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Biosignal Measurement System Based On Ultra-Wide Band Human Body Communication

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***Abstract*—**A wrist-band type biosignal measurement system and its data transfer through human body communication (HBC) were investigated. An HBC method based on pulses of ultra-wide band instead of using frequency or amplitude modulations was studied and implemented since the system became very compact and it was more suited for personal or mobile health monitoring. Our system measured photo-plethysmogram (PPG) and measured PPG signals were transmitted through a finger to a monitoring PC system. The device was compact and low-power consuming. HBC communication has very strong security measures since it does not use wireless network. Furthermore, biosignal monitoring system becomes handy because it does not need to have wire connections.

***Keywords*—**Biosignal, human body communication, mobile health, PPG, ultrawide band.

I. Introduction

RECENTLY health monitoring has more emphasis on preventive measures against diseases and, in accordance with this trend, wearable health monitoring systems have been being developed. The size and volume of the monitoring systems as well as power consumption become important design factors. Individuals carry mobile devices and the devices should provide with communication capabilities. Wireless networks have been well developed and they are available widely at this time. Examples include Bluetooth and Zigbee networks. The Bluetooth wireless network may be expensive and add extra volume. Moreover, inefficient and high power consumption makes it burdensome for use in wearable devices. Human body communication (HBC) can be one of the options for wireless network.

HBC is one of the communication methods where human body itself is being used as communication medium. T. G. Zimmerman performed communication experiments using human body based on electro-static induction method [1]. With HBC, multiples devices which are being used by an individual do not require additional electrical wires or wireless networks. In HBC, communication occurs among the devices through the human body and no electromagnetic wave emits into outer space. Tapping into HBC information is almost impossible and, therefore, there are no security problems. For efficient HBC, frequency ranges between 10 kHz and 10 MHz have been explored. Characteristics of transmission and reception on these frequency bands have been studied [2]-[5]. Handa et al. used modulators in order to increase transmission gain with various conditions and methods [2].Shinagawa et al. applied optic effect to enhance communication distance [6]. Song et al. used higher ADC and DAC of 24-bit in order to increase SNR's [7]. Other techniques such as wideband signaling for low-voltage and high-speed communication [8] and FSDT methods without using continuous frequency modulation [9] have been reported.

In this study, HBC based on pulse transmission based on ultra-wide band communication was used in implementing a biosignal measurement system. In this case, digital data was transmitted as pulses. Instead of having frequency or amplitude modulation, pulses were transmitted directly. The system can be smaller and less power consuming since modulation and demodulation circuits are not required. To produce a biosignal measurement system based on HBC, the circuit of measuring photo-plethysmogram (PPG) was manufactured and acquired data were transmitted to a laptop computer through fingers. A low-power microprocessor STM32L151 with 3 V operating voltage was used to reduce power consumption as much as possible. A relatively low frequency of 32 kHz was set as pulse rates. The use of low frequency permits to utilize low-frequency components which are less expensive. For biosignal monitoring devices, high frequency bands are not necessary because biosignal is mostly of low data rate.

II. Data Transmission through Human Body Communication

A. Pulse Transmission and Reception

Transmitting and receiving modules were developed. Their block diagrams are shown in Fig. 1. First, preamble bits were generated and data followed the preamble bits. Original pulses become distorted once they travel through human body. For clear pulse identification against pulse distortion, low (‘0’) bit was inserted between each data bit (‘0’ or ‘1’). A microprocessor (MCU) produced data and sent them from a GPIO pin to two electrodes. One electrode served as reference. The electrodes were attached to human body surface. Receiving electrodes detected pulses and a MCU in the receiving module decoded received pulses.

Fig. 2 shows actual transmitted and received pulses shown by an oscilloscope. Impedance of human body distorts traveling pulses. As shown in Fig. 2, received pulses looked similar to those of high-pass filtered signal. If high or low bits continue, then it is difficult to discriminate pulses. For example, high continues as seen the upper graph in Fig. 2, then it is difficult to

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identify continued high's. That is why each zero bit was inserted between data bits.

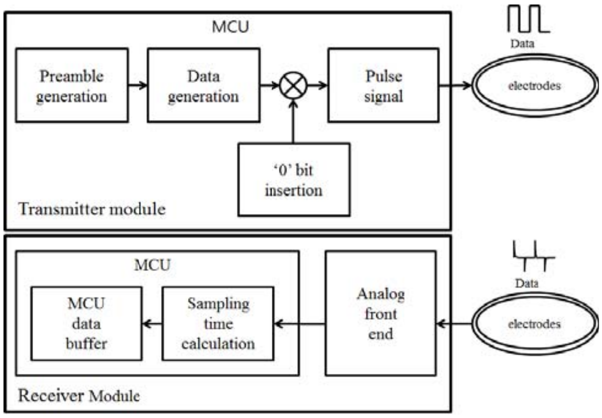

Fig. 1 Transmitter and receiver modules used in the experiments for data transfer using human body communication

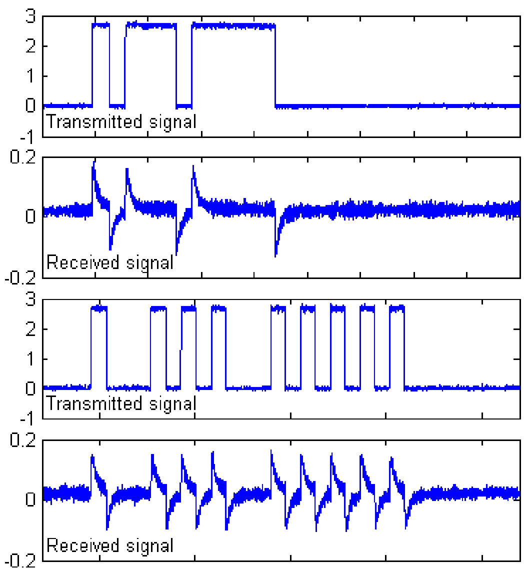

Fig. 2 Transmitted and received pulses through human body. Received pulses looked like high-pass filtered signal due to RC components in human body

B. Waveguide-Like Propagation

Pulses travel through human body and human body acts like a waveguide. Naturally, pulse amplitude experiences attenuation and human body impedance distorts waveform. It is important to find the distance between the transmitter and receiver modules. Received signal should have sufficient signal to noise ratio's to recover original data reliably.

We examined pulse propagation through arm and leg. Fig. 3 shows the locations of the electrodes for these experiments. Attenuations were measured as the distance between the transmitter and receiver increased. Fig. 4 shows measured attenuations with respect to the distance.

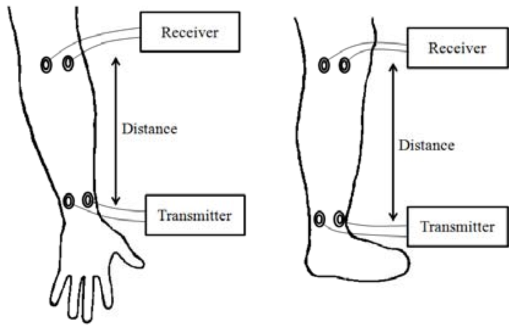

Fig. 3 Electrode locations are illustrated. Signal attenuation is measured as the receiver was moved away from the transmitter

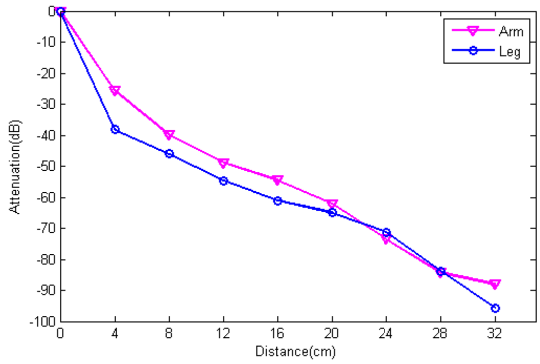

Fig. 4 Signal attenuations are shown with respect to distance. Two cases of arm and leg are measured

As shown in Fig. 4, measured attenuations for arm and leg were similar even though the attenuation was slightly higher with leg. The average attenuation in arm was -2.75 dB/cm and that in leg was -2.99 dB/cm. It was confirmed that data recovery was possible within a distance of 32 cm for arm and 28 cm for leg.

III. Development of Biosignal Measurement System

A biosignal measurement system based on HBC was developed. Most often personal health monitoring devices are attached to the wrist. One of the advantages of wrist-type is its convenience of taking or removing the device. The examples include Samsung Gearfit™ [10] and MIO alpha heart rate monitor watch™ [11]. One of the major difficulties of applying HBC in health monitoring was limited distance as discussed in the previous section. 32cm was our limitation with arm. However, there is no distance problem with a wrist-type health monitor in case that its data transfer through finger tips.

In our study, two fingers, the index and middle fingers were assigned as those that touched the device such as a laptop computer to which biosignal data would be sent. Along the wrist, we examined whether there were optimal positions of the electrodes. The better position meant that stronger signal could be detected at the receiver module. Several electrode positions were assigned as illustrated in Fig. 5.

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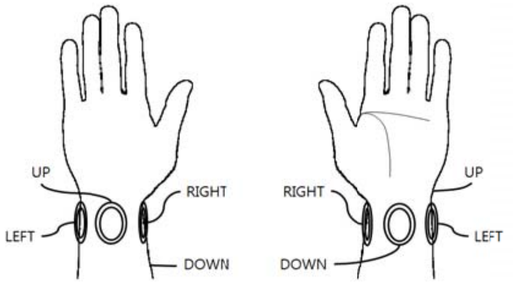

Fig. 5 Electrode positions of the transmitter module are designated

Attenuations at the receiver module were measured from different positions of the electrodes at the transmitter module. Table I summarizes the results. The strongest signal was detected when the electrodes were placed at LEFT and at RIGHT. In this case, the distance between the electrodes was farthest.

TABLE I
ATTENUATIONS AT THE RECEIVER MODULE FROM DIFFERENT POSITIONS OF TRANSMITTER ELECTRODES

Positions of two electrodes at the transmitter module	Attenuation at the receiver module [dB]
UP, RIGHT	-59.05
UP, LEFT	-62.11
DOWN, RIGHT	-63.59
DOWN, LEFT	-59.66
UP, DOWN	-67.82
LEFT, RIGHT	-55.68

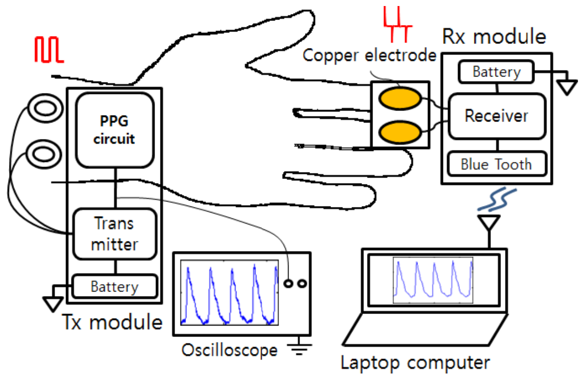

Fig. 6 Biosignal measurement system based on human body communication where measured PPG at the wrist was transmitted to the receiver module through mere touch of two fingers

In our investigation, photo-plethysmogram (PPG) was measured as biosignal. LED was used as light source and photo-transistor was used as detector. LED light is illuminated to body surface and light experiences multiple absorption and scattering. Back scattered light was measured by the photo-detector. PPG signal shows blood volume changes due to heart beats. Blood is a major substance of light absorption. During systolic period, there is more blood volume in body and detected signal becomes small. During diastolic period, detected signal becomes high. Measured signal was band-pass filtered to extract PPG waveform.

The biosignal monitoring unit was attached to the wrist as shown in Fig. 6. Measured PPG was transmitted to fingers through HBC. Two fingers touched two electrodes installed in the receiver module. The receiver module detected pulses and demodulated data. The receiver module sent data to a laptop computer through Bluetooth network. The laptop computer displayed measured PPG waveform in real time. The transmitter and receiver modules used battery as power source.

Fig. 7 shows pulses at different stages. Transmitted signal apparently had some noises. Received signal was apparently distorted due to travelling through human body that has capacitance and resistance (second from the top in Fig. 7). The final reconstructed signal was obtained by filtering received signal and by digital reconstruction using comparator.

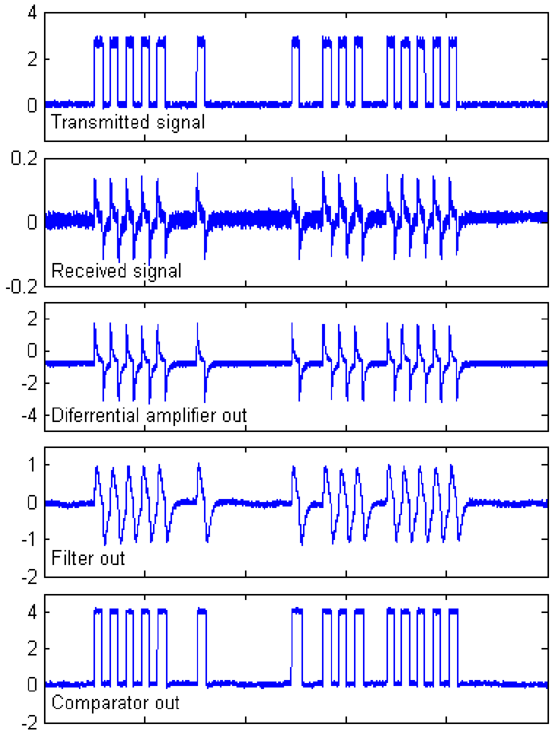

Fig. 7 Pulse waveform at different stage in human body communication

Fig. 8 shows PPG signal measured at the wrist (Fig. 8 (a)) and PPG signal displayed at the laptop computer (Fig. 8 (b)). They were of the same data and it proved that the biosignal measurement system through HBC worked successfully.

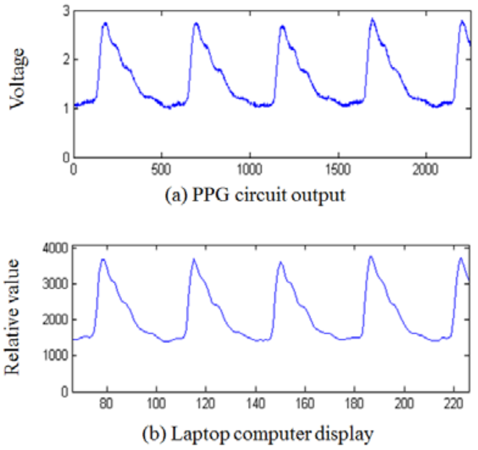

Fig. 8 Measured PPG waveform at the biosignal monitoring unit attached to the wrist is compared to that at the laptop computer display. Computer display shows data transmitted through human body communication. The same waveform proves that HBC functions successfully

IV. Discussions

In this study, a low voltage and low power consumption microcontroller, STM32L151 was used for the circuit. 32 kHz data rate with direct-coupling transmission method was implemented. However, '0' bit was inserted after each bit for reliable data recovery. Therefore the actual data was limited to 16 kHz.

Human body transmission guides data within the body and does not exert electromagnetic emission out of body. The influence of external noise becomes minimal. Although pulse becomes distorted due to RC components in body digital signal processing can recover original pulses from distorted pulses. Motion artifact and skin conditions do not cause problems in term of data transmission and reception in HBC. In our study, data rate is limited to relatively low rates. However, there was no problem in dealing with biosignal due to its low data-rate characteristics of PPG, ECG, temperature and others.

One of the major advantages of ultra-wide band is its simple electrical circuit since modulation and demodulation circuits are not required. Ultra-wide band communication is most appropriate for use with personal biosignal monitoring devices. Smaller volume and less power consumption are apparent compared to other methods such as frequency modulation techniques.

One drawback of applying our system is its limited distance between the transmitter and receiver. 32cm was for arm and 28 cm for leg in our particular case. This implies that distance limitation remains as substantial difficulty. Our preliminary investigation showed that HBC distance in ultra-wide human body communication can be increased substantially if we use the external earth ground. In this study, a pair of electrode was used all the time both for transmission and reception. By doing this, potential difference between the electrodes was measured and it was very reliable. When the earth ground or floor ground was utilized, communication distance of HBC increased substantially. Unfortunately, in this case, data transmission was not reliable sometimes due to unstable grounding effect. At this stage, we were not able to implement a reliable system with using the earth ground as reference

However, in the case of wrist attachment, which is at this time the most popular site for biosignal monitoring, our system can be well applied. Furthermore, applications of our study is not limited to biosignal monitoring, but can be extended to other areas such as ticketing and financial transaction and others. Numerable applications can be found.

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