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Biosignal Measurement using Personal Area Network based on Human Body Communication

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Abstract**—**In this study, we introduced a communication system where human body was used as medium through which data were transferred. Multiple biosignal sensing units were attached to a subject and wireless personal area network was formed. Data of the sensing units were shared among them. We used wideband pulse communication that was simple, low-power consuming and high data rated. Each unit functioned as independent communication device or node. A method of channel search and communication among the modes was developed. A protocol of carrier sense multiple access/collision detect was implemented in order to avoid data collision or interferences. Biosignal sensing units should be located at different locations due to the nature of biosignal origin. Our research provided a flexibility of collecting data without using electrical wires. More non-constrained measurement was accomplished which was more suitable for u-Health monitoring.

Keywords**—**Human body communication, wideband pulse communication, personal area network, biosignal.

I. Introduction

HUMAN body communication (HBC) uses human body as conducting medium and can form a personal area network. For this purpose, sensing units equipped with transmission and reception capabilities are installed on or in human body. They are connected one another through human body as conducting media. Obviously no electrical cables are required.

HBC was introduced by T. G. Zimmerman where weak electrical current was induced through electrostatic field in dielectric material [1]. Carrier frequency was used to send digital signals. Afterwards, there have been studies on various HBC methods such as changes of electric field on body surface [2], modulation and demodulation of frequency shift keying [3], wideband pulse communication of high data rate based pulse signal [4] and frequency selective digital communication [5].

We can categorize three types of communication and they are electrical wire communication, wireless communication and HBC. HBC, compared to wire network, is simple due to absence of electrical wires (low complexity in instrumentation). Power consumption of HBC is lower than that of wireless network. Table I summarizes several features among three different methods. In general, HBC is simple, portable and less power-consuming and HBC can have relatively high data rates at the same time. Besides, simple touch between persons can initiate data transfer. Another advantage of HBC is its strong security feature since data is contained within body.

However, it is important to be aware of its very limited applications since HBC should be always contained inside human body. Even though its applications are limited in general, there are some applications where HBC can be powerful and commercially attractive. Applying HBC to personal electronic devices such as MP3, PDA and smartphone can be promising [6]. HBC may be very effective especially for particular purposes shown in u-Healthcare system, implantable or wearable system.

TABLE I
COMPARISON OF THREE COMMUNICATION NETWORKS

	Wire	Wireless	Human Body
Complexity	High	Low	Low
Portability	Low	High	High
Power consumption	Low	High	Low
Data rates	High	Low	High

Currently HBC as wireless personal area network (WPAN) has expanded its network from 1:1 talking in its early stage to 1:N or N:N communication. Under WPAN, multiple devices form a bus-type topology as human body being medium or communication channel. It is easy to add or remove nodes in bus topology. However, data collision and interference in human body increase or one particular node can tend to occupy the channel as the number of nodes increases.

Therefore, it is necessary to implement multiple access control in order to eliminate or reduce the problems associated with multiple nodes. In broad sense, multiple access control can be categorized into three protocols; channel partitioning protocol, random access protocol and taking-turns protocol. Channel partitioning protocol assigns time, frequency or code to each node. Random access protocol lets a node to wait for a certain period of time and to send data again when collision occurs. Taking-turns protocol assigns the order of transmission among the nodes in advance.

The advantage of channel partition protocol is to minimize data collision and to reduce interference. Additional encoding and low data rate are the disadvantages. Random access protocol monitors channel status before transmission begins and let a node wait for certain time when channel collision occurs. Random access protocol has high data rate and is efficient under

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light communication traffic. Its weakness is the equal priority among the nodes. Taking-turns protocol shows very low data collision and has reduced waiting time with the arrangement of maximum transmission frames. However, it has a drawback of stopping the entire network when problem occurs within one node.

We have developed biosignal monitoring system for purpose of u-Healthcare system [7-9]. In these studies, electro-cardiogram (ECG), photo-plethysmogram (PPG), acceleration and temperature were measured at different locations on human body. These sensing units were connected with electrical wires as shown in Fig. 1. This arrangement was cumbersome and inconvenient in measuring biosignal. Removal of electrical wires alone would make the whole system more compact and a person would feel freer.

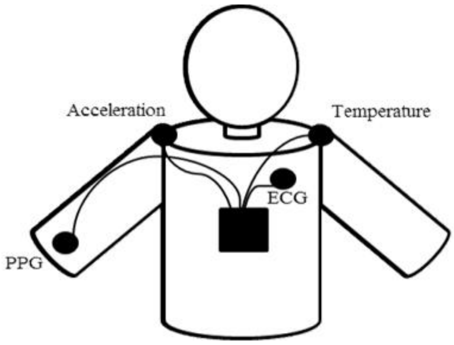

Fig. 1 Bio-sensing units connected through electrical wires

Our solution was to use HBC instead of electrical cables. Biosignal has usually low data rate and sensing requires very small electrical power. Therefore, HBC was an appropriate network method for our biosignal monitoring system. We decided to use random access protocol due to our low data rate. Particularly carrier sense multiple access/collision detect (CSMA/CD) was used in our study. Four bio-sensing units communicated one another through HBC.

II. Development of Human Body Network System

A. Design of Pulse Communication System

There have been studies on HBC. Their topics include channel modeling, communication distance, data rate, methods of transmission and reception and the influences on experimental environments [10-14]. It has been reported that 10 kHz ~ 100 MHz is appropriate as carrier frequency. Our system shown in Fig. 1 had four sensing units (ECG, PPG, acceleration and temperature). Each sensor was attached to human body and very closely located to each sensing unit. Each sensing unit behaved as node in communication topology. This is illustrated in Fig. 2.

Sampling rate were 300 Hz for ECG and PPG. PPG was measured at red light and infrared light and each waveform was being sampled at 300 Hz. Acceleration was 100 Hz for each axis and there were x, y, z-axis. Temperature was being monitored two times per second. Each sampling was done using 12 bits. A total data was 14,424 bits per second.

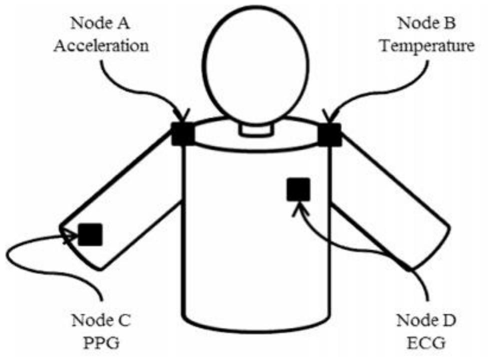

Fig. 2 Each bio-sensing unit functions as a node in communication network and four nodes formed a wireless personal area network

Even though a total of 14,424 bps should be handled, each node dealt with much less data size since each sensing unit handled its own senor signal. Therefore, data rate were 3,600 bps for Node A, 24 bps for Node B, 7,200 bps for Node C and 3,600 bps for Node D. This type of data dispersion can be regarded as another advantage of WPAN. Our communication speed should be greater than 7,200 bps. HBC needs to be between 10 kHz ~ 100 MHz and be higher than 10 kHz. We chose 21 kbps as our data rate.

In order to design sensing units to be compact and less power-consuming, we had to design HBC system carefully. There are two ways in implementing communication system. First is frequency shift keying (FSK) modulation/demodulation and the other is wideband pulse communication (WPC). FSK requires more hardware components both for transmission and reception. WPC is based on pulse transmission whose electronic circuit is simpler. Therefore, we selected WPC. As mentioned previously, random access protocol was programmed.

Fig. 3 shows a block diagram of pulse communication part of the sensing unit. For the parts of bio-signal measurement, please refer to the references [7-9]. The same node should be capable of transmission and reception. Transmitter produced digital pulses corresponding to signal sent from an on-board microcontroller. The amplitudes of pulses were adjusted by an amplifier. We had a current limiting circuit and we limited below 10 uA. Normally current into human body is recommended to be lower than 100 uA. The electrode shown in Fig. 3 is not the electrode that is used to detect biosignal. This electrode functions as interface between transmitter/receiver and human body since the electrode as a contact reduces interface loss. Either transmission or reception mode could be selected. Therefore, there was no confusion between transmission and reception mode. Received pulses had varied amplitudes because they travelled various parts of human body. They were amplified and detected using a Schmitt trigger circuit.

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Finally, digital pulses were re-produced and the microcontroller received and processed them.

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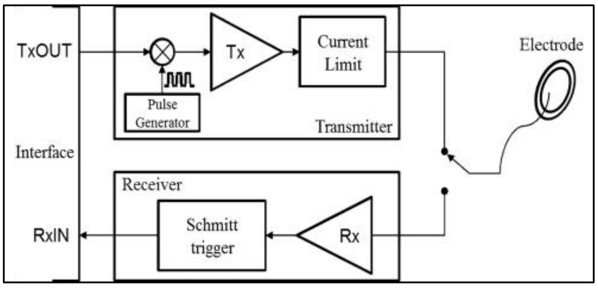

Fig. 3 Block diagram of pulse communication system which consisted of electrode, interface, transmitter and receiver

B. Transmission and Reception of Data

There were two design factors. One was to avoid data collision and interference. The other was to produce optimal amplitude of transmission data since each node was located at different location. Actual signal would vary depending on topological, physiological and environmental conditions. We designed for each node to control its transmission amplitude.

A transmitter sent jamming data of maximal amplitude to a designated receiver. The receiver sent back the same signal. This indicated that the current amplitude would be sufficient for communication. However, it was not sure whether we used more than enough power or there could be a chance of channel monopoly. Therefore, the transmitter repeated the same routine with reduced amplitude until the receiver could not respond. Then the previous amplitude that was successful was assigned as transmission amplitude. The process is similar to a behavior of CSMA/CD.

Another requirement was to control procedures that allowed channel access since there were many nodes. In HBC, human body functions as one electrical wire or channel. Our data rate was low and traffic load was light compared to other communication systems. Our biosignal monitoring system used data compression in order to reduce data size further [15]. CSMA/CD is a typical method of media access control in wire network [16]. In CSMA/CD, collision is checked before transmission. Transmission is delayed for certain period of time when collision occurs.

Table II shows our data frame. Preamble (PA) was a 14-bit where 10 bits were for synchronization between transmission and reception and 4 bits were assigned as frame start. Destination Address (DA) was the address of receiver. Data was transmitted to all the nodes in case of 00000101. Source Address (SA) was also 8-bit and represented the address of transmitter. Total Length (TL) was 12-bit long and indicated frame length. Time to Live (TTL) was 4-bit and contained the number of transmission tries. In our case, we attempted a maxim of 5 times and we had to use other measure when we exceeded this number.

Protocol (PT) was 4-bit size and selected the mode of internal communications such as 1:1, 1:N or N:N. Information (INFO) was data whose maximal size was 32,688 bits. Header checksum (HCS) and Frame checksum (FCS) were 16-bit each. These fields were used to check errors and, in our case, cyclic redundancy check (CRC-16) was used.

TABLE II
TRANSMISSION DATA FORMAT

PA (14bit)			
DA (8bit)			SA (8bit)
SA	CT (4bit)	TL (12bit)	
TL	TTL (4bit)	PT (4bit)	HCS (16bit)
HCS (16bit)			INFO
INFO (Max. 32,688 bit)			
FCS (16bit)			

PA = Preamble, DA = Destination Address, SA = Source Address; CT = Channel Type, TL = Total Length, TTL = Time To Live; PT = Protocol, HCS = Header Checksum, INFO = Information, FCS = Frame Checksum.

III. Results

We developed the human body communication network system that was described in the previous section. Measured biosignal included ECG, PPG, temperature and accelerations in 3-axes. Node B handled only 24 bps and we assigned Node B as a master node in u-Health monitoring system. Node B collected all the data and processed them in order to send to a remote healthcare center. Data transmission was set to be 21 kbps and pulse amplitudes were between 1 ~ 3 volts whose amplitude could be set in 10 different levels. Fig. 4 shows an example of data transmission and reception between the nodes. Fig. 4(a) is transmitted digital data including PPG signal from Node C and Fig. 4(b) was data received by Node B.

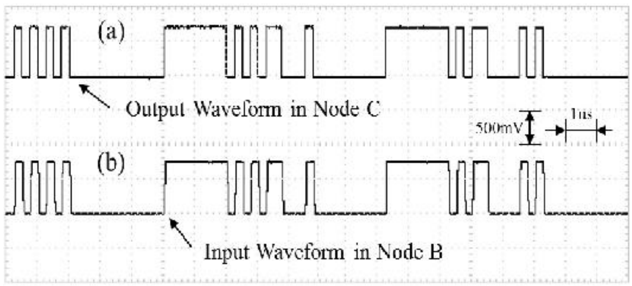

Fig. 4 Pulse waveform between Node B and Node C. It shows a frame including PPG data

IV. Summary

We placed four different biosignal sensing units on different parts of body. It was necessary to place sensing units on different locations due to the nature of biosignal origin. Each sensing unit functioned as node in communication topology. However, we removed all the electrical cables that would connect the nodes. Data were transmitted and received through human body as conducting medium. We used wideband pulse communication and could minimize the sizes of sensing units as well as power consumption. Biosignal measured at different nodes was sent to one node and WPAN was formulated.

Pulse amplitude was controlled such that stable, but minimal-energy transmission network was established. In order to avoid data interference or collision, we adapted CSMA/CD protocol. Experimental results of measuring various vital signs for the purpose of u-Health monitoring were very successful.

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