HUMAN PHYSICAL ACTIVITY MEASUREMENT METHOD BASED ON ELECTROSTATIC INDUCTION

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Abstract:
In this study, an effective noncontact technique for the detection of human physical activity is proposed. We have develop a method for measuring human physical activity, which is based on detecting the electrostatic induction current generated by the walking motion under non-contact and non-attached conditions. A theoretical model for the electrostatic induction current generated because of a change in the electric potential of the human body is also proposed. By comparing the obtained electrostatic induction current with the theoretical model, it becomes obvious that this model effectively explains the behavior of the waveform of the electrostatic induction current. The normal walking motions of daily living are recorded using a portable sensor measurement located in an ordinary house. The obtained results show that detailed information regarding physical activity such as a walking cycle can be estimated using our proposed technique. This suggests that the proposed technique, which is based on the detection of the walking signal, can be successfully applied to the estimation of human physical activity.

Keywords: Human walking, Electrostatic induction, Human physical activity

1. INTRODUCTION

Physical activity improves health and well-being. The benefits of physical activity for the prevention of cardiovascular disease, cerebral accidents, and some cancers are now well established. These benefits are also enjoyed in old age, where the incidence of many diseases and disabilities increases. Researchers have made numerous attempts to develop methods to measure physical activity. This is because precise measurements of physical activity would allow assessment of physical activity in the same way as a physical activity diary. Estimates of physical activity are often made using self-report measures. However, these have some disadvantages such as the impossibility of estimating activity patterns throughout the day [1] and fluctuations in health status [2]. Therefore, objective measurement methods for physical activity are attracting a great deal of attention as they would overcome the limitations of self-report measures. In particular, measurement of the acceleration of a subject's body provides information on the amount, frequency, and duration of physical activity [3]. An objective physical activity measurement method such as accelerometry can also assess free-living activity. Objective physical activity measurements [4] make it obvious that participation in non-exercise physical activity such as housework and stair climbing improves mortality risk.

In particular, it has been noted that walking for exercise is especially effective for long-term weight loss [5], increasing HDL [6], reducing blood pressure [7], and lowering the risk of heart disease and cancer initiation. In the last decade, human walking analysis has attracted much attention from computer vision researchers motivated by its wide application potential. Normally, in vision-based human walking detection, motion features are extracted from image sequences. Subsequently, feature amounts are compared as an identification process. However, in conventional human walking detection methods, experimental conditions such as the distance between the subject and camera, the angle of the camera, and the pixel density of the camera significantly influence the recognition rate of the system. Moreover, the main drawback of these methods is that they cannot detect anything in the dead zone of the camera. Furthermore, many image-processing systems require complex logic to ignore the disturbances caused by the motion of objects other than humans.

Alternatively, body-mounted accelerometers are extensively used for monitoring human motion because these systems are inexpensive compared to an optoelectronic motion capture system. Another advantage of body-mounted accelerometers is that the system is available in an indoor-outdoor space. Additionally, several methods have been presented to measure human activity using various techniques, e.g., an ultrasonic motion analysis system to temporally and spatially measure the amount of human activity, an electromagnetic 3D orientation estimation system that uses the earth's magnetic field, and a wearable ultrasonic motion analysis system. However, in these measurement systems, it is necessary to use some kind of sensor or marker that remains in contact with the subject. Therefore, these methods have not been applied to non-contact detection for human activity measurement.

In this paper, we present a new direction for a human activity estimation technique that does not use a camera or accelerometry. We have developed an effective non-contact technique for the detection of human walking motion using human-generated body charge. This technique involves the detection of an electrostatic induction current on the order of approximately sub-picoamperes flowing through an electrode placed at a distance of 3 m from a subject. The absolute value of the electrostatic induction current depends on the type of footwear and floor material. However, we confirmed that this technique has sufficient sensitivity to detect the electrostatic induction current generated by the walking motion in daily life. This technique effectively explains the behavior of the waveform of the electrostatic induction current flowing through a given measurement electrode using a capacitance model for the human body.

2. PRINCIPLE

The human body is electrically charged during walking [8]. In the case of a subject that is standing or walking, we assume that there are two highly resistive layers between the feet of the subject and the floor, as shown in Fig. 1. One layer is the sole of the subject's footwear. The other is the surface of the floor. Capacitance C_{sf} of the feet relative to the ground may be calculated as the sum of capacitance C_s of the sole and capacitance C_f of the floor surface.

$$\frac{1}{C_{sf}} = \frac{1}{C_s} + \frac{1}{C_f}, \tag{1}$$

On the other hand, addition, the electric capacitance C_x between the sole and floor can be expressed as follows:

$$C_x = \frac{\varepsilon_a S_{nc}}{(x - x_0)} + \frac{\varepsilon_f S_c}{x_0} = \frac{\varepsilon_a S_{nc} x_0 + \varepsilon_f S_c (x - x_0)}{(x - x_0) x_0}, \tag{2}$$

where S_c is the contact area between the sole and floor, S_{nc} is the delamination area of the sole against the floor, x is the distance between the sole and the earth, x_0 is the distance between the floor surface and the earth, ε_a is the permittivity of the air gap between the sole and floor, and ε_f is the averaged permittivity of the floor materials between the floor surface and the earth. Therefore, the electric capacitance C_B of the human body during walking motion can be expressed as follows:

$$\frac{1}{C_B} = \frac{1}{C_{sf}} + \frac{1}{C_x}, \tag{3}$$

Therefore, potential U_B of the human body during walking motion can be expressed as follows:

$$U_B = \frac{Q_B}{C_B} = \frac{Q_B}{C_{sf}} + Q_B \frac{(x - x_0) x_0}{\varepsilon_a S_{nc} x_0 + \varepsilon_f S_c (x - x_0)}, \tag{4}$$

Q_B is the instantaneous charge of the human body during walking motion. The induced charge, Q, of a measurement electrode placed at a certain distance from the subject can be expressed as follows:

$$Q = C(U_B - V), \tag{5}$$

where C is the capacitance between the human body and measurement electrode in the wireless portable sensor, and V is the potential of the measurement electrode. From the above two equations, the induced current, I, flowing through the measurement electrode can be expressed as follows:

$$I = \frac{dQ}{dt} = C\frac{dU_B}{dt} = Q_B \frac{d}{dt}\left(\frac{1}{C_x}\right)$$

$$= Q_B \frac{d}{dt}\left\{\frac{(x - x_0) x_0}{\varepsilon_a S_{cn} x_0 + \varepsilon_f S_c (x - x_0)}\right\}$$

$$= A\left\{x_0^2 \varepsilon_a S_{nc} \frac{dx}{dt} - (x - x_0) x_0^2 \varepsilon_a \frac{dS_{nc}}{dt} - (x - x_0)^2 x_0 \varepsilon_f \frac{dS_c}{dt}\right\}, \tag{6}$$

where

$$A = \frac{Q_B}{\left[\varepsilon_a S_{cn} x_0 + \varepsilon_f S_c (x - x_0)\right]^2}. \tag{7}$$

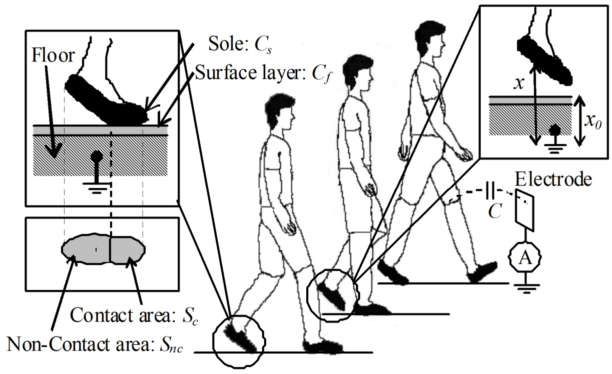

Fig. 1: Scheme of the interaction between the human body and the surface layer of the floor in walking motion

We assume that the human body is a good conductor. The third term in Eq. (6) represents the current induced by the motion of the foot before it is lifted off the floor. When the toe of the right foot is lifted off the floor, the contact area S_c between the sole and floor decreases. Therefore, the electrostatic induction current I increases as predicted by the third term on the right-hand side of Eq. (6). The second term in Eq. (6) represents the current induced by the motion of the foot before it is lifted off the floor. However, the second term of Eq. (6) has little influence on the electrostatic induction current because the permittivity of the air ε_a is small compared to the averaged permittivity of the floor materials ε_f. The first term represents the current induced by the motion of the foot and leg after the foot is lifted off the floor. The first term is approximately proportional to the velocity of the foot. Therefore, in the case of walking motion near the measurement electrode as shown in Fig.1, it is possible to measure the current generated under perfect non-contact conditions.

3. EXPERIMENTAL METHOD

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 is shown in Fig. 1. The electrostatic induction current flowing through an electrode in the wireless portable sensor placed less than 5 m from the subject's body is converted into voltage using an I–V converter with a conversion ratio of 20 V/pA and comprising an operational amplifier (op-amp). The *I–V* converter consists of two low-input-current op-amps, where the feedback capacitance C_f is 1 pF and the feedback resistance R_f is 10 TΩ as shown in Fig. 2. 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.

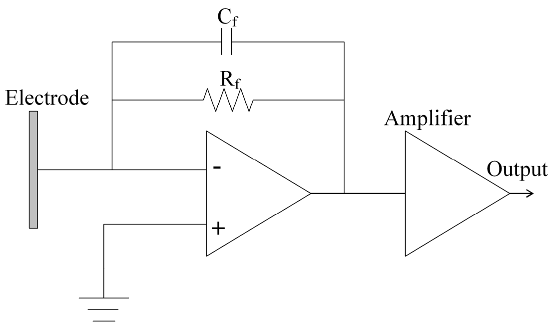

Fig. 2: Schematic circuit diagram of the I–V converter

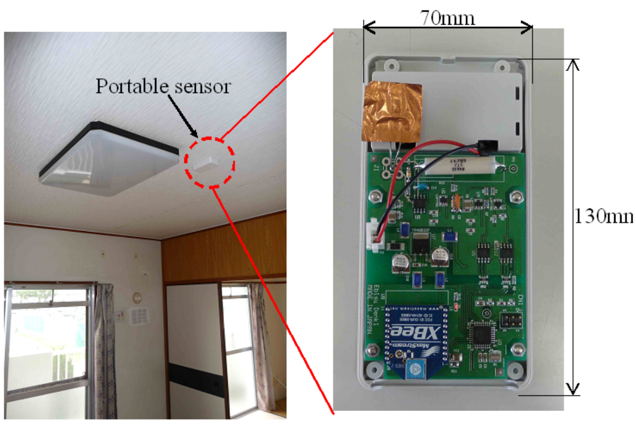

Fig. 3: Photograph of portable sensor

The analog signals are subsequently converted into digital signals using an A/D converter. We used the ZigBee protocol for wireless data transmission to a personal computer from the portable walking detection system. Data were acquired at a sampling frequency of 100 Hz, which is safe given that the actual data transmission rate on ZigBee 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 wireless portable sensor is shown in Fig. 3.

The wireless portable sensor was placed in ceiling of an ordinary house with a wooden floor as shown in Fig. 4. The subjects were asked to walk normally wearing slippers on a wooden floor. The subjects (A, B, and C) were 3 healthy men aged between 19 and 20 years. The subjects were asked to walk in a cycle of 100 steps per minute in order to keep the same cycle of walking.

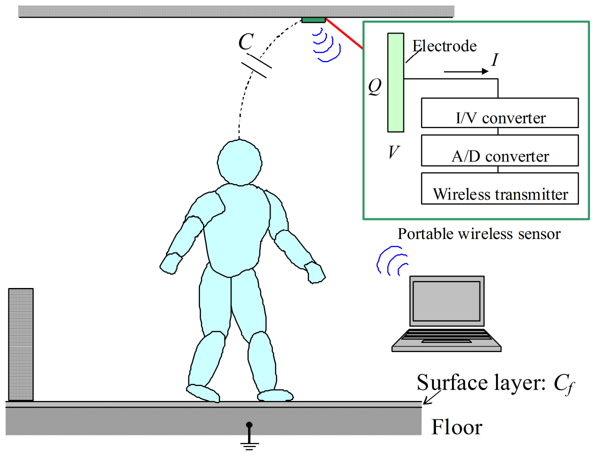

Fig. 4: Schematic of system for detecting walking motion in house by using portable sensor

4. RESULTS AND DISCUSSION

Figure 5 shows the typical waveform of the current generated by the human motion of walking. Cadence components are observed in the resulting waveform for each case. These components indicate the presence of a gait cycle in the walking motion. This gait cycle consists of a combination of alternating swing and stance phases for the left and right feet. The waveform contains cadence component for both feet during bipedal walking; this reveals that the toe of the left foot is lifted off the floor while the heel of the right foot simultaneously comes into contact with the floor. When the toe of the right foot is lifted off the floor, the effective sole area, *S*, decreases and the distance, *x*, between the right foot and floor increases continuously. As a result of the walking motion, the current, *I*, flowing through the measurement electrode increases, as predicted by the third term on the right-hand side of Eq. (6). In rapid succession, *I* decreases, as predicted by the first term on the right-hand side of Eq. (6). Furthermore, in the second half of the swing phase, a rapid decrease in *x* induces a decrease in *I*, as predicted by the third term on the right-hand side of Eq. (6). In rapid succession, *I* decreases, with an increase in the effective sole area, *S*, resulting from the heel contact, as predicted by the first term on the right-hand side of Eq. (6). Therefore, Eq. (6) effectively explains the behavior of the waveform of the electrostatic induction current, *I*, flowing through the measurement electrode.

The portable sensor was placed in ceiling of an ordinary house with a wooden floor, as shown in Fig. 4. The subjects were asked to walk normally wearing slippers on a wooden floor. The waveforms of the electrostatic induction currents generated by walking motion are shown in Fig. 6. The change in the intensity of the walking signal obtained by the portable sensor suggests that the subject is drawing closer to the portable sensor and then moving away from it. Therefore, detailed information about physical activity can be estimated using our proposed technique. We have developed an effective non-contact technique for the detection of human physical activity using human-generated body charge.

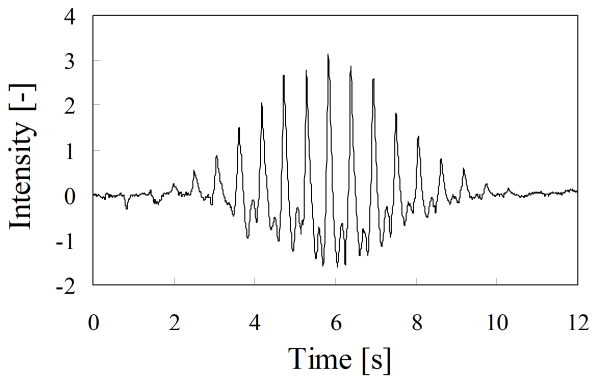

Fig. 5: Typical waveform of current generated by human walking motion

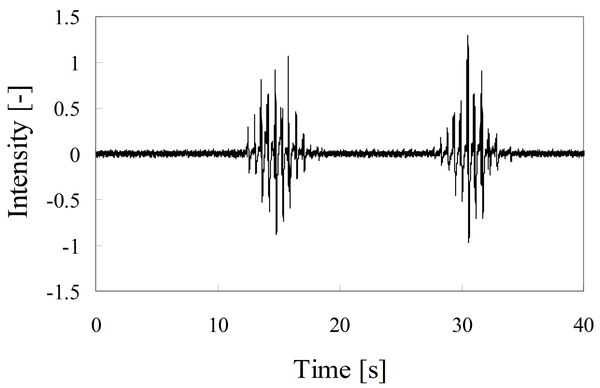

Fig. 6: Typical waveform of current generated by human walking motion

5. CONCLUSIONS

This paper described the development of an effective non-contact technique for the detection of human physical activity using human-generated body charge. This technique involves the detection of an electrostatic induction current on the order of approximately sub-picoamperes flowing through an electrode.

We proposed a theoretical model for the electrostatic induction current generated by the walking motion. By comparing the typical waveform of the electrostatic induction current obtained by walking motion with the theoretical model, it became obvious that this model effectively explains the behavior of the waveform of the electrostatic induction current, *I*, flowing through the measurement electrode. The normal walking motions of daily living were obtained using a portable sensor located in an ordinary house. The obtained results showed that detailed information regarding physical activity such as a walking cycle could be estimated using our proposed technique. Therefore, the proposed technique based on the detection of the walking signal can be successfully applied, not only to estimate human physical activity, but also to confirm the safety of an elderly person living alone.

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