

CẢM BIẾN SINH HỌC SỬ DỤNG THIẾT BỊ GIA TỐC ĐỂ THEO DÕI HOẠT ĐỘNG CỦA TIM

BIOSENSOR USING ACCELEROMETER FOR CARDIAC CYCLE MONITORING

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TÓM TẮT

Một loại cảm biến sinh học được phát triển để theo dõi chức năng hoạt động của tim và được dùng trong y tế điện tử và y học lâm sàng (theo dõi và chẩn đoán). Cảm biến sử dụng một thiết bị gia tốc ba trục để ghi lại những rung động ở tần số cực thấp của trái tim. Mạch lọc và khuếch đại thích hợp được kết hợp để tạo ra một máy ghi xung động của tim nhờ đó cho thấy hoạt động của tim. Các tín hiệu sau đó được số hóa và lưu lại trong một thẻ SD nhằm để phân tích dữ liệu sau hoặc được gửi đi trên hệ truyền thông không dây liên kết với một điện thoại thông minh để theo dõi thời gian thực. Sự cải tiến của những thiết bị như vậy có thể trở thành công cụ theo dõi tim dễ dàng và hứa hẹn tiềm năng trong lĩnh vực sức khỏe tim mạch.

Từ khoá: cảm biến sinh học, tim mạch, điện thoại thông minh, thẻ SD.

ABSTRACT

A biosensor is developed to monitor cardiac function to be used in e-health and clinical medicine (screening and diagnosis). The sensor uses a tri-axial accelerometer to record the ultra low-frequency vibrations of the heart. Appropriate filtering and amplification were built to provide a seismocardiograph which represents the heart activity. The signals are then digitized and stored in a SD card for later analysis or sent over a wireless communications link to a smartphone for real time monitoring. The development of such device can become an easy-to-use cardiac screening tool which has a potential impact in cardiovascular health.

Keywords: biosensor, cardiovascular, smart phone, seismocardiograph.

I. Introduction

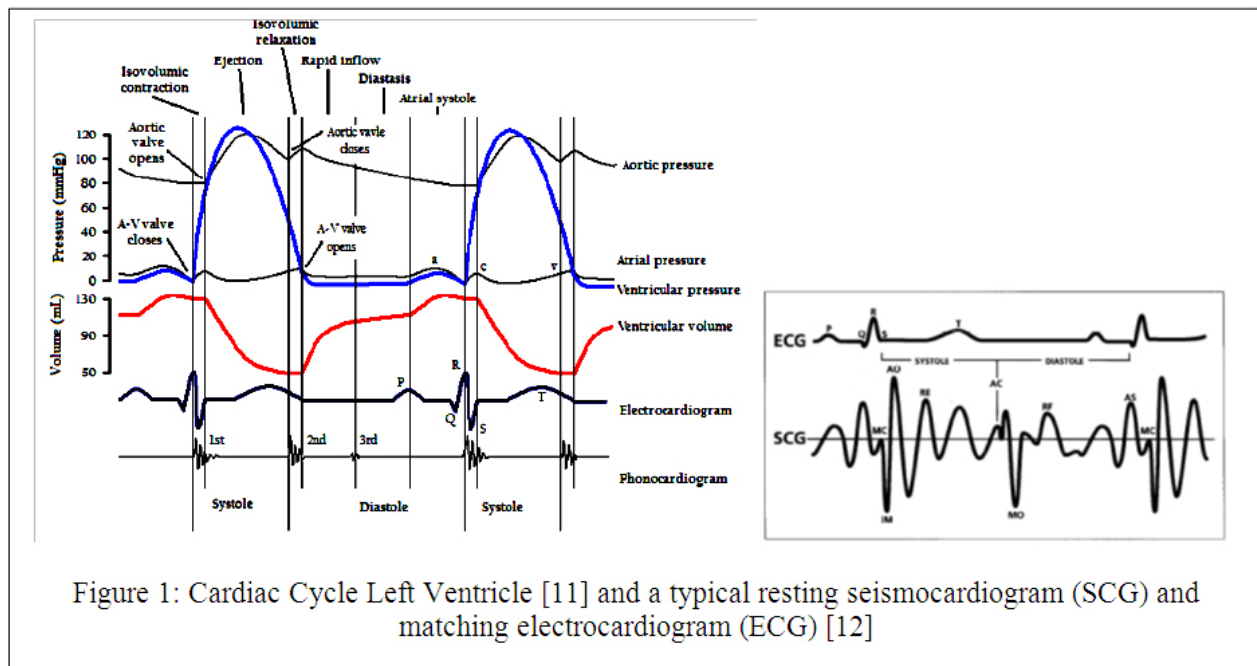
The heart is one of the utmost important organs in a human body. Cardiovascular disease, including heart disease, peripheral vascular disease, and stroke account for more deaths than any other disease. The economic cost due to cardiovascular disease is tremendous, in particular the expensive screening using echocardiography and magnetic resonance imaging. One of the

defect of the heart can cause severe consequence is cardiac arrest (or cardiopulmonary arrest). The arrest is the cessation of normal circulation of the blood due to failure of the heart to contract effectively [1]. For the best chance of survival and neurological recovery of a cardiac arrest, it is imperative to take immediate and decisive treatment [2]. A fast response in a case of heart

failure is very important to save life. Developing a device to continuously monitor the heart activity in the high risk population to reduce death rate due to cardiovascular disease is highly desired.

Many methods can be used to monitor the heart operation, one of which is the use of a graphical picture of the heart electrical activity is called electrocardiogram (EKG) [3]. EKG can be viewed as an interpretation of the heart activity over a period of time, as detected by electrodes attached to the outer surface of the skin and recorded

by a device external to the body. Using ECG signal, one can monitor and detect irregularity of the heart [4,5,6]. Another technique is the use of phonocardiograph [7]. Phonocardiography is a recording of the sounds made by the heart during a cardiac cycle. Authors in [8,9] have developed device to monitor heart activity based on phonocardiograph. In this paper, the cardiac monitoring device is designed and built based on seismocardiography (SCG).



Legend:

- MC Mitral (Valve) Closure
- AO Aortic (Valve) Opening
- RE Rapid (Ventricular) Ejection
- MO Mitral (Valve) Opening
- RF Rapid (Ventricular) Filling
- AS Atrial Systole
- AC Aortic (Valve) Closure

Seismocardiogram is the recording of body vibrations induced by the heart beat [10]. Thus, SCG can be used to record the timing events, amplitudes and durations of the cardiac cycle, and therefore, provides an indication of the systolic and diastolic events of the heart. SCG was discovered in the late 19th century, but was

not studied extensively until the 1930s to the late 1960s, but was abandoned because of the arduous equipment required to record and monitor the SCG signal. However, recent developments in MEMS accelerometer and advances in automated waveform analysis combined with wireless technology allow the techniques to be applied simply. Since SCG measures cardiac accelerations in systole (contraction) and diastole (relaxation), these accelerations can be used to assess cardiac function. Figure 1 shows the cardiac cycle with corresponding ECG and phonocardiogram. The overall goal of this work is to develop an advanced biosensor technology for biological monitoring in areas of cardiac disease, occupational health and safety, military operations, and E-health. The work also provides a “proof of concept” for the potential

commercialization of the SCG that will be used in various applications including clinical medical research.

II. Sensor circuit and monitoring system

Figure 2 shows the set-up of the monitoring system in which the main component is a biosensor to sense the mechanism activity of the heart. Signals are then can be sent to a data logger to store data in a SD card or wirelessly sent to a network connected smartphone for real time monitoring. The SCG signals are collected to provide time events for the heart action assessment.

The sensor includes a small size triple-axis accelerometer and a circuit to process the sensing signals from the accelerometer (i.e., the SCG) into a suitable form to interface to other devices or systems. The seismocardiogram sensor is a triple-axis accelerometer, MMA7260QT, made by Freescale. The sensor has a low power shut-

down mode, high sensitivity output with selectable ranges ($\pm 1.5, 2, 4, \text{ and } 6g$). The accelerometer is mounted on a small printed circuit board (PCB) and supplied by a 3.3VDC. There are 3 analog voltages for its three x, y, and z axis outputs. The voltages are in ratio to the measured acceleration and to the supply voltage (i.e., ratiometric). The three acceleration voltages are amplified and filtered before they become useful. Detail of the accelerometer sensing, filtering, and amplification is shown in Figure 3. As shown, signal processing and conditioning also includes a monostable circuit to convert the acceleration (i.e., SCG signal) into a pulse. An output pulse of this monostable circuit represents a heart beat. Counting a number of pulse per minute provides the heart rate (i.e., pulse per minute, PPM). This counting is performed on the microcontroller before sending to the BlueTooth module.

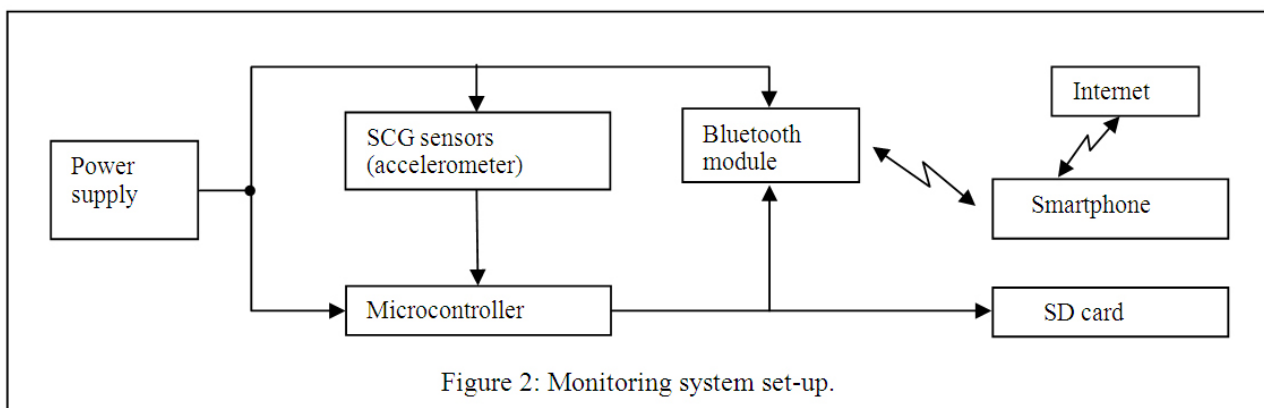
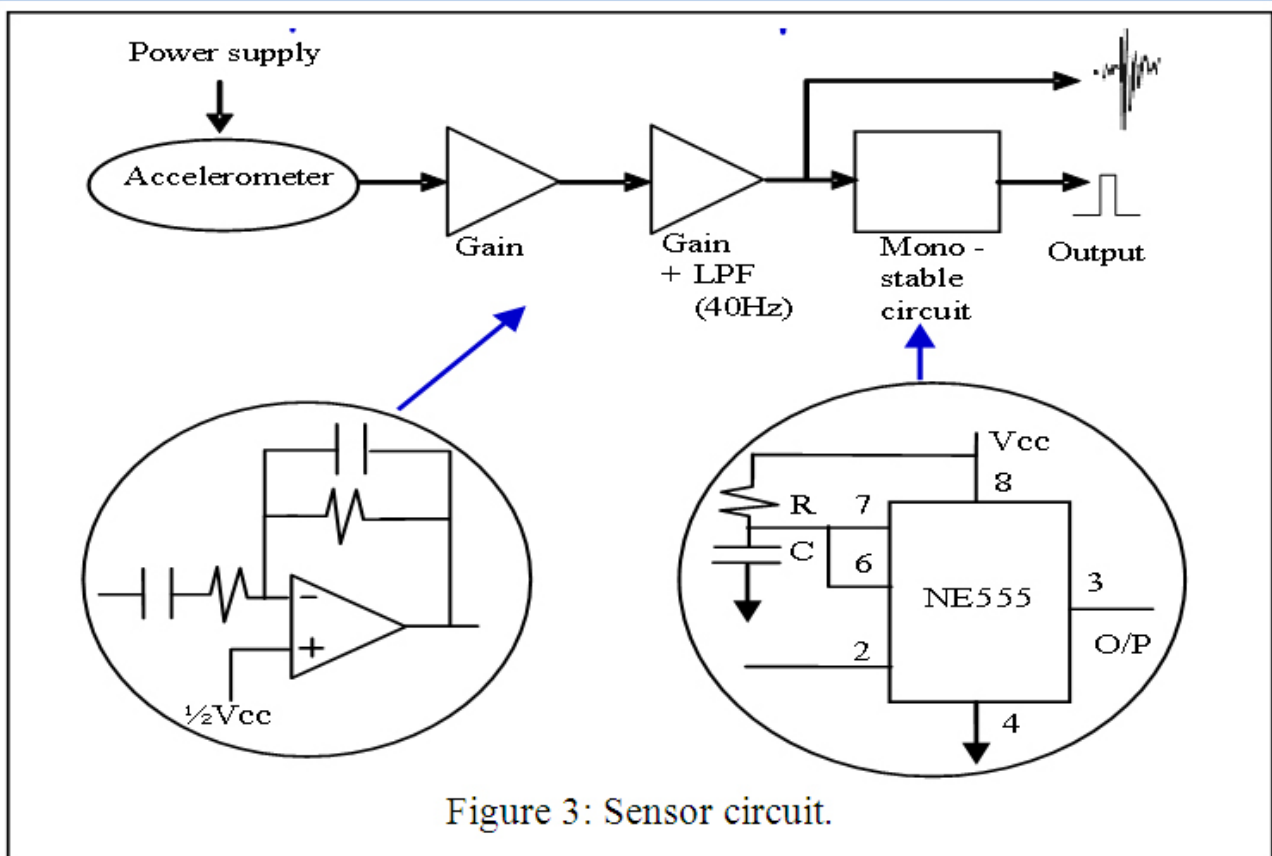


Figure 2: Monitoring system set-up.

The wireless communications module used in this system is the Bluetooth RN-41 manufactured by Roving Networks. The RN41 is a small form factor, low power, highly economic Bluetooth radio. The module provides a low cost and developing time for this specific application. The RN41 module sends data to the Smartphone using Serial Protocol Interface (SPI) over Bluetooth v2.1. This module is programmed to sleep mode (consumes 300 μ A), transmit mode (65mA), and sniff mode (2mA) to conserve power consumption.

The data logger is a module made by SFI, the Logomatic V2.0. The module uses an ARM processor, the LPC2138 made by NXP (Philips), to handle signal sample and storage. The ECG, z-axis seismocardiograph, and the pulse are sampled at 400Hz by the internal 10-bit ADCs of the microcontroller. The SCG signals after conditioning and proper filtering and amplification are send directly to the ADC's of the datalogger to be sampled. Sampled rate can be set from 10 up to 1000 sample per second. Sensor data are logged in ASCII format in a text file. A 1GB SD card is used in this application.



III. Experimental results

Figure 4 shows the experiment results to verify the functionality of the designed system. An ECG circuit was built and included in the system set-up for the purpose of proving the correlation between SCG and ECG for each cardiac cycle. The accelerometer is attached to the thorax of a healthy patient using medical tape. It has been found that the best location for the accelerometer to sense well defined SCG signals is about 1 inch above the top of the diaphragm. The accelerations are oriented as follows: 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 smart phone in Figure 5(b), 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 smart phone).

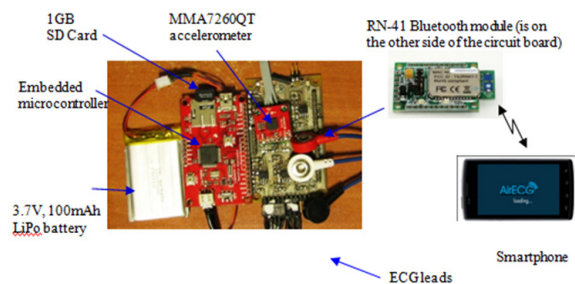


Figure 4: Experiment set-up including a ECG circuit to verify the SCG signal correlated to the ECG signal.

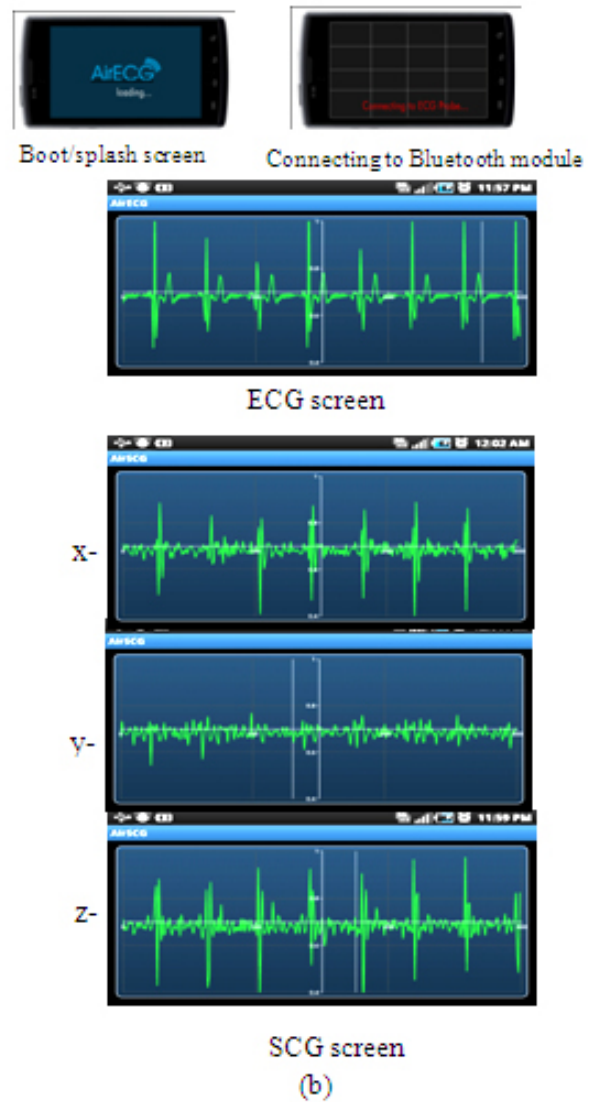
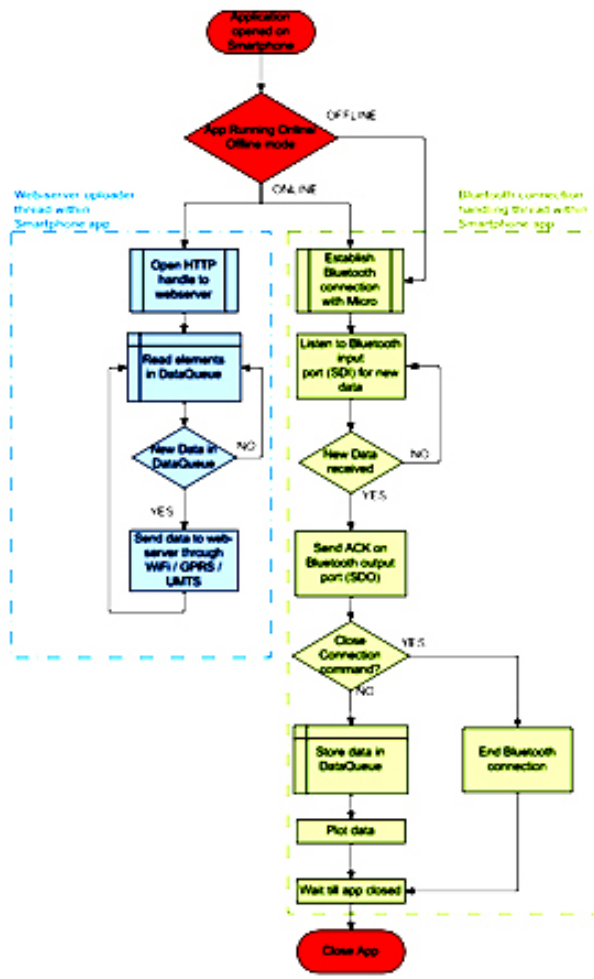


Figure 5: (a) Smartphone flowchart, (b) and screen display of an experiment.

Shown in Fig. 5(a) is the flow chart of the smartphone app. 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.

For long term monitoring, the system is built as a wearable device and the ECG and SCG

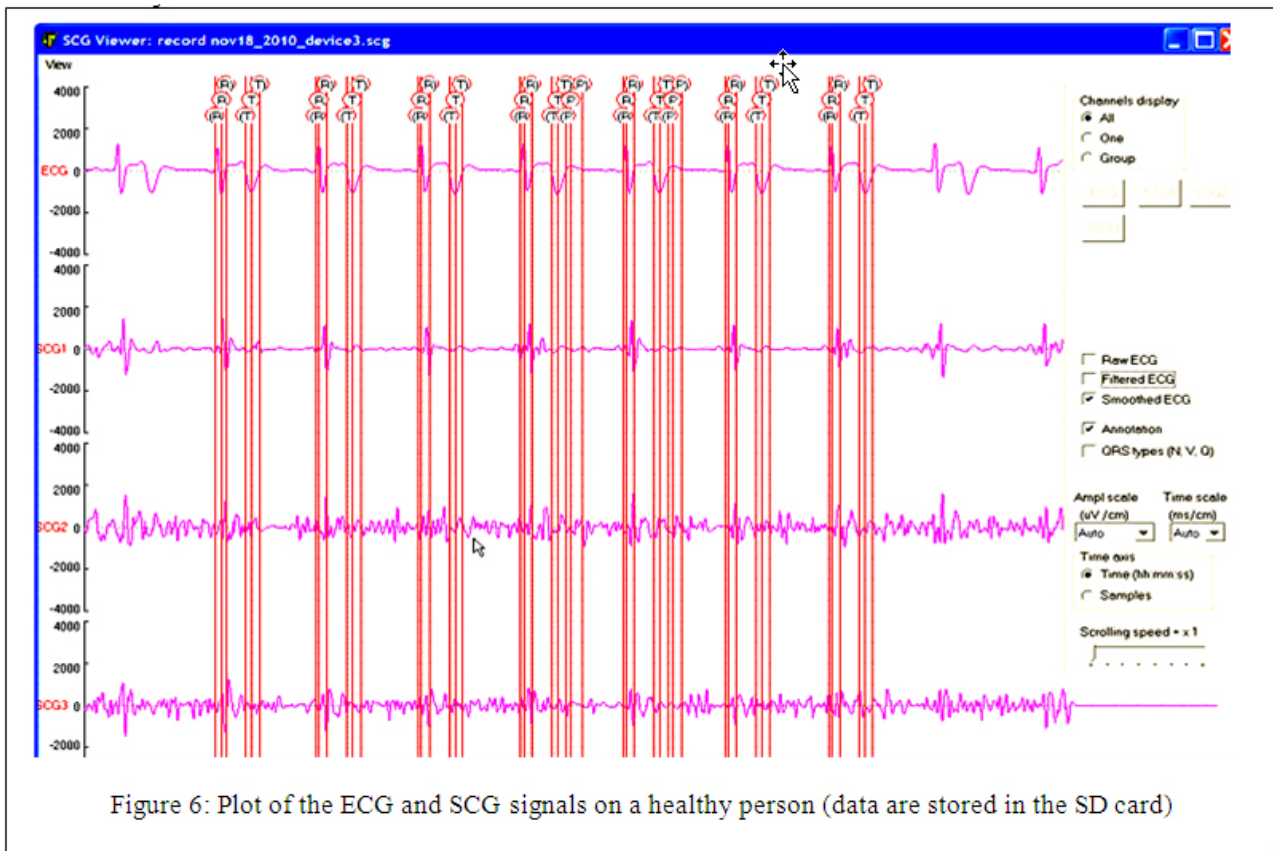
signals are stored in the SD card. Data are stored in ASCII format and easily to retrieve, monitor, plot, and analyze. Figure 6 shows a plot of the data collected from the sensor on a healthy subject in supine position. The peaks of ECG and SCG signals are identified. It is clearly shown the SCG signals in all 3 axis have been sensed, stored, and monitored for cardiac cycle with timing for further analysis to diagnose the health of the heart.

IV. Conclusion

A design using off-the-shelf components for heart activity monitoring system was successfully built and tested. A tri-axis accelerometer is used as a sensing elements is to detect movement of the heart to build a seismocardiograph. The SCG

signals are then processed and sent to a smart phone or a storage device. 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. More work to eliminate the artifact of the SCG is needed.



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