Effect of Human Movement on Galvanic Intra-Body Communication during Single Gait Cycle

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Abstract. Intra-body communication (IBC) is a communication system that uses human body as a signal transmission medium. From previous research, two coupling methods of IBC were concluded which are capacitive coupling and galvanic coupling. This paper investigates the effect of human movement on IBC using the galvanic coupling method. Because the human movement is control by the limb joint, the knee flexion angle during gait cycle was used to examine the influence of human movement on galvanic coupling IBC. The gait cycle is a cycle of people walking that start from one foot touch the ground till that foot touch the ground again. Frequency range from 300 kHz to 200MHz was swept in order to investigate the signal transmission loss and the result was focused on operating frequency 70MHz to 90MHz. Results show that the transmission loss varies when the knee flexion angle increased. The highest loss of signal at frequency range between 70MHz to 90 MHz was 69dB when the knee flexion angle is 50° and the minimum loss was 51dB during the flexion angle is 5°.

1. Introduction

With the busy lifestyle of people today, the important to always continuous monitoring the patients are become a must. A system where a patient vital sign can always be monitored without visiting the hospital can solve this problem. The system that no need for manual self-administered health system consists of body area network (BAN) and infrastructure area network [1]. A new wireless body area network (WBAN) standard, IEEE 802.15.6 was ratified in 2012. This WBAN consist of RF and Non-RF WBAN which is intra-body communication (IBC). Nowadays, the miniature sensor that capable of monitoring vital sign such as heart beat, glucose level, and blood pressure already applies in biomedical system monitoring using the RF propagation. Figure 1 show the modern hospital monitoring network consists of implantable sensor and using the IBC system [2].

Intra-body communication (IBC) was first introduced by Zimmerman in 1995 which is called as personal area network (PAN) [3]. IBC is a wireless communication system where human body acts as a medium for the signal transmission between transmitter and receiver. There are two coupling methods for IBC which are capacitive and galvanic coupling. For the capacitive coupling, the signal transceiver electrode is attached at human body and the ground electrode is floating. In galvanic coupling method, both transceiver electrodes are attached at human body.
Most research done in IBC is focused on electrical properties of human body, modeling method of body tissues and also hardware design of the IBC system. In order to design the IBC transceiver, the understanding of communication channel is important. Therefore, the effect of human body movement as communication channel was investigated in this paper. The galvanic coupling IBC approach was used to measure the signal loss when there is movement. Since the subject will bend their knee in order to walk, the measurement was related with gait cycle analysis that also called walking cycle.

There also some research that relate with body movement was study previously. The impedance change when the body is in motion was measured by Hachisuka et al. in 2003 [4]. Then Schenk et al. also reported that there were small channel attenuation variation when the body moving [5]. Recently, the influence of sitting and standing position to the capacitive coupling method also were investigated by Lucev et al. [6]. The main objective of this paper is to investigate the effect of knee joint existence and flexion angle on galvanic coupling IBC signal attenuation using single gait cycle analysis. A portable vector network analyzer (miniVNA pro) was used to transmit the signal from transmitter and measure the signal at the receiver.

The frequency range in this study is from 300 kHz to 200 MHz and mainly focused on 70 MHz to 90 MHz. This paper is organized into 4 sections. Section 2 briefly explains the method of how experiment was done. Section 3 presents the experimental result and discussion during no movement and during movement and the section 4 give the final conclusion of the empirical measurement.

2. Method

2.1. Galvanic Coupling Approach

In the galvanic coupling method, an electrical signal is applied differentially between two transmitter electrodes [7]. Majority of current will flow between the two transmitters electrodes while only small portions of current arriving at the receivers electrodes. The signal attenuation that arrives at the receivers’ electrode was measured for different knee flexion angle. Figure 2 below shows the setup for galvanic coupling IBC. The galvanic coupling method was choose based on previous study that concluded galvanic coupling proved to have superior data transmitting compare with capacitive [8].
2.2. Experiment Setup
The experiment for effect of human movement on galvanic IBC was setup as in Figure 3. To generate signal at transmitter and measure signal at receiver module, a portable vector network analyser (miniVNA Pro) was used. A pair of baluns also placed on the transceiver to provide realistic signal transmission path.

For the frequency, the generate signal from miniVNA Pro was sweep from 300 kHz to 200MHz. A pair of receiver (RX) electrodes was placed on the subject’s right waist and transmitter (TX) electrodes placed above subject’s right ankle. The distance between transmitter and receiver electrodes was set to 90 cm calculated from the centres of electrodes.

In order to measure the effect of human movement, the experiment was related with gait analysis: specifically, knee flexion during a gait cycle. Figure 4 shows the sagittal plane joint angles (degree) during a single gait cycle of knee flexion. Referring to Figure 4 it shows that at 70% of single gait cycle the knee flexion is at its maximum nearly 50˚ of the joint angle. These maximum degrees of joint angle happen in feet adjacent (FA) position.

The reading was repeated based on the positions of the legs during a single gait cycle by the right leg [8] shown in Figure 5. The positions are initial contact (IO), opposite toe off (OT), heel rise (HR), opposite initial contact (OI), toe off (TO), feet adjacent (FA), and tibia vertical (TV). The signal transmission losses were measured at each leg position and were repeated three times in order to get the average signal value. The average was compared and reported.

**Figure 4.** Sagittal plane joint angles (degree) during single gait cycle of knee (flexion) [9].

**Figure 5.** Positions of the legs during a single gait cycle by the right leg [9].
2.3. Protocol
The attenuation signal was measured for the frequency sweep of 300 KHz to 200 MHz. The result was focused between our decided operating frequency 70 MHz to 90 MHz for each of the measured transmission losses. This range frequency was choose based on previous study that concluded within this frequency range, the capacitive and galvanic method have minimum attenuation as shown in Figure 6 [7].

![Figure 6](image.png)

**Figure 6.** Signal attenuation for galvanic method from 0 to 200MHz [7].

3. Result and Discussion

3.1. During no Movement.
Human body consist of limb joint that allow the movement of body from one place to another and also a motion like stretching and bending. When people move or walking, the limb joint segment also will bend and the angle between limbs joint also keep changing. Hence, an experiment was done to investigate the effect of knee joint existence and flexion angle on galvanic coupling IBC signal attenuation with a fixed distance between transceiver and receiver, which is between ankle and waist that are 90 cm. First, we test the loss that came from the utilized cable. We connect the transmitter cable to the receiver cable and run the attenuation sweep from 300 kHz to 200 MHz.

Figure 7(a) show signal loss from the cable. From figure 7(b), it can be seen that the loss at 80 MHz was 7 dB. Referring to Figure 8 during no human movement (no knee flexion) the maximum loss was 40 dB at our operating frequency. We also monitor that between 20 MHz and 40 MHz, the loss is higher at 65 dB. Another major thing can be notice that at each stage of the gait cycle, below 40 MHz the results’ variation in attenuation between – 50 dB and – 70 dB, which further support why in this design, frequency around 80 MHz was focused. Thus, in our experiment, we look at the attenuation between 70 and 90 MHz.
3.2. During Gait Cycle.

Figure 9 shows attenuation sweep from 300 kHz to 200 MHz for initial contact, the maximum transmission loss between 70 and 90 MHz was 58 dB. Figure 10 reveals that the maximum transmission loss between 70 and 90 MHz was 54 dB for opposite toe off position of the gait cycle. For heel rise the loss was 61 dB as shown in Figure 11. The attenuation for opposite initial contact was 61 dB as revealed in Figure 12. Figure 13 shows attenuation sweep from 300 kHz to 200 MHz for toe off, the maximum transmission loss between 70 and 90 MHz was 56 dB. Figure 14 reveals that the maximum transmission loss between 70 and 90 MHz was 69 dB for feet adjacent position of gait cycle and in Figure 15, the maximum transmission loss between 70 and 90 MHz was 51 dB for tibia vertical position.
Figure 9. IBC movement effect – initial contact position: (a) transmission loss between 0 MHz to 180 MHz, (b) transmission loss between 70 MHz to 90 MHz.

Figure 10. IBC movement effect – opposite toe off position: (a) transmission loss between 0 MHz to 180 MHz, (b) transmission loss between 70 MHz to 90 MHz.

Figure 11. IBC movement effect – heel rise position: (a) transmission loss between 0 MHz to 180 MHz, (b) transmission loss between 70 MHz to 90 MHz.
Figure 12. IBC movement effect – opposite initial contact position: (a) transmission loss between 0 MHz to 180 MHz, (b) transmission loss between 70 MHz to 90 MHz.

Figure 13. IBC movement effect – toe off position: (a) transmission loss between 0 MHz to 180 MHz, (b) transmission loss between 70 MHz to 90 MHz.

Figure 14. IBC movement effect – opposite initial contact position: (a) transmission loss between 0 MHz to 180 MHz, (b) transmission loss between 70 MHz to 90 MHz.
4. Conclusion
From the result gathered we can conclude that first the frequency range between 70 to 90 MHz is suitable for galvanic approach using our system design. Second, based on the gait cycle study, we conclude that the transmission loss varies when the position of the gait cycle changes. The transmission loss increase as the knee flexion angle increased. We monitored that the highest loss was 69 dB at feet adjacent position of the gait cycle. The knee flexion angle at feet adjacent position is 50˚. The lowest loss was 51 dB at the tibia vertical position. Here the knee flexion angle is 5˚. These high losses affected the quality of the transmission of galvanic coupling IBC.

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