Heart Activity Monitoring on Smartphone

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Abstract. Heart related diseases kill more and more people every year. The cost to detect and treat cardiovascular disease is too high. Monitoring and assessing the health of the heart for every cardiac cycle is of important and essential. A simple, easy to used heart activity monitoring system was designed and tested. The activity includes electrocardiogram and seismocardiography. A tri-axis accelerometer is used as a sensor to detect seismocardiography in 3-D. Bluetooth wireless is used to send the heart activity to a smartphone to be displayed, relayed, and stored in a network for further assessment.

Keywords: heart activity, seismocardiography, accelerometer, electrocardiogram, smartphone, Bluetooth

1. Introduction

The heart activity includes electrical signal (electrocardiogram or ECG) and mechanical actions. The electrical system is also called the cardiac conduction system. A graphical picture of the heart electrical activity is called electrocardiogram (EKG) [1]. Events in each heartbeat are very precise and highly coordinated. The mechanical events happen in the every cardiac cycle are described as shown in Fig. 1 [2]. This figure also shows the relationship in time between ECG and the action of the heart which includes opening and closing of the valves and the contractions of the muscles to retrieve and deliver blood. The bottom waveform is called a seismocardiography (SCG). SCG is the measurement of forces generated by the myocardial contraction and the ejection and movement of blood from the heart to the periphery. Since SCG is recorded in time which is matched to the amplitudes and durations of the cardiac cycle, the SCG provides an indication of the systolic and diastolic events of the heart. SCG was discovered in the late 19th century but has not been extensively studied until recent year [3-8]. The return of SCG study is due to the advanced technology allowing precision in sensing and signal processing. Seismocardiography waveforms are consistent for specific components of the cardiac cycle and have been correlated previously with the echocardiography [9-12]. Since SCG measures cardiac accelerations in systole (contraction) and diastole (relaxation), these accelerations can be used to assess cardiac function. Heart related diseases such as cardiovascular disease, peripheral vascular disease, and stroke are number one killer. The estimate economic cost direct and indirect in North America alone is close to $90 billion in 2009. Development of a practical screening tool to non-invasively assess cardiac function for a low cost will be beneficial. This paper describes such a system which can be used in tele-health applications to assess the health status of the heart. The system includes ECG sensor and SCG sensor to collect both electrical and mechanical heart activity signals. Signals are then sent to a smartphone using the Bluetooth radio technology. The phone which connected to the network can take instruction from the healthcare personnel to take measurement, display, and store the heart activity waveforms for heart status assessment. The set-up provides continuous monitoring if necessary or on-call basis when needed. Stored data can also be retrieved later for further assessment on the history change of the heart status.

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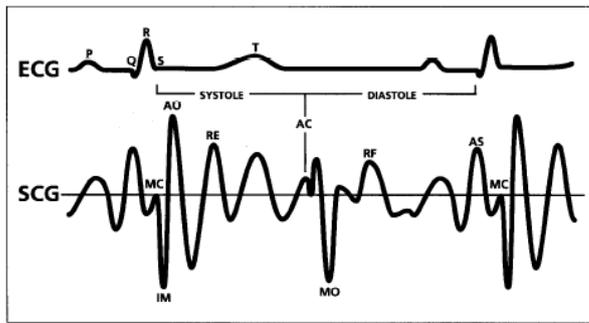
Legend:
MC= Mitral (Valve) Closure
A0 =Aortic (Valve) Opening
RE = Rapid (Ventricu1ar) Ejection
MO = Mitral (Valve) Opening
RF = Rapid (Ventricular) Filling
AS =Atrial Systole
AC =Aortic (Valve) Closure

Fig. 1: A typical resting seismocardiogram (SCG) and matching electrocardiogram (ECG) [2].

2. System Description

Figure 2 shows the designed system. This monitoring set-up includes a biosensor (i.e., a wearable device) to sense the heart activity and send the signals wirelessly to a smart phone to display and relay the signals to store in a network. ECG and SCG of the heart activity are collected at the same time to provide time events for the heart action assessment.
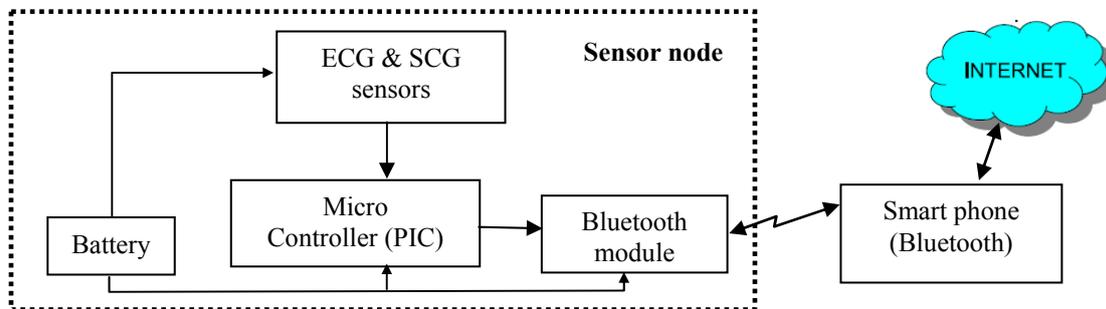

Fig. 2: Monitoring system set-up.

2.1. Signal Sensing and Transmitting

Fig. 3 shows the complete sensor node. The main sensors are an ECG circuit to detect ECG signal and an accelerometer to detect SCG signal. The sensors are to be embedded in a wearable unit. The wearable device is to be worn on the patient chest. A microcontroller is used to take the signals from the ECG sensor and SCG sensor, convert into digital form, and send the data to the Bluetooth module. A rechargeable 3.7V LiPo battery is used to power the node. The weight and size of the node depend on the battery used.

As shown in Fig.3, the tri-axis accelerometer is uses as a SCG sensor. This type of sensing is non-intrusive and easy to use. The accelerometer is just simply taped on the chest of the patient making sure the accelerometer touch the skin. As mentioned, the SCG sensor senses the forces generated by the contraction and relaxation of the heart. Fig. 4 shows the sensing side (accelerometer) and the circuit side including amplification and signal conversion of the SCG sensor. The triple-axis accelerometer MMA7260QT made by Freescale is used. The accelerometer range is set at ±6g. A 3.3V DC is used to supply the power to the accelerometer and the signal processing circuit. Accelerations are filtered and amplified through two stages of low pass filter (LPF) with a cut-off frequency of 40Hz. In addition to signal conditioning of the accelerations, the z-axis acceleration is connected to a monostable circuit to generate a pulse for every heart beat. The use of the digital pulse is easier to calculate the heart rate and reducing transmitting power in wireless applications such as heart rate monitoring. The traditional ECG sensor includes 3 electrodes (Left, Right, and Ground) and signal amplification circuit is shown and self-explained in Fig. 4.

2.2. Signal Receiving

The application in the smart phone comprises of three modular threads: the Bluetooth transceiver module, data processing and plotter module, and the data up-loader module. The Bluetooth Transceiver module establishes a connection with the Bluetooth module in the sensor node to transmit appropriate control signals

(packet) when needed. The application also sends an acknowledgement signal via serial data output back to the PIC microcontroller via the Bluetooth module on successful data reception via Serial Data Input. The Data Processing and Plotter Module stores the data received from the BT module onto a queue which will then be plotted on the application using a suitable algorithm. The algorithm needs to calculate the user's heart beat reading based on the contents of the queue. Primary function of the Data Up-loader Module is to establish a connection to the Web Server using secure HTTP authentication. The module populates data from the queue made by the Data Processing and Plotter unit and uploads to the Web Server.
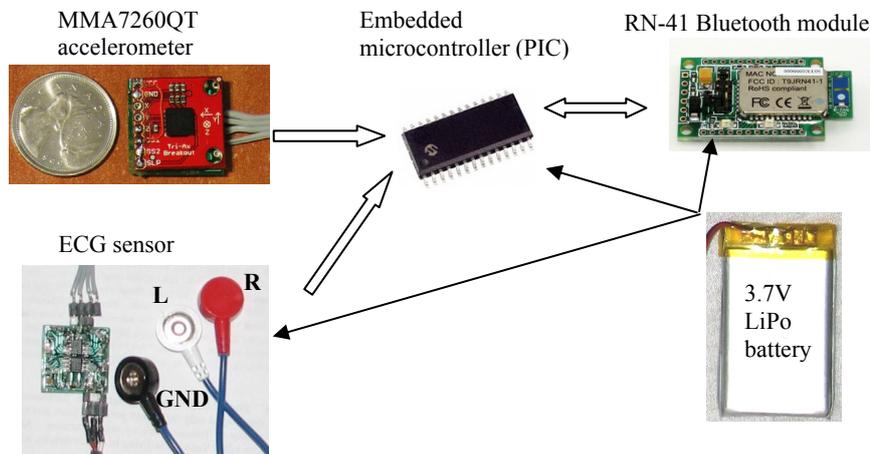

Fig. 3: Sensor node.

The PIC microcontroller converts the analog voltages of the sensors into digital form. The PIC packs and sends data to the Bluetooth module using Rx-Tx Serial UART interface. The Bluetooth RN-41 module manufactured by Roving Networks is used. The RN41module sends data to the Smartphone using Serial Protocol Interface (SPI) over Bluetooth v2.1. This module is programmed to sleep mode (consumes 300μA), transmit mode (65mA), and sniff mode (2mA) to conserve power consumption.
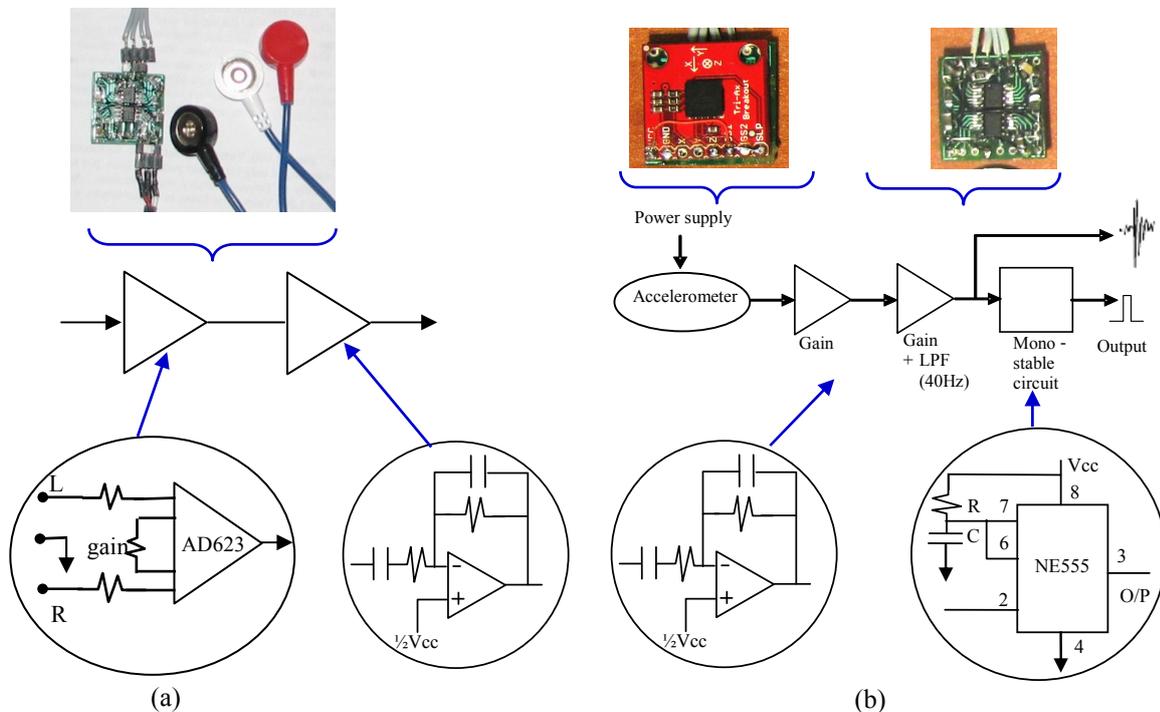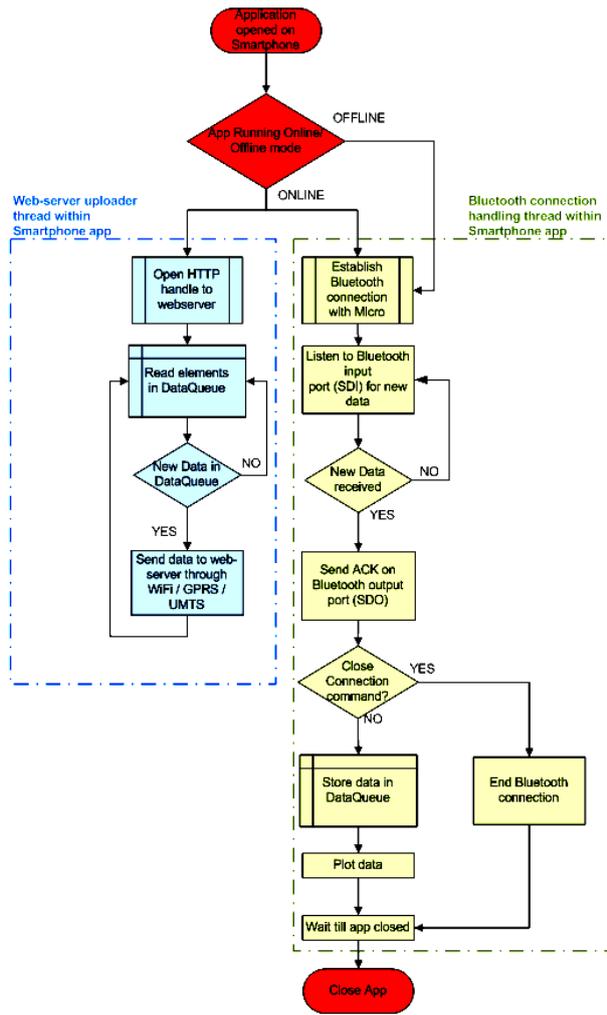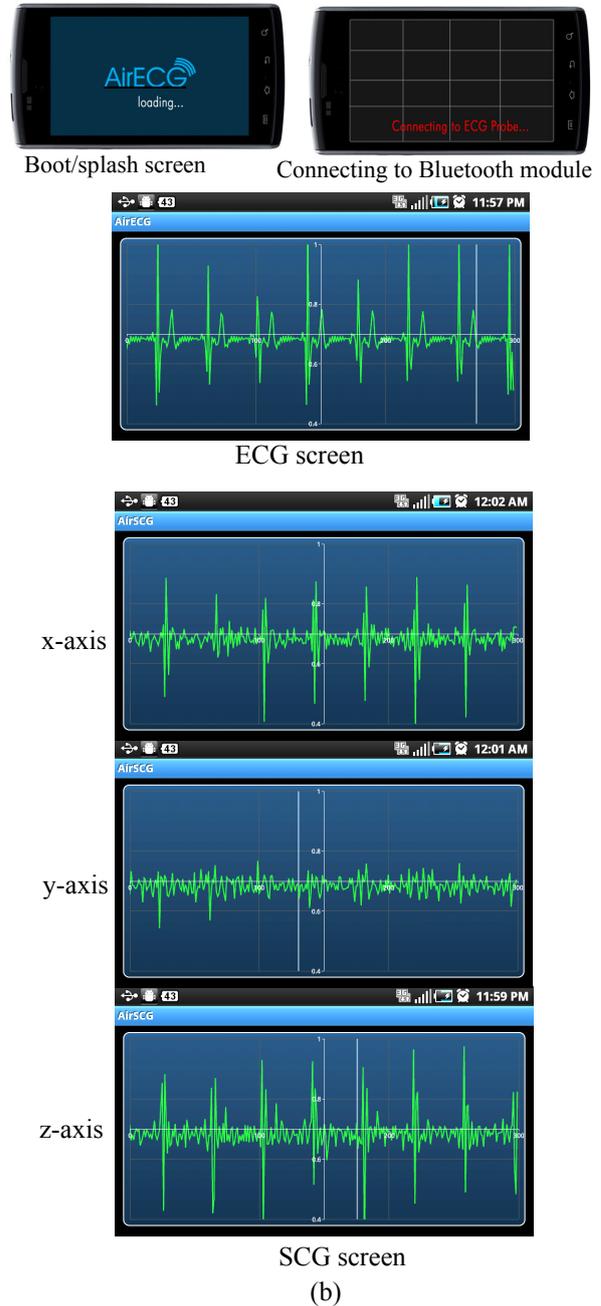

Fig. 4: Sensor circuitry: (a) ECG, (b) SCG.

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The function of the Web Server is to listen to a port for new data and plot/publish the data received to a webpage (data are also stored). The client PC (the smartphone) establishes a session connection with the server during initialization. Once an active connection has been established, the server manager initiates a listener method. This listener method listens to a port for new data packets. Once the data packet is received, the listener method decodes the packet and stores the data in a queue buffer. While the listener method stores data in the queue buffer, another process called real-time web-plotter pops data off the queue and plots on a graph. Shown in Fig. 5(a) is the flow chart of the smartphone app.

(a)

Boot/splash screen   Connecting to Bluetooth module

ECG screen

x-axis

y-axis

z-axis

SCG screen

(b)

Fig. 5: Smartphone flowchart (a) and screen display of an experiment (b).

3. Experiment Results

Figure 5(b) shows the experiment results to verify the functionality of the designed system. The ECG electrodes are connected to the chest of a testing subject. The accelerometer is taped on the chest at the thorax. The z-axis is pointing outward from the body, the y-axis is from head-to-toe, and the x-axis is from left-to-right. The subject is at sitting position in this experiment. The accelerations and ECG signals are sampled at 40Hz by the ADCs of the PIC microcontroller. As shown on the screen of the smartphone, the

ECG and SCG waveforms are successfully sensed, processed, sent, received, displayed, and stored. The familiar ECG waveform is displayed on the top. The other waveforms are for the three axes of the accelerometer. It is clearly shown the action of the heart in each cardiac cycle. The y-axis does not have a well defined waveform as other two since the movement of the heart is limited in the up-down direction. It is also observed that the output of the mono-stable circuit described above generating a pulse for every heart beat (was not displayed on the smartphone).

4. Conclusion

A simple design, light weight, easy to use, heart activity monitoring system was designed and successfully tested. The ECG and SCG signals are sensed, processed, and sent to a smartphone for storage and displayed. One of the problems in the detection of the SCG is the noise entering to the signal when the patient is in motion making the SCG waveforms undistinguishable.

5. References

[1]   http://www.nhlbi.nih.gov/health/dci/Diseases/hhw/hhw_electrical.html. Accessed on Feb. 14, 2011.

[2]   Richard Wilson, Richard A. Wilson, MD, Virinderjit S. Bamrah, MD, Joseph Lindsay, Jr., MD, Markus Schwaiger, MD, and Joel Morganroth, MD. Accuracy of Seismocardiography Compared with Electrocardiography for the Anatomic and Physiologic Diagnosis of Coronary Artery Disease During Exercise Testing. *The American Journal of Cardiology*, Vol. 71, March 1, 1993, pp. 536-545.

[3]   M. Stork, Z. Trefny. Electronic system for a Seismography measuring and signal processing. *Applied Electronics International Conference,* Sept 2005, Pilsen, Czech Republic.

[4]   D. Salerno, J Zanetti. Seismocardiography: A new technique for recording cardiac vibration. Concept, method and initial observation. *Journal of Cardiovasc. Technol.,* 9, 1990, 111–117.

[5]   J.M. Zanetti, D.M. Salerno. Seismocardiography: a technique for recording precordial acceleration. *Computer-Based Medical Systems, Proceedings of the Fourth Annual IEEE Symposium,* 1991, pp. 4 – 9.

[6]   A. Akhbardeh, K. Tavakolian, V. Gurev, T. Lee, W. New, B. Kaminska, N. Trayanova. Comparative analysis of three different modalities for characterization of the seismocardiogram. *Engineering in Medicine and Biology Society, 2009, EMBC 2009, Annual International Conference of the IEEE,* Minneapolis, Minnesota, USA, pp. 2899 – 2903.

[7]   P. Castiglioni, A. Faini, G. Parati, M. Di Rienzo. Wearable Seismocardiography. *Engineering in Medicine and Biology Society, 2007, EMBS 2007. 29th Annual International Conference of the IEEE,* Lyon, France, pp. 3954 – 3957.

[8]   Smrcka, P.; Jirina, M.; Trefny, Z.; Hana, K. New methods for precise detection of systolic complexes in the signal acquired from quantitative seismocardiograph. *Intelligent Signal Processing, 2005 IEEE International Workshop on ,* 2005, pp. 375 – 380.

[9]   Richard A. Wilson MD, Virinderjit S. Bamrah MD, Joseph Lindsay, Jr. MD, Markus Schwaiger MD and Joel Morganroth MD. Diagnostic accuracy of seismocardiography compared with electrocardiography for the anatomic and physiologic diagnosis of coronary artery disease during exercise testing. *The American Journal of Cardiology,* Volume 71, Issue 7, 1 March 1993, pp. 536-545.

[10] Liudas Gargasas, Arturas Janusauskas, Arunas Lukosevicius, Alfonsas Vainoras, Rimtautas Ruseckas, Stasys Korsakas, Vytenis Miskinis. Development of Methods for Monitoring of Electrocardiograms, Impedance Cardiograms and Seismocardiograms. *Studies in Health Technology and Informatics, IOS Press, ISSN 0926-9630, ISBM* 978-1-58603-438-2, 2005, pp. 131-141.

[11] A. Gray. *Modern Differential Geometry*. CRE Press, 1998.

[12] T.D. Shick, E.K. Franke. Comparison of the Ballistocardiogram with the Electrocardiogram. *IEEE Transaction on Biomedical Engineering*, Vol. 25, July 1978.