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# Detection of Human Respiration Based on Measurement of Current Generated by Electrostatic Induction

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***Abstract***: 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. 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 current flowing through the measurement electrode.

***Keywords***: Noncontact measurement, Respiration rate, Current measurement, Human heartbeat

## I. INTRODUCTION

Obstructive sleep apnea syndrome (OSAS) 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 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.

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 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.

## 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:

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

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:

$$Q = C(U_B - V), \tag{2}$$

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 $\varepsilon_a$ 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.

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.

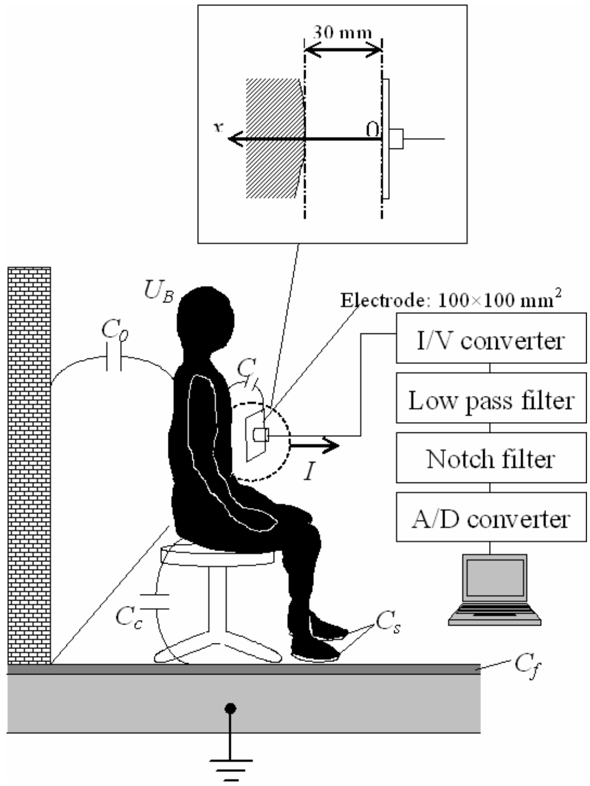


Fig.1. Schematic of the measurement system for measuring the electrostatic induction current

## III. EXPERIMENTAL

A schematic of the measurement system for measuring the electrostatic induction current generated by human respiration is shown in Fig. 1. 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 subpicoampere level. In addition, the induction currents generated by commercial power sources were present in the form of noise. Therefore, a filtering system with a cutoff frequency of 20 Hz was used. The analog signals were subsequently converted into digital signals by an analog-to-digital (A/D) converter. The data were acquired at a sampling frequency of 100 or 250 Hz and stored on a personal computer. The measurement electrode was 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.

## IV. RESULTS AND DISCUSSIONS

The upper panel in Fig. 2 shows a waveform of the current generated by human respiration for subject A with a sampling frequency of 100 Hz. Periodical components with a period of approximately 4.2 s are observed in the resulting waveform.

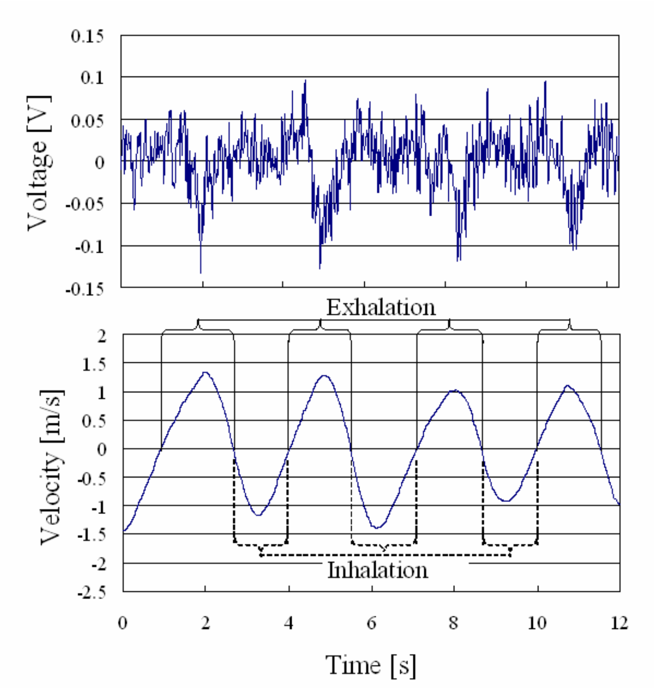


Fig. 2. Waveform of electrostatic induction current (upper panel) and of the velocity of the subject's abdomen (lower panel) generated by human respiration for subject A

The lower panel shows the waveform of the velocity of the subject's abdomen with respect to the electrode. 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 regions indicating exhalation and inhalation are indicated by the solid and broken lines, respectively. Therefore, we can conclude that Eq. (4) effectively describes the behavior of the waveform of $I$.

Figure 3 shows the waveform of the current generated by human respiration for subject B with a sampling frequency of 250 Hz. Periodical components with a period of approximately 4.2 s are observed here as well. Figure 4 shows a magnified version of a part of the waveform in Fig. 3. Periodical components with a period of approximately 0.9 s are observed in Fig. 4. At this point, the origin of the short-period components is still unclear. They may originate from the human heartbeat because the observed signal has a similar cycle.

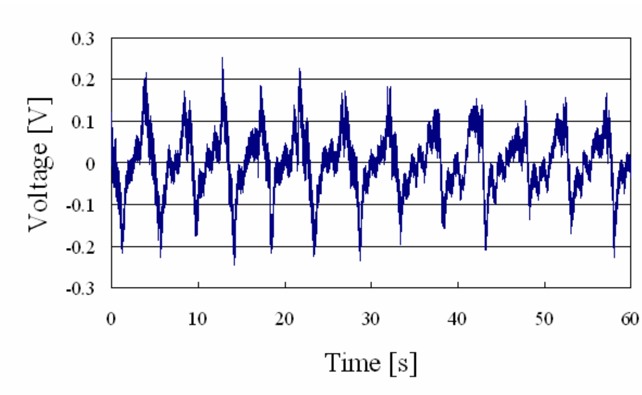


Fig. 3. Waveform of electrostatic induction current generated by human respiration for subject B with a sampling frequency of 250 Hz

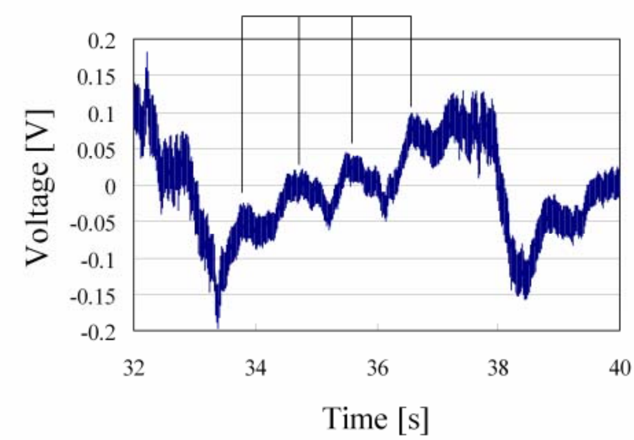


Fig.4. Magnified waveform of electrostatic induction current generated by human respiration for subject B with a sampling frequency of 250 Hz

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. The proposed technique showed good measurement reproducibility.

## 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 subpicoampere 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.

In the magnified waveform, periodical components with a period of approximately 0.9 s are observed. They may originate from the human heartbeat, because the observed signal has a similar cycle. The proposed technique showed good measurement reproducibility.

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