DEVELOPMENT AND PERFORMANCE ANALYSIS OF AN INTRA-BODY COMMUNICATION DEVICE

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ABSTRACT

Personal area networks would benefit from a wireless communication system in which a variety of information could be exchanged through wearable electronic devices and sensors. Intra-body communication using the human body as the transmission medium enables wireless communication without transmitting radio waves through the air. A human arm phantom is designed and used to reduce uncertainty in experiments with the human body. The phantom exhibits transmission characteristics similar to those of the human body at frequencies between 1 MHz and 10 MHz. A 10.7 MHz frequency modulation (FM) intra-body transmitter and receiver are developed which allow transmission of analog sine waves even in the presence of external noise. Digital data transmission at 9600 bps was also achieved using newly fabricated 10.7 MHz frequency shift keying (FSK) transmitter and receiver devices. The carrier frequency of 10.7 MHz, which is the intermediate frequency in FM radio receivers, means that a wide selection of commercial radio frequency (RF) devices is available.

INTRODUCTION

Intra-body communication in which the human body is used as a signal transmission guide has attracted much attention in the study of personal area networks (PANs) [1]. Because signals pass through the human body, electromagnetic noise and interference have little influence on transmissions, while the signals are largely contained by the skin. These characteristics are superior to those of other radio-based network technologies, such as Bluetooth and IrDA.

Methods for intra-body transmission can be divided into the three types shown in Fig. 1: the simple circuit, electrostatic coupling, and waveguide. In the first method, the simple circuit, the human body is treated as a conductor. This principle is already used by devices such as body fat meters. Although this is a simple method, it requires the use of a wire external to the body. In electrostatic coupling [2-4], devices need to be grounded. This type of transmission was used in the study of PAN by Zimmerman [1]. Although electrostatic coupling is not dependent on an external wire, transmission quality is dependent on the surrounding environment. In the third method, the human body is treated as a waveguide, with the high-frequency electromagnetic waves generated at a terminal propagating through the body, and being received by another terminal [5,6]. External wires are not necessary and transmission quality is not affected by an individual’s surroundings.

However, a completely detailed analysis of the model of signal transmission in intra-body communication has not been conducted. Moreover, the optimum frequency of transmissions for consuming the least amount of energy has not yet been determined.

This paper focuses on waveguide intra-body communication methods, as these do not require external cables, with signals transmitted by high-frequency carrier waves. Several basic experiments are conducted to determine the transmission characteristics of the human body. In particular, the optimum frequency for intra-body communications is investigated for the first time. A human arm phantom is created to obtain reproducible results over repeated experiments. The results are applied to the development of small analog and digital data transmission devices, the performance of which are studied.

EXPERIMENTAL

Signal Transmission Characteristics. To determine the basic transmission characteristics of the human body as a waveguide, signal input to output (I/O) gain was investigated. As shown in Fig. 2, two pairs of Ag-AgCl electrodes were attached to the wrist and the upper arm using electrically conductive paste. Input signals were sine waves of frequencies between 1 and 40 MHz (1 V peak-to-peak) that were produced by a function generator and applied to the upper arm electrodes. Output signals were measured using an oscilloscope. The I/O gain of propagation in air (i.e., not through the body) was also investigated for comparison to intra-body propagation.

From the results shown in Fig. 3, propagation through the body can be seen to be superior to propagation through air at frequencies of up to 30 MHz, with I/O gain reaching a maximum of -26 dB at around 10 MHz. Transmission
gain of the human body has been measured previously over the frequency range of 10 kHz to 100 kHz, with the maximum I/O gain of approximately -73 dB found at around 50 kHz [6]. Thus, 10 MHz is the most suitable carrier wave frequency for transmitting data with minimal energy consumption.

The impact of the height of the experimental position above the ground on transmission characters was next investigated, with transmission characteristics found to be independent of the distance between the ground and the body.

Figure 2. Experimental setup for the measurement of intra-body propagation gain.

Figure 3. Gain comparison between intra-body propagation and airborne propagation.

Impedance Fluctuations. Although conductive paste was applied to the Ag-AgCl electrodes in the experiment, repeatedly spreading paste onto the electrodes is inconvenient. Moreover, the conductive paste may cause inflammation of the skin. Consequently, electrodes are needed that do not require electrically conductive paste to make good electrical contact with the skin. Six additional common commercial metals (aluminum, copper, bronze, brass, stainless steel, and nickel silver) were used as wearable electrodes without conductive paste to measure the contact impedance between contacts at the wrist and upper arm, a separation of 280 mm. The dimension of each electrode was 30 mm by 30 mm. Contact impedance was measured using the simple circuit model, because the inputs and outputs are the same as the waveguide model.

The contact impedance of each electrode is shown in Fig. 4. As can be seen, impedance of the electrodes is largely independent of the electrode metal. This indicates that stable communication through the human body can be achieved using different kinds of electrodes, even when electrically conductive paste is not used to reduce contact impedance.

Figure 4. Comparison of impedance of the contact between the human body and electrodes of different metals.

Human Phantom. By taking the human arm as a column, a human phantom was created consisting of an elongated insulator containing conductive liquid. After investigating differences in the material and thickness of the insulator, and the concentration of conductor in the solution, a polyvinyl chloride (PVC) phantom filled with 0.9% physiological saline was produced, as shown in Fig. 5. The thickness of the PVC skin of the phantom is 98 µm, which is similar to that of human skin.

Signal transmission characteristics of the phantom were then investigated in a similar way to that used for the human body, with the results shown in Fig. 6. The gain of the phantom is about the same as the human body for frequencies of up to 10 MHz. Above 10 MHz, although differences between the two mediums exist, the shapes of the gain curves are similar. By using the phantom, reproducible results may be obtained over repeated experiments without using the human body.

Figure 5. Human arm phantom consisting of a PVC bag filled with 0.9% physiological saline.

Figure 6. Comparison of transmission gains in the human body and the phantom at frequencies under 20 MHz.
INTRA-BODY COMMUNICATION DEVICES

Analog Data Transmission. Small, lightweight, energy-saving, wearable intra-body FM transmitters and receivers were assembled (Fig. 7). A carrier frequency of 10.7 MHz was selected because 10.7 MHz is in the middle of the frequencies used in FM radios, and thus 10.7 MHz ICs are readily available. Moreover, because 10.7 MHz is seldom used for transmission, there is little noise associated with this frequency. The selection was also influenced by the gain characteristics of the human body. Both the transmitter and receiver measured 30 mm by 30 mm. With no batteries, the transmitter weighed 4.3 g and the receiver 5.4 g, with energy supplied by 3 V dry cells.

Using these devices, the influence of outside noise on intra-body communications was measured. A cathode ray tube (CRT) monitor, drier, mobile phone, lathe and microwave were chosen as noise sources, with a 500 Hz sine wave (200 mV peak-to-peak) used as the signal to be transmitted through the body. Figure 8 shows a comparison between the output signal spectrum without any noise source, and with a mobile phone noise source. As can be seen, the 500 Hz signal peak is clearly apparent in both spectra, and the contribution of the mobile phone noise source appears to be negligible. The effects of the other noise sources were similarly small. Intra-body communication thus appears to be tolerant to external noise sources.

An experiment was setup in which heartbeat information collected by a portable accelerometer worn over the heart was transmitted through the body with a lathe located nearby as a noise source. Figure 9 shows the signals before and after transmission through the body, demonstrating that heartbeat information can be successfully transmitted through the human body, even in the presence of excessive external noise.

Digital Data Transmission. Based on specifications for intra-body transmission of digital data using FSK, new data transmission devices were fabricated, as shown in Fig. 10. The new devices used the same carrier frequency as the analog devices, and were of the same weights and dimensions.

Using these devices, transmission of vital signs data was performed as an example of digital data transmission using the process shown in Fig. 11. Digital heart rate and oxygen saturation (SpO₂) data that was measured using a pulse oxymeter fitted to a finger was fed to the intra-body FSK transmitter at 9600 bps. After intra-body propagation, signals were received and demodulated by the intra-body FSK receiver, which was connected to an oscilloscope. The signal reported by the receiver could then be compared visually with the signal directly from the pulse oxymeter. A comparison of the waveforms is shown in Fig. 12. Although the latency between the input and output signals is 180 µs (constant), and the output signal is inverted, the lossless transmission of digital information was clearly achieved using intra-body propagation. For comparison, signals that were transmitted through the air could not be demodulated nor recovered. Thus data can be transmitted with less energy consumption using intra-body communication.

Figure 7. Intra-body FM transmitter and receiver.

Figure 8. Comparison of output signal spectra for a 500 Hz sine wave signal with (a) no external noise source present, and (b) a mobile phone as an external noise source.

Figure 9. Transmission of analog heartbeat data through the human body using the intra-body FM transmitter and receiver. Heartbeat information can be measured in spite of excessive lathe noise.
CONCLUSIONS

The characteristics of the human body as a medium for a PAN in which the body is treated as a waveguide were investigated. A human arm phantom was produced which exhibited similar transmission characteristics to the human arm at frequencies below 10 MHz. On the basis of characteristics observed in the phantom, wearable intra-body communication devices (of size 30 mm by 30 mm, weight approximately 5 g, and voltage requirement of DC 3 V) were assembled. Information transmission experiments were performed using these devices, confirming the possibility of intra-body communication. This constitutes another step towards intra-body communication systems in daily life for healthcare, music distribution and other uses.

Figure 10. Wearable intra-body digital transmitter and receiver. Two stainless steel electrodes of size 20 mm by 30 mm are located on the back of the wrist strap.

Figure 11. Real time sensing of heart rate and SpO₂ using a portable sensing unit.

Figure 12. Comparison between transmitted and received signals during digital data transmission using different transmission media.

References