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Human Respiration Detection Technique based on Measurement of Current Generated by Electrostatic Induction*

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Abstract— **We developed an effective non-contact technique for measuring human respiration using a nonattached electrode. The technique requires measurement of the current generated due to the difference in capacitance between a given electrode and the human body. The electrostatic induction current flowing through the electrode when placed a few centimeters from the subject is detected. We propose a theoretical model for the electrostatic induction current generated by the change in the capacitance caused by the movement of the body surface while taking a breath. This model effectively describes the behavior of the waveform of the current flowing through the measurement electrode.**

I. INTRODUCTION

Health monitoring is conventionally regarded as an important determinant in promoting the general health and well-being of people around the world. In particular, obstructive sleep apnea syndrome affects many people, frequently as an asymptomatic, undiagnosed condition, and is associated with increased morbidity and mortality. Conventional diagnosis requires overnight monitoring in a specially equipped sleep laboratory. Furthermore, the conventional thermocouple method used for detecting human respiration requires insertion of a sensor directly into the nose. The inconvenience of overnight polysomnography (PSG) has led to a need for more easily implemented techniques for detecting respiration using nonattached probes. Recently, researchers investigating noncontact respiration monitoring have been trying to create easier-to-use techniques for diagnosis and measurement of breathing rate. For example, Yama [1] proposed capacity-coupled electrodes, Jong [2] attempted the use of phase detection radar, Tanaka [3] suggested a pressure sensor, and Aoki [4] relied on near-infrared light pattern projection.

We think that among the above, the most effective technique is the use of a capacity-coupled electrode. The capacitance measured is between the human body and an electrode that is isolated from human body by a dielectric such as cloth. In the conventional capacity-coupled electrode method, the voltage on the electrode is measured against the body surface. An isolated electrode must be attached to the human body because of the low permittivity of the air between the body and electrode. However, if we can monitor the respiration rate or other parameters without the use of an attached electrode, the method will find wide application in medical practice. On the other hand, when subject sleep with his/her body under the covers, the remote monitoring method such as near-infrared light pattern projection cannot allow detection of human respiration. Improvements are needed in the detection of human respiration regardless of whether a blanket is used.

In this study, we developed an effective technique for measuring human respiration using a noncontact and nonattached electrode. The technique requires measurement of the current generated due to the difference in capacitance between a given electrode and the human body. The subpicoampere electrostatic induction current flowing through the electrode when placed a few centimeters from the subject is detected. It is necessary to emphasize that the method for the detection of the electrostatic induction current is different from the conventional method described in the previous paragraph.

Furthermore, we propose a theoretical model for the electrostatic induction current generated by the change in the capacitance caused by the movement of the body surface while taking a breath. This model effectively describes the behavior of the electrostatic induction current flowing through the measurement electrode.

II. PRINCIPLE

It is well known that the human body is electrically charged at all times [5–10]. Let us assume that for a subject sitting on a chair, there are two highly resistive objects between the subject's body and the surface of the floor, as shown in Fig. 1. One layer is the sole of the subject's footwear (C_s) and the other is the chair (C_c). The capacitance of the feet relative to the ground is the sum of the capacitances $C_s + C_c$ and that of the floor surface C_f. In addition, C_o is the capacitance of the rest of the subject's body relative to neighboring objects on the floor. We assume that the human body is a good conductor. Therefore, the potential U_B of the body on the chair can be expressed as follows:

$$U_B = Q_B /(\frac{(C_S + C_c)C_f}{C_S + C_c + C_f} + C_O), \quad (1)$$

where Q_B is the instantaneous charge of the human body.

The induced charge Q on the measurement electrode placed at distance d from the subject's body can be expressed as follows:

$$Q = C(U_B - V), \quad (2)$$

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where C represents the capacitance between the human body and the measurement electrode, and V is the potential of the measurement electrode.

When the subject moves his/her abdomen during respiration such that it is almost perpendicular to the electrode, the capacitance C can be expressed as follows:

$$C \propto \frac{\varepsilon_a S}{x}, \tag{3}$$

where S represents the area of the electrode, x represents the distance between the subject's abdomen and the electrode, and ε_a represents the permittivity of air. Using the above equations, we can express the induced current I flowing through the measurement electrode as follows:

$$I = \frac{dQ}{dt} = U_B \frac{dC}{dt} \propto -U_B \frac{\varepsilon_a S}{x^2} v, \tag{4}$$

where v represents the velocity of the body surface.

Because the electric charge of the subject's body generated due to triboelectricity between subject's body and surrounding objects does not charge rapidly, we can detect the electrostatic induction current generated due to human respiration unaffected by the influence of the change of the electric potential U_B.

Equation (4) describes the electrostatic induction current resulting from the motion of the subject's abdomen toward the electrode. The current generated is approximately proportional to the velocity of the movement of the subject's abdomen. Therefore, we can conclude that under perfect noncontact conditions, it is possible to measure the electrostatic induction current generated due to the movement of the abdomen by the respiration.

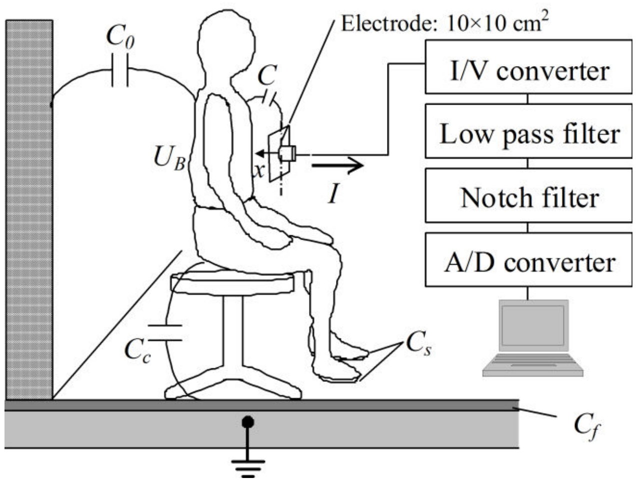

Figure 1. Schematic diagram of the system for measuring the electrostatic induction current.

III. Experimental Method

A. Wired Measurement System (Preliminary Experiment)

A schematic of the measurement system for measuring the electrostatic induction current generated by human respiration is shown in Fig. 1. This measurement system was used as preliminary experiment for detection of human respiration. The electrostatic induction current flowing through an electrode placed 30 mm from the subject's abdomen was converted into a voltage by an *I–V* converter comprising an operational amplifier. The conversion ratio was 15 V/pA because the electric current was on the subpicoamperes level. the *I–V* converter consists of two low-input-current op-amps, where C_f is 1 pF and R_f is 3 TΩ. The selected low-noise op-amp has an input offset voltage of 40 μV and input offset current of 1 pA. The feedback resistor connected to the op-amp is a hermetically sealed high register that can prevent stray current due to humidity. For such measurements with high input resistance, a conventional guarding method is absolutely imperative for shielding used with op-amps; this prevents stray currents from entering sensitive nodes. Sensitive nodes are completely surrounded by a guard conductor that is kept at the same electric potential as the sensitive node.

In addition, induction currents generated by commercial power sources manifest in the form of noise. Therefore, a filtering system with a cutoff frequency of 20 Hz is used. This measurement system is unaffected by the noise from other electronic devices such as mobile phones or microwave ovens. The analog signals are subsequently converted into digital signals using an analog-to-digital (A/D) converter. We cannot categorically state the SN ratio of this system, because the SN ratio depends on the experimental conditions. Data are acquired at a sampling frequency of 250 Hz and stored on a personal computer. The measurement electrode is square in shape with a side length of 10 cm.

During the experiment, the subject was asked to sit comfortably in a chair. Further, the movement of subject's abdomen surface was tracked by a wireless accelerometer attached to the subject's navel. The acceleration of the subject's abdomen with respect to the electrode and the electrostatic induction current were all measured simultaneously. The acceleration data were acquired at a sampling frequency of 200 Hz and stored on a personal computer. The obtained acceleration data were converted by numerical integral into velocity data for the subject's abdomen with respect to the electrode.

The static electric field due to the charged material surrounding the electrode does affect the absolute value of the capacitance C between the subject's body and a given measurement electrode. However, the static electric field has little effect on the measurement, because the instantaneous electrostatic induction current arises from the changes of the capacitance C according to the subject's respiration. In fact, the generated transient current reflects only contact between the subject's body and the wall.

B. *Wireless Measurement System*

As mentioned above, we can detect signals generated by the changes in the electric capacitance between the electrode and a subject's body by using a measurement electrode located less than 30 mm from the subject. However, to use this technique for wide range, the electrode must be use to connect to *I*–*V* convertor by a BNC cable. To solve this problem, we developed a wireless portable sensor to detect signal generated due to the movement of the subject's respiration. A schematic of the measurement system for detecting the electrostatic induction current generated by the changes in the electric potential of a subject's body while in bed is shown in Fig. 2. The electrostatic induction current flowing through an electrode placed at 80 millimeters from the subject's body is converted into voltage using an *I*–*V* converter with a conversion ratio of 50 V/pA and comprising an op-amplifier. The proposed portable wireless sensor attached to back of bed can detect the respiration signals. A schematic of the portable measurement system is similar to Fig. 1, except for using a wireless transmitter. The sensor provides the subject information about the respiration rate while in bed under noncontact and nonattached conditions.

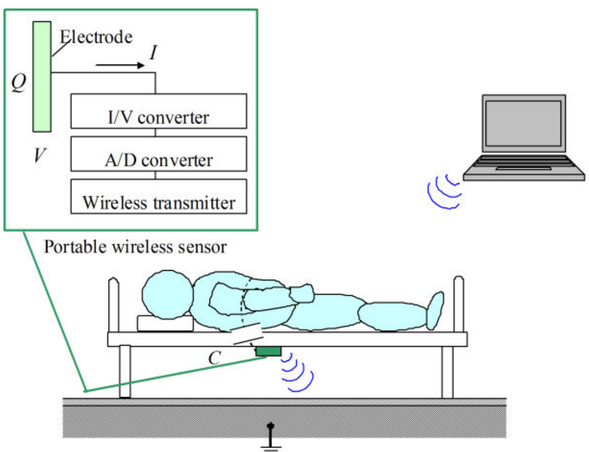

Figure 2. Schematic diagram of the system for measuring the electrostatic induction current while in bed.

Figure 3. Photograph of a protable wireless sensor.

The analog signals are subsequently converted into digital signals using an A/D converter. We used the XBee protocol for wireless data transmission to a personal computer from the portable contact detection system. Data were acquired at a sampling frequency of 100 Hz, which is safe given that the actual data transmission rate on XBee networks is as low as about 10 kbps. However, this sampling frequency was sufficient for detecting contact events. The measurement electrode is square with a side length of 2 cm. A photograph of the prototype portable wireless respiration detection sensor is shown in Fig. 3.

IV. Results and Discussions

Figure 4 shows a waveform of the current generated by human respiration for subject A with a sampling frequency of 250 Hz. Periodical components with a period of approximately 4.2 s are observed in the resulting waveform.

As predicted by Eq. (4), movement of the subject's body surface toward the electrode resulted in an increase in *I*, whereas movement of the subject's body surface away from the electrode resulted in a decrease. The positive and negative peaks are observed corresponding to exhalation and inhalation, respectively. Therefore, we can conclude that Eq. (4) effectively describes the behavior of the waveform of *I*.

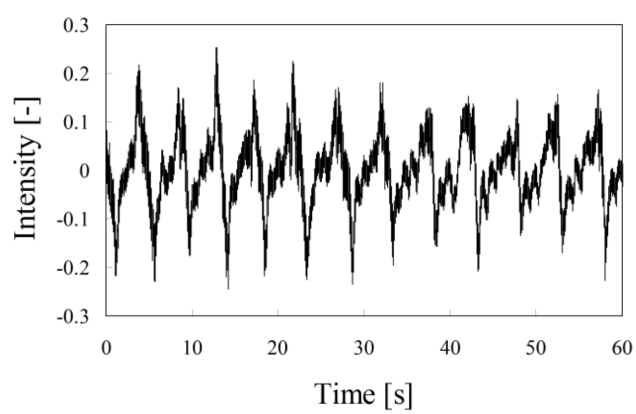

Figure 4. Waveform of the electrostatic induction current generated due to respiration by using wired measurement system.

Figure 5 shows the waveform of the current generated by human respiration for subject B with a sampling frequency of 100 Hz. Periodical components with a period of approximately 5.2 s are observed here as well. The obtained waveforms for subjects A and B have a periodical component due to human respiration. It was observed that the intensity of the electrostatic induction current was inversely proportional to the square of the distance between the electrode and the body surface, and was proportional to the velocity of the body surface. Moreover, the proposed technique can allow detection of the rollover movement in his/her sleep because of the high sensitivity of the proposed detection system. It's common knowledge that the times and the time-interval of rollover in a full night's sleep influence sleeping quality.

Proposed portable sensor cannot only allow detection of the human respiration but also detection of rollover movement under noncontact and nonattached conditions.

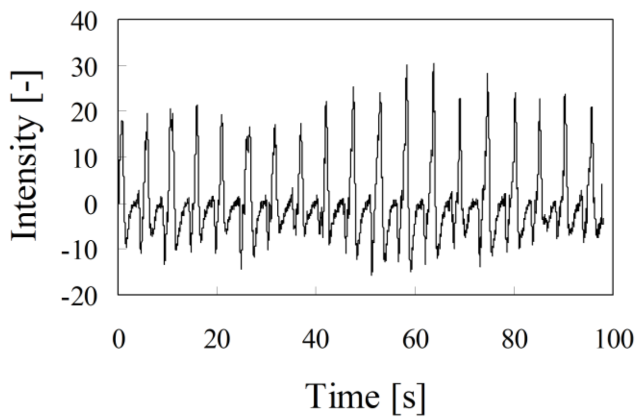

Figure 5. Waveform of the electrostatic induction current generated due to respiration by using wireless measurement system.

V. Conclusion

In this study, we developed an effective technique for measuring human respiration using a noncontact and nonattached electrode. The technique requires measurement of the current generated due to the difference in capacitance between a given electrode and the human body. The electrostatic induction current flowing through the electrode when placed a few centimeters from the subject is detected. Furthermore, we propose an occurrence model for the electrostatic induction current generated by the change in the capacitance caused by the movement of the body surface while taking a breath. This model effectively describes the behavior of the electrostatic induction current flowing through the measurement electrode. The proposed technique showed good measurement reproducibility.

References

[1] Y. Yama and A. Ueno, "Unrestrained facile measurement of narrow-band ECG and respiratory variation in infants with a capacitive sheet-type sensor (in Japanese)," *Transactions of Japanese Society for Medical and Biological Engineering*, vol. 47, no. 1, pp. 42–50, Feb. 2009.

[2] H. J. Jong, et al, "Measurement of human heartbeat and respiration signals using phase detection radar," *Review of Scientific Instruments*, vol. 78, no. 10, pp. 104703–104703-3, 2007.

[3] S. Tanaka, et al, "Clinical evaluation of a fully automated physiological monitoring system for providing support on the medical care (in Japanese)," *IEICE Technical Report*, MBE2007-13, pp. 49–52, 2007.

[4] H. Aoki H, et al, "Basic study on noncontact respiration measurement under pedaling motion with upright bicycle ergometer," *WACBE World Congress on Bioengineering* 2009, pp. 193, 2009.

[5] V. Amoruso, et al, "An improved model of man for ESD application," *Journal of Electrostatics*, vol. 49, pp. 225–244, 2000.

[6] A. Ohsawa, "Electrostatic characterization of antistatic floors using an equivalent circuit model," *Journal of Electrostatics,* vol. 51–52, pp. 625–631, 2001.

[7] O. Fujiwara, et al, "Electrification properties of human body by walking," *The Transactions of the IEICE*, vol. 73, no. 6, pp. 876–878, 1990.

[8] O. Fujiwara, "New approaches for measurement of static electricity toward preventing ESD," *IEICE Trans. Commun.*, vol. E75-B, no. 3, pp. 131–140, 1992.

[9] O. Fujiwara, et al, "An analysis of charged floor potential using electromagnetic field theory," *Electron. Commun. Japan*, vol. 81, pp. 28–35, 1998.

[10] T. Ficker, "Electrification of human body by walking," *Journal of Electrostatics*, Vol. 64, pp. 10–16, 2006.