Multichannel Human Body Communication

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Abstract. Human Body Communication is an attractive alternative for traditional wireless communication (Bluetooth, ZigBee) in case of Body Sensor Networks. Low power, high data rates and data security makes it ideal solution for medical applications. In this paper, signal attenuation for different frequencies, using FR4 electrodes, has been investigated. Performance of single and multichannel transmission with frequency modulation of analog signal has been tested. Experiment results show that HBC is a feasible solution for transmitting data between BSN nodes.

1. Introduction

Many diagnostic procedures based on long term monitoring require a number of biosignals. Typically sensors or electrodes are placed all over the patient’s body and are connected with the central unit using wires. An example of such a procedure could be polysomnography, which involves all-night recording of electrocardiogram (ECG), electroencephalogram (EEG), electrooculogram (EOG), respiration signal and blood oxygen saturation. Each sensor is connected by wire with the central unit, which makes sleeping uncomfortable and unnatural. This could lead to incorrect diagnosis. Recording and examination of physiological signals and associated parameters is another example of possible application [1]. Each wire, that could be removed from the measurement system increases the patient’s comfort during examination and the accuracy of the diagnostic procedure.

To reduce the number of wire connections, wireless data transmission could be used. Traditional technologies can be applied to gather biosignals, like Near Field Communication (NFC) [2], ZigBee [3] or Bluetooth [4]. Unfortunately, these methods have some drawbacks. ZigBee and Bluetooth are characterized by quite large range, way beyond the limits of patient’s body, which can easily cause interference with other Body Sensor Networks (BSN) and leads to performance degradation [5]. Additionally, relatively high power consumption of Bluetooth and low data rate of ZigBee limit the possible uses of those technologies in BSN. On the other hand, NFC has low data rate and it’s not suitable for application that requires constant connectivity between sensor nodes [6]. To overcome these issues, Human Body Communication (HBC) could be utilized. The main concept of HBC is to transmit the information via the human body through electrodes attached to the skin [7]. Relatively high conductivity of the human body, in comparison to air, makes the HBC an energy saving method, while data rates of 2Mb/s and higher make it an interesting alternative for wireless communication within BSN [8].
HBC can be categorized into two different types: electric field coupling (figure 1) [9], and electromagnetic coupling (figure 2) [10]. Using electric field coupling, only one electrode is attached to the patient’s body on the receiver and transmitter side. High frequency signal is propagated through the body, while the return path is coupled by the near electric field. This implies that the signal quality is dependent on the surrounding environment. On the other hand, electric field coupling provides lower attenuation of the signal than the other method. Electromagnetic coupling requires two electrodes on each side of the communication channel. The human body is treated as a waveguide, with the high frequency electromagnetic waves generated by transmitter. Transmission quality is not affected by the surrounding environment, however signal attenuation is much higher.

The main goal of this study is to test the performance of the electric filed coupling HBC for analog signal transmission. Two scenarios will be tested: 1 transmitter / 1 receiver, and 2 transmitters / 2 receivers working simultaneously.

2. Methods and materials

Signals which are transmitted with HBC need to be modulated with a high frequency carrier. Two methods are available in order to transmit the analog signal. It can be directly connected to Voltage Controlled Oscillator (VCO) input. The receiver will demodulate the signal and pass it to the Analog to Digital Converter (ADC). Alternatively, the ADC could be placed on the transmitter side. Data would be modulated using Frequency Shift Keying (FSK) or similar method, and then transmitted. It could be saved, or displayed directly after demodulation. The first method is cost- and power-effective, since it requires only one ADC on the receiver side in central unit, while the second is more noise immune, since it transfers binary data. Transmitting analog signal has one more advantage – it does not introduce any delay to the signal which could be extremely important in case of biosignals recording, for example for pulse wave velocity measurement [11]. In this study, analog signal without ADC conversion will be sent.
2.1. Electrodes’ placement and attenuation measurement
In order to evaluate the performance of HBC, three different types of electrodes have been tested. They were square pieces two-side FR4 laminate with dimensions 10 mm × 10 mm, 20 mm × 20 mm and 30 mm × 30 mm. One side of the electrode was connected to the signal input / output, while the other was connected to ground. Electrodes were attached to the patient’s body in four different locations, presented in figure 3a-d, signal side towards the body. Distances between the transmitter and receiver were approximately 30 cm, 60 cm, 160 cm and 50 cm respectively.

![Figure 3. Electrodes’ placement](image)

Signal attenuation was measured for frequencies between 0.5 MHz and 20 MHz. Function generator was used as signal source, while the digital oscilloscope played the role of the receiver.

2.2. Signal transmission performance
For next experiments, the transmitter and receiver circuits were designed. Transmitter modulates the analog input signal with high frequency carrier. For frequency modulation, VCO was used. On the receiver side, signal was amplified and demodulated using a Phase Locked Loop (PLL) device. It contains a VCO and a phase comparator which is exclusive-or network. Demodulated analog signal was connected to the input of a 14-bit ADC.

Five sinus waves with frequencies 1 Hz, 5 Hz, 10 Hz, 20 Hz and 40 Hz were modulated and transmitted. After demodulation, signals were sampled with a 14-bit ADC, 250 samples/s. For each of them, Signal to Noise Ratio (SNR) was calculated, defined as a ratio between the power of the input signal, and noise.

2.3. Multichannel transmission
Two transmitter circuits with different output frequency ranges were used. The first one generates an output signal in a range of 0.67 MHz – 0.79 MHz, while the output of the second was within 1.6 MHz – 1.86 MHz. Transmitters are battery powered. Since both of them worked simultaneously, an additional filter stage at the receiver side was necessary. Simple LC bandpass filters were designed for this purpose, with 3 dB frequency bandwidth matching the output frequency range of the modulators. (figure 4).

![Figure 4. Simple LC bandpass filters](image)

After input filtering the signal was amplified and demodulated using a PLL. The demodulated analog signal was connected to the input of the 14-bit ADC. Sinusoidal signals with different frequencies, between 1 Hz and 40 Hz were transmitted, using the designed devices. SNR was determined for both frequencies. For this experiment, transmitter circuits were placed on both wrists, while the receiver circuit was attached to the patient’s chest (figure 5).
3. Results

Signal attenuation for different electrode sizes and signal frequencies is shown in figure 6.

**Figure 4.** AC response of the input filter stage of the receiver circuit, for both used ranges (0.67-0.79 and 1.60-1.86 MHz)

**Figure 5.** Electrodes’ placement for multichannel configuration

**Figure 6.** Signal attenuation
SNR for single-channel transmission as a function of input signal frequency is presented in figure 7. For this test, the worst-case scenario was used – transmitter and receiver were placed on the left and right wrist respectively (the longest distance to travel for the signal), and the signal was transmitted with the smallest electrodes (the greatest signal attenuation).

Finally, the multichannel configuration was tested. There was no significant difference in transmission performance between the two channels with different carrier frequency. Figure 8 presents SNR as a function of the input signal frequency for one of them.

All experiments were conducted twice. First with no patient movements, later with the patient’s arm moving up and down during transmission. No differences between those two sets of measurements were observed.

4. Discussion and Conclusion

In this paper, the performance of HBC has been investigated. High frequency signal attenuation measurements allow for choosing the optimum carrier frequency for the modulator circuit. The obtained results are slightly different from those presented in previous work [10], [12]. This can be caused by the differences in the size and materials of the electrodes used in different studies. In our case, the optimum band is below 5 MHz. The experiment has proved that the size of the electrode is not critical in this frequency range and could be as small as 1 cm².

Frequency modulation of the analog signal could be used for analog data transmission. Such approach could be extremely useful in case of biosignals transmission, where the delay between the
actual and transmitted signal might be critical. Analog signal modulation is more noise-sensitive. Thus, low noise transmission channel is desirable. The presented solution is characterized by SNR as high as 50 dB. Channel performance in higher frequencies is limited by the sampling rate of the recording device [13].

Modern medical devices contain a number of sensors connected by wires with the central unit. Reduction of such connections will increase the patient’s comfort, and make the examination procedure less invasive. This could lead to the increase in accuracy for some type of diagnostic methods, like sleep disorders detection. The solution is to reduce the number of sensors [14], or to use wireless data transmission. For each sensor, that has to be connected with the central unit without a wire, a pair of transmitter and receiver is necessary. Each pair needs to use a different carrier frequency. The presented experiment proves that it is possible to use more than one transmitter-receiver pair at a time. Moreover, no degradation in transmission channel performance was observed.

Patient’s movements have negligible influence on signal transmission. This means that it is suitable to use HBC in long term patient monitoring.

Future research of HBC will cover the selection of the optimal size and material of the electrodes, as well as evaluation of HBC performance in all night recordings.

5. References

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