conditions of the living body always fluctuate because of sebum, sweat, wiping state before measurement, and individual differences; therefore, the results of the measurement also vary. In addition, the amount of hum noise existing in the actual conditions fluctuates persistently. The biosignals are mainly contaminated by the hum noise because of commercial power supply. Because the amount of fluctuation of the hum noise affects the signal-to-noise ratio (SNR) of the measurement result, the evaluation of the effects of other noises and signal quality becomes difficult. In order to effectively evaluate the contact resistance and the amount of noise, the states of the skin and environmental noise must be maintained constant, as shown in Fig. 1(b).

Fig. 2 shows the overall configuration of the device. The device is composed of the pseudo-skin, minute signal

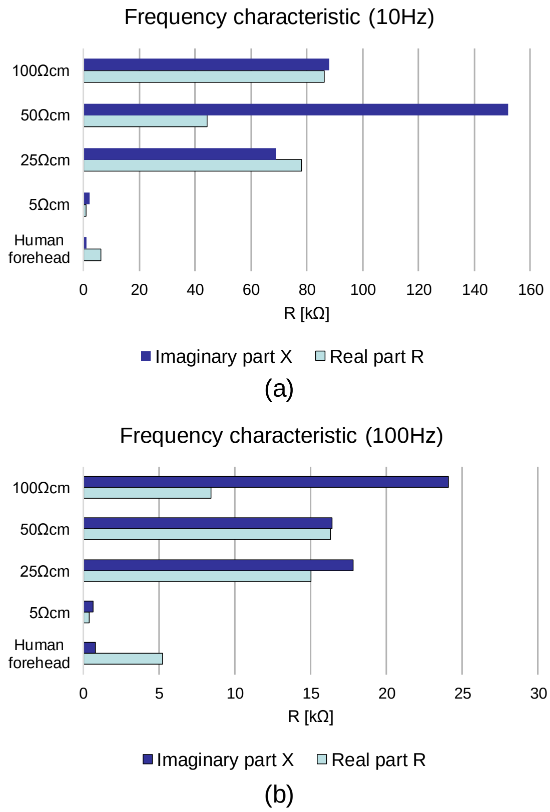


Fig. 4. Measured result of impedance.

generating circuits for imitation of EEG, circuits for pseudo hum noise, and a coil to emit the pseudo hum noise into the test space.

A. Pseudo-skin

To maintain a constant experimental condition, a pseudo-skin made of conductive rubber is used in the proposed test equipment instead of living body. Four types of conductive rubber with conductivities of 5 Ω·cm, 25 Ω·cm, 50 Ω·cm, and 100 Ω·cm were evaluated to obtain a pseudo-skin with characteristics similar to the skin of human forehead. The impedance of the conductive rubbers was measured using an LCR meter, as shown in Fig. 3. Then, a comparison of the frequency characteristics of the conductive rubbers and human forehead was made.

The measurement results of the impedance of the conductive rubbers and human forehead are shown in Fig. 4 In the imaginary part X, which indicates the capacitance characteristics, the result of the conductive rubber with the conductivity of 5 Ω·cm is much similar to the human forehead than the other conductive rubbers. However, in the real part R, the human forehead displays higher resistance than the above-mentioned conductive rubber. Because the human body has a resistance of about 500 Ω, an equivalent resistance was incorporated to the pseudo-skin to improve its characteristics. The conductive rubber was cut into small pieces of 20 mm × 30 mm, and were connected by a fixed resistance of 510 Ω, as shown in Fig. 5.

B. Pseudo hum noise

To maintain the amount of hum noise constant, we fabricated signal-generating circuits capable of generating

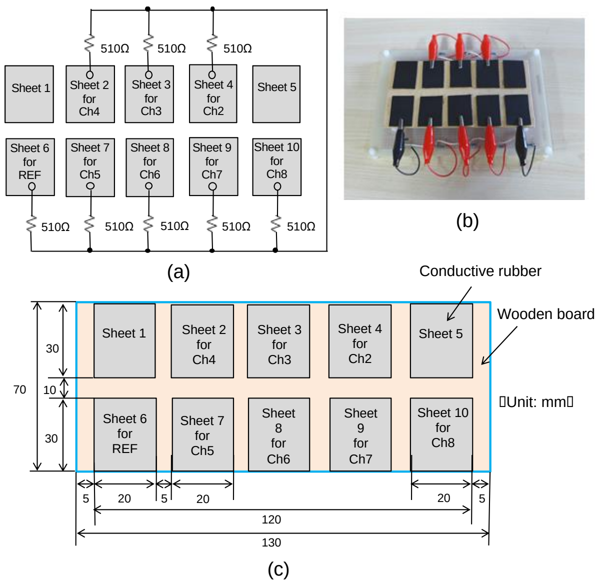


Fig. 5. (a) Block diagram of the pseudo-skin,
(b) Appearance of the pseudo-skin, and (c) Dimensional drawing.

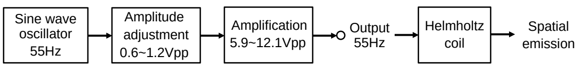


Fig. 6. Pseudo hum noise generation unit and an emitter unit.

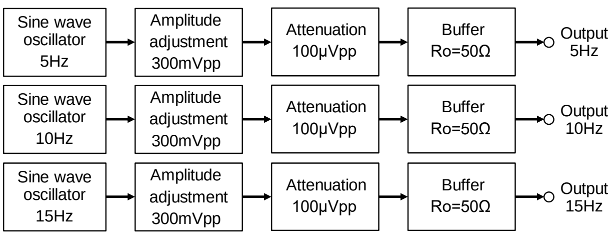


Fig. 7. Configuration of pseudo-EEG generator.

pseudo hum noise. The frequency of the pseudo hum noise was set as 55 Hz to distinguish it from the actual hum noise frequencies of 50 Hz or 60 Hz existing in the surrounding environment.

Then, to emit the pseudo hum noise into the space, a Helmholtz coil capable of generating a uniform magnetic field was introduced. The driving power of the coil was set as 1 W.

C. Pseudo-EEG

We developed signal-generating circuits to function as the pseudo-EEG generator to generate low frequency minute sine signals of 5 Hz, 10 Hz, and 15 Hz. The output of the minute signal was set as 100 μV, which corresponds to the voltage of the actual EEG. The pseudo-EEG generator was used to ensure that the feeble signals equivalent to actual EEG can be measured on the pseudo skin. This signal can also be used for general operation verification of evaluation target systems.

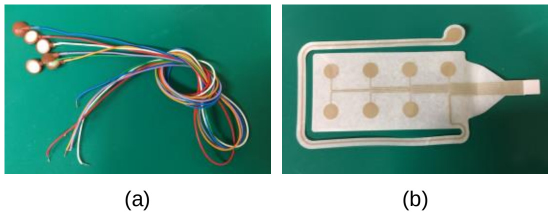


Fig. 8. (a) Circular electrodes and (b) Electrode sheet.

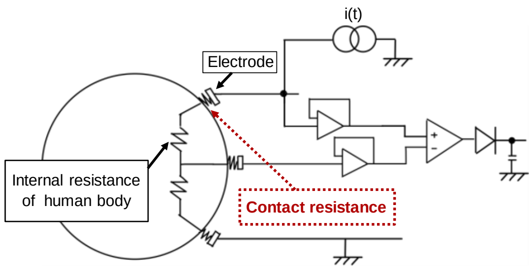


Fig. 9. Schematic of contact resistance measurement circuit.

III. Evaluation Result

A. Contact Resistance

To investigate the validity of the pseudo-skin as a substitute for the human skin, the contact resistance measurement experiment was conducted. The contact resistance of the forehead of two participants (24-year old female and 40-year old female) and that of the pseudo-skin were measured using a multichannel Electrode sheet (PGV Inc., patch-type EEG sensor sheet [1], shown in Fig. 8(b)), and circular electrodes (Nihon Kohden, NE-144A, shown in Fig. 8(a)). Fig. 9 shows the experimental set up. The three terminal measurement method was used for the contact resistance measurement, and the measurement was performed twice for each electrode using a conductive paste (East Medic Co., Ltd., Ten 20).

The results of the contact resistance measurement indicated that the standard deviations (SD) of human foreheads and the pseudo-skin were 5.30 and 2.14, respectively, when using circular electrodes. When electrode sheets were used, the SDs of human foreheads and the pseudo-skin were 5.57 and 1.70, respectively. The results indicate that the pseudo-skin has smaller dispersion of contact resistance than the human forehead, for both electrodes (Fig. 10).

The variations in the contact resistance of human foreheads appear to have been caused by the wiping state before measurement, individual differences, state changes in the skin due to multiple measurements, and contact states due to the electrode pasting position. The pseudo-skin is not affected by these conditions, and the contact resistance can be evaluated stably. This result indicates that a more objective and efficient evaluation of biosignal sensors is possible using the pseudo-skin, which can reproduce the characteristics of human skin under constant conditions.

B. Noise Amount

Finally, to investigate the validity of the device, an experiment to evaluate the amount of noise was conducted. In this section, the correlation between the contact resistance and the amount of noise in the measurement results is determined.

Three kinds of conductive gels with different contact resistances were attached to each channel of an electrode sheet (PGV Inc., patch-type EEG sensor sheet). A wireless module, capable of transmitting the measured data to PC using Bluetooth 4.0, was connected with the electrode. The pseudo-skin together with the electrode and wireless module was placed into the Helmholtz coil that emits pseudo hum noise of frequency 55 Hz (Fig. 11). Because the pseudo-skin does not completely fit in the uniform magnetic field generated by the Helmholtz coil, the position of the measured target channel was adjusted to be near the center of the coil. Then, the noise-amount measurements were performed 10 times for each conductive gel. In this study, the noise-amount denotes the standard deviation of the voltage amplitude of the measurement data. If the system is not irradiated by the noise, the measured output will be 0 V.

The measurement results indicated that the amount of noise of the conductive gels with contact resistances of 32.65 kΩ, 85.17 kΩ, and 405 kΩ were 597.37 μVrms, 1063.09 μVrms, and 1694.04 μVrms, respectively. This result indicates that the amount of noise increases with the increasing contact resistance of the conductive gel (Fig. 12).

IV. Conclusion

In this study, a test equipment was developed to evaluate the contact resistance and the amount of noise of biosignal sensors in a constant test condition, similar to actual biosignal measurement. The proposed system consisted of pseudo-skin made of conductive rubber, having properties similar to the human skin, and the pseudo hum noise generation system. The evaluation results indicated that the conductive rubber can be utilized as the pseudo-skin. Further, it was demonstrated that the proposed system has sufficient feasibility for the evaluation of the amount of noise of biosignal sensor devices. Although this work tested the device for a limited measurement conditions, further experiments using other sensors and materials will be conducted in our future work, and also properties of the pseudo-skin need to be compared with other artificial skins of the previous studies.

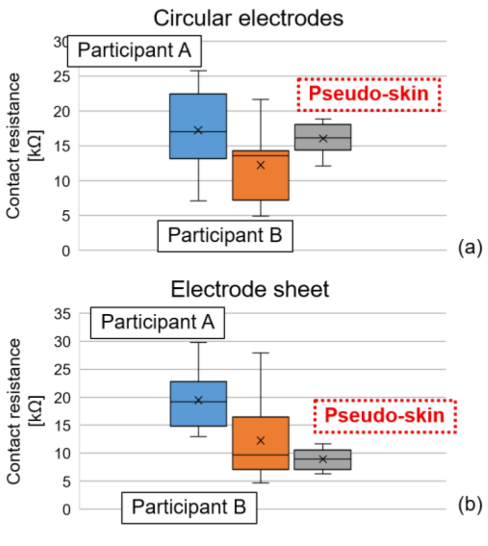


Fig. 10. (a) Measurement result of contact resistance when using circular electrodes, and (b) when using electrode sheet.

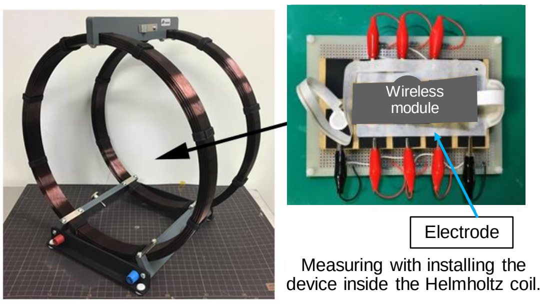
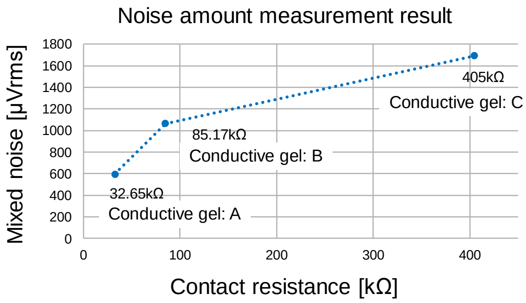


Fig. 11. Experimental setup of noise quantity evaluation.



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