Intra-body Communication Using Ultrasonic Wave Propagation

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Abstract - With advances in technology and people’s increasing emphasis on health issues, there has been a rapid development of wearable and implantable biomedical sensors. However, radio frequency waves dominate wireless communications, despite disadvantages such as high attenuation in the human body, considerable power consumption, and complicated wireless antenna design, which has hampered the development of body area networks. Therefore, we propose a novel transmission medium that uses ultrasound as the information carrier for body-sensor wireless communication.

Keywords: Ultrasonic, Intra-body communication, Digital communication, Body area network

1 Introduction

Radio frequency (RF) communication has been the dominant method for wireless communication. It provides advanced features such as diverse modulation techniques, protocols, and standards. For intra-body communication, it provides a simple network that enables the on/off conversation between sensors and actuators. The sensor under the skin for the monitoring purpose is the special element, and when the detecting element is in the risk region, the sensor will send a signal to the attached device on the skin. The device transfers the information through the RF to the hospital. Subsequently, the doctor can diagnosis the patient and send information back to the wearable device. An actuator can inject the medicine to the skin. Thus, a smart healthcare system could be realized.

For short-distance communication, ultrasound could be an alternative to RF waves for intra-body communication. RF waves have high attenuation during their propagation in tissue [1]. The high attenuation necessitates high-powered RF signals, which expose the skin to high intensity RF radiation. An implanted sensor with an RF antenna could enlarge the size of the whole sensor [2]. RF communication consumes considerable energy [3]. Especially, there is a conflict with implantable sensor design. Approximately 60% of the human body is water. Ultrasonic waves can propagate well in water. Moreover, ultrasound has been widely applied in medical imaging and diagnosis. Based on non-ionizing radiation, which does not have the same risks as X-rays or other unfavorable radiations, it has had an excellent safety record during the past years.

2 Characteristic of ultrasound propagation in human body

2.1 Attenuation

Ultrasound waves are attenuated when they travel through a medium. Absorption and scattering are the major causes for attenuation. The attenuation in decibels is expressed by the following formula [4]:

\[
\text{Attenuation} = \alpha [\text{dB/(MHz\cdot cm)}] \cdot \iota [\text{cm}] \cdot f [\text{MHz}]
\]  

(1)

where \( \alpha \) is the attenuation coefficient, \( \iota \) is the distance, and \( f \) is the frequency. The amplitude also decays with the distance and medium coefficient, according to the following expression [5]:

\[
A = A_0 e^{-\alpha \iota}
\]  

(2)

Table I lists the values of the attenuation coefficient in human tissue. Marginal attenuation occurs in blood, which is a good transmitter of ultrasound energy. Though a low attenuation has been predicted in theory, we found greater energy dissipation in real-time experiments. Therefore, we aimed to find the reason to match with physical characters. The spread and far field values are found to be consistent between theory and experimental results.

<table>
<thead>
<tr>
<th>Material</th>
<th>( \alpha ) [dB/(MHz\cdot cm)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver</td>
<td>0.6-0.9</td>
</tr>
<tr>
<td>Kidney</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td>Blood</td>
<td>0.17-0.24</td>
</tr>
<tr>
<td>Bone</td>
<td>16.0-23.0</td>
</tr>
<tr>
<td>Soft tissue (average)</td>
<td>0.54</td>
</tr>
</tbody>
</table>
2.2 Far Field

An ultrasonic beam is classified into two areas—near field and far field—as shown in Fig. 1. The amplitude in the near field is irregular, and its accurate evaluation can be extremely difficult in a transmission. The area beyond the near field, where the amplitude of the ultrasonic beam is more uniform, is called the far field. In this area, the amplitude is inversely proportional to the distance from the transducer.

![Beam profile with different distance.](image)

Fig. 1. Beam profile with different distance.

3 Method

Three principle digital-communication modulation schemes were used in the experiments—amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). In this study, only binary modulation was considered. Binary ASK is in form of on-off keying (OOK).

ASK is a form of amplitude modulation that represents the digital signals as amplitude variations of the carrier wave. Binary ASK signaling is the simplest form of ASK with two symbol states. A 0 indicates zero-amplitude carrier transmission, and a 1 indicates non-zero amplitude. Binary ASK signaling is also called on–off keying (OOK). The general analytical expression for the modulated signal $S_i(t)$ is

$$S_i(t) = \sqrt{\frac{2E_i(t)}{T}} \cos(\omega t + \phi) \quad 0 \leq t \leq T; \quad i=1,\ldots,M \quad (3)$$

where $E$ is the symbol energy, $T$ is the symbol duration, the amplitude term $\sqrt{2E_i(t)/T}$ has $M$ discrete values, and $\phi$ is the phase. In the case of OOK, $M = 2$, corresponding to two waveform types.

FSK is a frequency modulation scheme that conveys data using distinct frequencies to represent symbol states. The simplest FSK is binary FSK (BFSK). BFSK uses a pair of discrete frequencies to transmit binary information. The general analytical expression for a modulated BFSK signal is

$$S_i(t) = \sqrt{\frac{2E}{T}} \cos(\omega t + \phi) \quad 0 \leq t \leq T; \quad i=1,\ldots,M \quad (4)$$

PSK conveys data by changing the phase of the carrier. Binary PSK (BPSK) has only two phases, 0 and $\pi$. The mathematical expression is

$$S_i(t) = \sqrt{\frac{2E}{T}} \cos(\omega t + \phi) \quad 0 \leq t \leq T; \quad i=1,\ldots,M \quad (5)$$

4 Conclusions

The novelty of this study was the use of ultrasonic waves for wireless communication in intra-body sensor networks. Three principal modulation schemes—OOK, BPSK, and BFSK—are provided. The experiment could be set up both in water and air to mimic a human-body environment. We expect the use of ultrasonic waves as communication carriers to revolutionize the field of body area networks.

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References


