STUDY ON THE OPTIMAL DIRECTION OF ELECTRODES OF A WEARABLE DEVICE USING THE HUMAN BODY AS A TRANSMISSION CHANNEL

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1. Introduction

Studies of wearable computers have attracted public attention these days and one of the area of interest is the communication system adopted in such wearable computers. As an example, wearable devices which use the human body as a transmission channel have been developed [1]-[3]. This communication system uses the near field region of the electromagnetic wave generated by the device which is eventually coupled to the human body by electrodes. Hence, the structure of electrodes is one of the key issues for the transmission using human body. However, little is known about the transmission mechanism of such devices in the physical layer. Figure 1 shows an example of communication system that uses the human body as a transmission channel. When a user wearing the transmitter shown in Fig. 2 (from Sony Computer Science Laboratories, Inc.) touches the electrode of the receiver shown in Fig. 3, a transmission channel is formed via the human body. In this case, the receiver recognizes the user's ID and it can be personalized.

In a previous study, we proposed some calculation models of the transmitter and the receiver attached to the arm using the FDTD method [4]. From them, we estimated the difference in the received signal level due to the electrode structures of the transmitter under various conditions. Moreover, in order to verify the validity of these calculation models, we compared the calculated received signal levels to the measured ones by using a biological tissue-equivalent phantom with the transmitter and the receiver. The result showed a good agreement between calculated and measured received signal levels. In addition, it was found that the GND electrode of the transmitter strengthens the generated electric field around the arm. However, the investigations were limited only to the electric field distributions around the arm, and very few attempts have been made to study the magnetic field distributions around the arm. In this paper, we focused our attention on measuring the magnetic field distributions using a shielded loop antenna. From these results, we proposed the optimal direction of electrodes of the transmitter to use human body as a transmission channel.

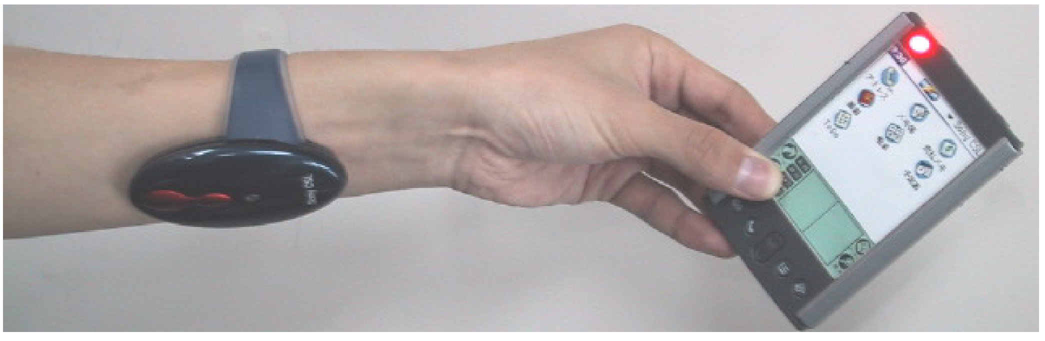

Fig. 1 Transmission system using human body.

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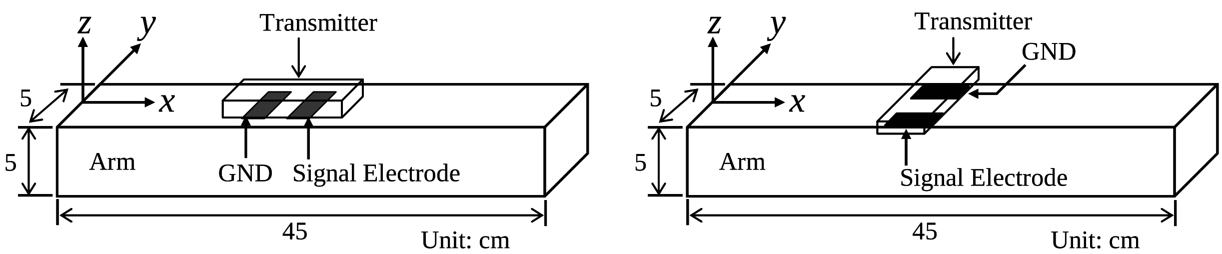
Fig. 2 Wearable transmitter.

Fig. 3 Target mobile receivers.

2. Magnetic field distributions around the arm with the wearable transmitter

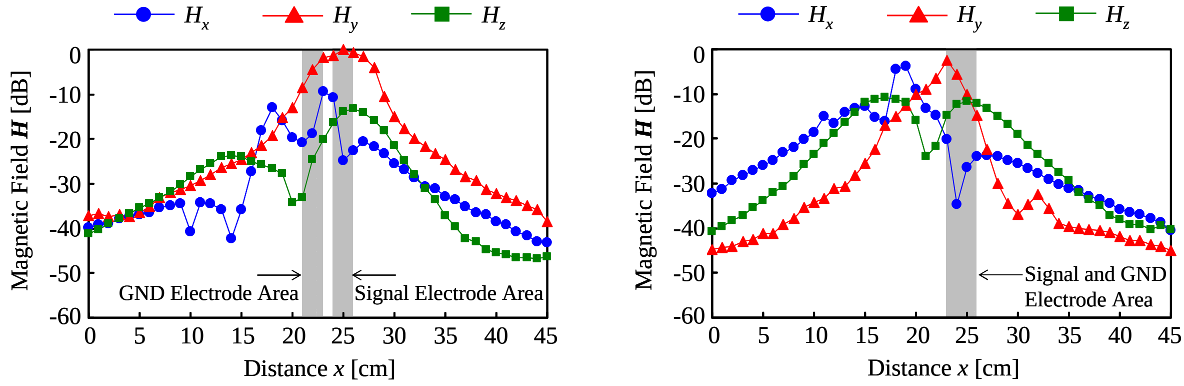
In this part, we investigate on the optimal direction of electrodes of the transmitter by measuring the magnetic field distributions around the arm with the transmitter. A shielded loop antenna whose diameter was 6 cm and a spectrum analyzer (Agilent E4403B) were used to measure the magnetic field distributions around the arm. Figure 4 shows the condition of the measurement for the magnetic field distributions. A tissue equivalent phantom with the transmitter whose carrier frequency is 10 MHz was used to measure the magnetic field distribution of various components. The shielded loop antenna was set 6 cm away from the surface of the arm. The direction of the transmitter was changed according to two patterns to compare the magnetic field distributions. One is the longitudinal direction shown in Fig. 4 (a), the other one is the transversal direction shown in Fig. 4 (b).



(a) Longitudinal direction. (b) Transversal direction.

Fig. 4 Location of the transmitter attached to the arm.

Figure 5 shows the various components of the magnetic field distribution around the arm with the transmitter. The level of each point is normalized by the maximum value of all measured data. In the case of the transmitter set to the longitudinal direction in Fig. 5 (a), the dominant current distribution inside the arm is the *x* component because H_y component is stronger compared to the H_x and H_z components. On the other hand, in the case of the transmitter attached to the transversal direction in Fig. 5 (b), the dominant current distribution inside the arm is the *y* component because the H_x and H_z components are stronger than the H_y components. From what has been discussed above, we can conclude that the direction of the dominant current distribution inside the arm is the same one as the electrodes of the transmitter, because the current is formed between signal electrode and GND electrode.

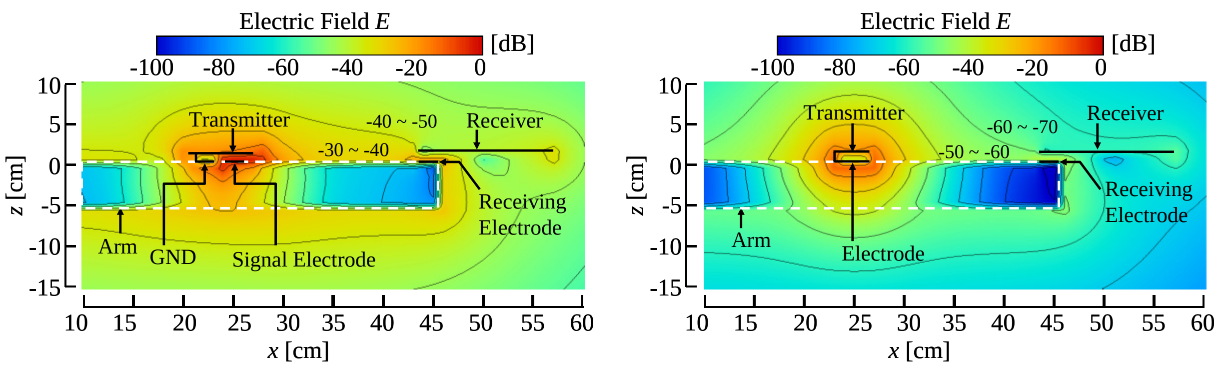


(a) Longitudinal direction. (b) Transversal direction.

Fig. 5 Magnetic field distributions around the arm with the transmitter.

3. Electric field distributions in and around the arm with the wearable transmitter and receiver

Figure 6 illustrates the electric field distributions of both directions of the electrodes of the transmitter. The calculation models of the arm with the transmitter and receiver was constructed by using the FDTD method as in Fig. 4. The electrodes and circuit boards are modeled as perfect conductor sheets. The size of the electrode and the circuit board of the receiver are 7 cm × 3 cm and 13 cm × 7 cm, respectively. The distance between the transmitter and receiver electrodes is fixed to 17 cm. A continuous sine wave (3 V) feeding is used between the signal electrode and the circuit board. The carrier frequency is 10 MHz. The arm is modeled as a rectangular parallelepiped (5 cm × 5 cm × 45 cm) and the electrical parameters are equal to the muscle. The observation plane is the *x*-*z* plane at *y* = 0. The electric field is normalized to the value of the one at the feeding gap. In the case of the longitudinal direction of the transmitter in Fig. 6 (a), the electric field propagates along the surface of the arm (-30 to -40 dB). However, in Fig. 6 (b), the level of the electric field on the surface of the arm seems low (-50 to -60 dB) and the electric field does not propagate along the surface of the arm and it is radiated on the upper side of the arm.

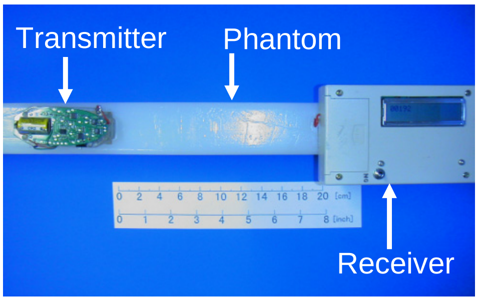


(a) Longitudinal direction. (b) Transversal direction.

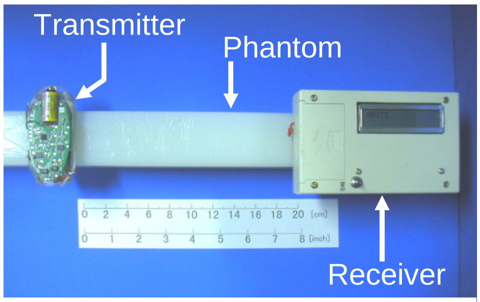
Fig. 6 Electric field distributions in and around the arm with the transmitter and receiver.

4. Received signal voltage in relation with the direction of the electrodes

The pictures shown in Fig.7 are the measurement conditions of the received signal voltage according to the direction of the electrodes of the transmitter. In order to verify the validity of the calculation models, we compared the received signal voltages by the calculation to the measured ones by using a biological tissue-equivalent phantom with the transmitter and the receiver. The phantom used for the arm, which is modeled by a rectangular parallelepiped (5 cm × 5 cm × 45 cm) has the relative permittivity ε_r set to 81 and the conductivity σ set to 0.62 S/m. The distance between the transmitter and receiver is fixed to 17 cm. In Fig. 7 (a), the transmitter is attached in the longitudinal direction. On the other hand, Fig. 7 (b) indicates the transversal direction.



(a) Longitudinal direction.



(b) Transversal direction.

Fig. 7 Measurement condition of the received signal voltage.

Figure 8 shows the comparison between the measured received signal voltages and the calculated ones by the FDTD method. When compared to the received signal voltage of the longitudinal direction in Fig. 8, the one of the transversal direction drops of nearly 10 percents. Moreover, the result shows a good agreement of the calculated and measured received signal levels that indicates a considerable validity in the FDTD calculation. These results lead us to the conclusion that the direction of the electrodes which is desirable for an effective transmission using the human body as a transmission channel is the longitudinal one.

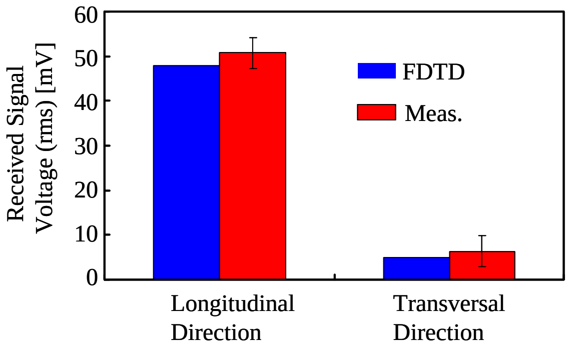


Fig. 8 Received signal voltages.

5. Conclusion

In this paper, in order to determine the optimal direction of the electrodes of a transmitter using the human body as a transmission channel, the magnetic field distributions around the arm with the transmitter has been measured by the use of a shielded loop antenna. The result shows that the direction of the electrode which is desirable for an effective transmission is the longitudinal one for higher signal level reception, compared to the transversal direction.

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References

[1] Thomas Guthric Zimmerman, "Personal Area Networks (PAN) : Near-Field Intra-Body Communication," M. S. Thesis, MIT Media Laboratory, 1995.
[2] Nobuyuki Matsushita et al., "Wearable key: device for personalizing nearby environment," Proc. of ISWC 2000, pp. 119-126, Oct. 2000.
[3] Keisuke Hachisuka et al., "Development of wearable intra-body communication devices," Sensors and Actuators A: Physical, vol.105, issue 1, pp.109-115, 2003
[4] Katsuyuki Fujii et al., "A study on the receiving signal level in relation with the location of electrodes for wearable devices using human body as a transmission channel," Proc. IEEE APS/URSI, vol.3, pp.1071-1074, June 2003.