Design and Development of a Novel Wireless EKG System Utilizing the Low-Power Zigbee Standard

Vidyasagar Mukala, Anya N. Traille, Vasileios Lakafosis, and Manos M. Tentzeris
GEDC, Georgia Institute of Technology, Atlanta, GA, 30332-250, U.S.A
E-mail: etentze@ece.gatech.edu

Introduction

Electrocardiography has been in clinical use for the diagnosis and monitoring of heart abnormalities for more than a century. It remains the best and least invasive method for the task it performs. EKG measurement systems have followed trends in technological advancement becoming more reliable, able to perform a wider range of functions and simpler to use as time has progressed. The next step forward for the technological advancement of electrocardiography is a completely wireless system of measurement. Such a system would facilitate the tasks of doctors eliminating the usage of wires in operation theaters, as well as for senior people that need to wear monitoring devices for a continuous tracking of their heart condition. Another need for such a system would arise in war scenarios where the remote monitoring of the heart rate of every soldier would tremendously enhance rescue chances. A low form factor is very important as it can further increase the use of such a device in pediatrics. The electrical impulses within the heart act as a source of voltage, which generates a current flow in the torso and corresponding potentials on the skin. An accurate indication of the frontal projection of the cardiac vector can be provided by three leads/electrodes, one connected at each of the three vertices of the Einthoven triangle, shown in Fig.1. The most basic EKG leads are the 3 standard limb leads, which are bipolar leads which measure the potential difference between the right arm, left arm, and left leg. In this paper we focus on the Standard Limb leads and not the pre-cordial lead configuration. They are positioned as follows [1]:

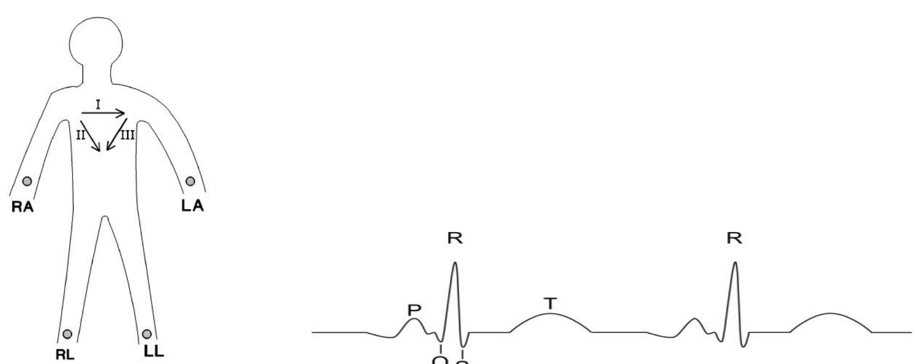

Fig. 1. EKG Vectors in relation to a person (left) Lead II EKG signal (right)

978-1-4244-4968-2/10/$25.00 ©2010 IEEE

In Figure 1, Lead I: Difference between the left arm (LA) and right arm (RA). Lead II: Difference between the left leg (LL) and right arm (RA). Lead III: Difference between the left leg (LL) and left arm (LA). A fourth electrode is placed on the right leg (RL) to use as ground. The most prevalent and significant among them is Lead II for diagnosing rhythm problems. EKG Lead II signal is shown in Fig. 1.

Antenna and Substrate Issues

Considering the low form factor and the frequency of operation (2.4GHz) a dipole antenna offers good prospects while implementing a wearable EKG system. Nevertheless, it is well known that the degraded performance of the most commonly used metal antennas close to the human body is one of the limiting factors of the power efficiency and range of bio-sensors and wireless body area networks (WBAN). Due to the high dielectric and conductivity contrast with respect to most parts of the human body (blood, skin), the range of most of the wireless sensors operating in RF and microwave frequencies is very limited, when attached to the body. In the final paper, we will present the dramatically improved results replacing the metal dipole with liquid antennas. It was recently published [2] that this approach allows for the improvement of the range by a factor of 5-10 in a very easy-to-realize way, just modifying the salinity of the aqueous solution of the antenna. The liquid antennas will be initially used for the Receiver module and then, they will be mounted on each electrode for "RFID-like" signal transmission to the wireless Tx module without the need of electrode mounting.

An alternative wearable "smart textile" configuration is currently tested for the substrate of the wearable EKG system including conducting nylon, phosphor bronze mesh, conducting paint, conducting ribbon and insulating wire. Care should be taken to maintain a balance feed in order to get good transmission characteristics. The characteristics of the materials can be obtained from IFAC website [3]. The calculated dielectric constant of the body while modeling the antenna should be lower than the average dielectric constant of the body muscle in the entire area. The reason being body consists of fatty tissue, which dielectric constant has much lower real and imaginary dielectric constants than the average muscle value.

Wireless Modules

The size of both wireless modules proposed in this paper is 7cm x 7cm x 1cm. The advantage of this design is the low form factor. Multi hopping is done to increase the range of transmission. However, one disadvantage of design 1 is the high current demand of Digi module which requires the usage of a high rated battery. Hence, power consumption while implementing multi hopping with this design is very high. This disadvantage is overcome by using CC2530 in design 2 proposed in this paper. The form factor of design 2 is almost same as design 1, but it gives an extra edge over design 1 by reducing power consumption of the device, thereby effectively doubling the battery life. The careful design of the transmitter section is important as it is to be integrated along with the electrodes and its power consumption directly impacts the battery life. Two wireless modules, Xbee Pro (Digi) and CC2530 (Texas Instruments) were analyzed. Both modules operate on Zigbee protocol, that was chosen due its capability to support Wireless connectivity with low power consumption and reliability.

Design I: Atmega32 microcontroller is programmed for the ADC conversion and interfaced with the Xbee Pro Zigbee module for the wireless transmission. ADS 1178 can be used for simultaneous sampling. Simultaneous sampling is important when multiple leads information is to be transmitted simultaneously. Fig. 2 shows the transmitter and receiver pair design 1.

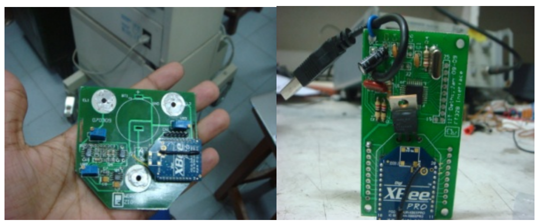

Fig. 2. Transmitter-receiver pair - Design 1

Design II: CC2530 (Texas Instruments) is programmed for ADC conversion and wireless transmission. The advantage of this design is CC2530 has an integrated microcontroller with an RF transmitter which minimizes the transmitter circuitry. Multi hopping [4] can be implemented using this design which helps in increasing the range of transmission Both designs operate at a bit rate of 9600 bits/sec for transmission of a single lead II signal. The sampling rate used is 500 samples/sec and resolution of ADC is 8 bit in Design 1 and 9 bit in Design 2. However for transmission of multiple signals simultaneously a much higher bit rate is required.

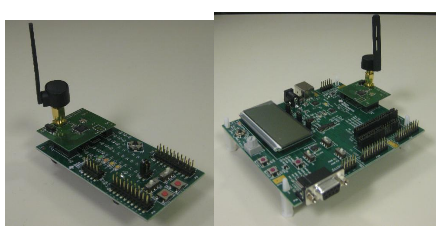

Fig. 3. Transmitter-receiver pair - Design 2

Results

Analysis showed closer placement of electrodes to the heart resulted in a better quality of signal obtained. Both Design 1 and Design 2 are analyzed with electrodes placed close to the heart. Fig. 4 shows EKG data obtained from the tested circuit on the oscilloscope. The experimental set up is conducted by having a fixed receiver. The source bears the EKG device and moves away from receiver.

It is observed that a good-quality signal was obtained until the source was within a certain distance from the transmitter beyond which the signal was distorted. We fixed this point as the range of transmission. The distorted signal had lot of glitches which cannot be used for arrhythmia analysis. Power consumption is calculated by taking an average of worst case and best case power consumption. Best case is when the source is very close to the receiver. Worst case is when the source is at the maximum possible distance from the receiver.

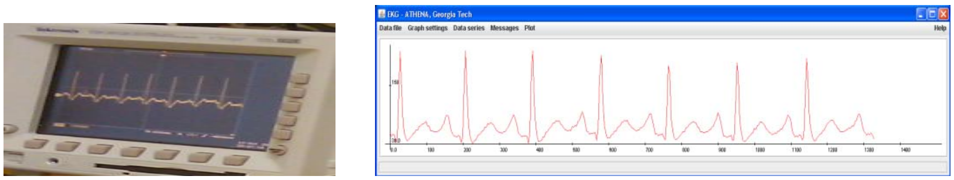

Fig. 4. Lead II EKG signal obtained on oscilloscope and reconstructed signal

TABLE I
COMPARISON OF OUR DESIGN WITH PREVIOUS RESEARCH

Design	Power	Transmit Range
[5]	60mW	20-30m
[6]	170mW	20m
Design 1	0.774W	150m
Design 2	87mW	432m

Acknowledgments

The authors would like to acknowledge the support of NSF ECS-0801798, of Georgia Electronic Design Center and of IFC Center.

References

[1] http://www.biomed.mtu.edu/osoykan/classes/be3600/3600_lab/exp04.pdf
[2] A.Traille, L.Yang, A.Rida and M.M.Tentzeris, “A Novel Liquid Antenna For Wearable Biomonitoring Applications”, Procs. 2008 IEEE IMS Symp., pp.923-926, Atlanta, GA, June 2008.
[3] http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.htm
[4] Chong-Jing Chen, Seung-mok Yoo, P. H Chou, “Low-Complexity High-Throughput Multiple-Access Wireless Protocol for Body Sensor Networks,” Wearable and Implantable Body Sensor Networks, Sixth Int. Workshop, pp. 109 - 113, June 2009.
[5] T. R. F Fulford-Jones, Gu-Yeon Wei; M. Welsh, “A portable, low-power, wireless two-lead EKG system”, Engin. in Medicine and Biology Society, IEMBS '04, pp. 2141-2144, September 2004.
[6] Martin Ekström; “Small wireless ECG with Bluetooth™ communication to a PDA”, M.Sc. Thesis in electronic sciences, The Dept. of Computer Science and Electronics, Mälardalen University, May 2006.