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Development of Acquisition of ECG during Treadmill Exercise

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Abstract— Exercise tolerance testing is an important diagnostic and prognostic tool for assessing patients with suspected or known ischaemic heart disease. During exercise, coronary blood flow must increase to meet the higher metabolic demands of the myocardium. Limiting the coronary blood flow may result in electrocardiographic changes.

In this study hardware was developed for the acquisition of ECG during treadmill exercise. The ECG acquired was corrupted by motion artifacts as the subject was constantly moving. In order to obtain clean ECG, adaptive filtering technique was applied. An accelerometer was used to measure the acceleration signal of the vibrations or movement of the trunk as the reference inputs of the adaptive filter. The acquired real ECG and accelerometer data were simultaneously processed and analysed using the most widely used adaptive filtering algorithm, Least Mean Squares (LMS). The results show that the proposed method can be adapted to effectively reduce motion artifacts in stress or exercise ECG.

Index Terms— Exercise ECG, Motion Artifacts, Accelerometer, Adaptive Filtering, Least Mean Square (LMS) Algorithm

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1 INTRODUCTION

CARDIAC stress test (or Cardiac diagnostic test) is a test used in medicine and cardiology to measure the heart's ability to respond to external stress in a controlled clinical environment. Cardiovascular disease is the leading cause of death. Assessing the hearts function and examining the seriousness of coronary artery disease are the goals of cardiac stress testing.

Putting stress on the heart such as with exercise or certain medications makes the heart work harder. The cardiac stress test is done with heart stimulation, either by exercise on a treadmill, pedaling a stationary exercise bicycle ergometer or with intravenous pharmacological stimulation, with the patient connected to an electrocardiogram (or ECG). People who cannot use their legs may exercise with a bicycle-like crank that they turn with their arms. The level of mechanical stress is progressively increased by adjusting the difficulty (steepness of the slope) and speed. The test administrator or attending physician examines the symptoms and blood pressure response.

A stress test is recommended to:

- Diagnose coronary artery disease
- Diagnose a possible heart-related cause of symptoms such as chest pain, shortness of breath or lightheadedness
- Determine a safe level of exercise
- Check the effectiveness of procedures done to improve coronary artery circulation in patients with coronary artery disease.
- Predict risk of dangerous heart-related conditions such as a heart attack.

Persons who have symptoms of heart disease undergo a stress test for evaluation. Symptoms of cardiac disorder include chest, arm or jaw pain (angina), shortness of breath, swelling of lower legs and feet, palpitations and unexplained fatigue or nausea.

There are many ways of performing cardiac stress test, the most common of which is treadmill testing. Exercise performance on treadmill is adjustable to 3 basic variables:

1. Speed of the treadmill
2. Grade and slope of the treadmill
3. Duration of exercise

The amount of exercise may be maximal or submaximal.

MAXIMAL TESTING: It is defined as testing in which the systemic oxygen consumption reaches a plateau before the exercise is terminated. Maximal effort is approximated by exercising the individual to an age adjusted predicted maximal heart rate. The test is continued till the predicted maximal heart rate or maximum perceived effort or until angina, ischemia, or arrhythmia occurs.

SUBMAXIMAL TESTING: is defined as testing in which the systemic oxygen consumption is not achieved. The test may be terminated prematurely as per design or due to the appearance of angina, ischemia, or arrhythmia. It is useful and safe for the early determination of prognosis soon after myocardial infarction.

This paper proposes a system for acquiring ECG during treadmill exercise which uses a triaxial accelerometer to detect the subject's movement. The triaxial acceleration signals were used as reference signals for the adaptive filter to cancel the ECG motion artifacts. The system uses Bluetooth

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technology to transmit data. The experimental results showed that the adaptive filter could effectively reduce the motion artifacts in stress ECG signal.

2 Methods

The hardware for acquiring ECG was designed as follows:

Two inputs were taken from the skin surface with the help of disposable electrodes and were given to buffer amplifier. Buffer amplifier also known as voltage follower or unity gain amplifier (gain of 1) outputs the signal of the same amplitude as the input. The output from two buffers was given to instrumentation amplifier which amplifies the difference between two input signal voltages while rejecting any signals that are common to both the inputs. The gain of amplifier was set using the formula: Gain (G)=1+(49.4K/Rg) where Rg is a gain resistor. The reference of instrumentation amplifier receives the output of integrator.

The integrator receives the input from the output of an instrumentation amplifier. Small DC offset may be present at the input which also may go on amplifying in the system causing amplifier saturation. To avoid this, the output of instrumentation amplifier was fed to an integrator circuit. The output of the integrator was connected to the reference of the instrumentation amplifier. So the DC value is integrated through the integrator and shifts the reference. Since the last stage of instrumentation amplifier is differential amplifier, it eliminates the DC voltage. Second order Butterworth High Pass Filter (HPF) and Low Pass Filter (LPF) were used with desired cut off frequencies of 0.05 Hz and 150 Hz respectively. As ECG signal is quite low in amplitude (order of mV) voltage amplifier was used to produce an output signal which is readable and measurable. The block diagram of stress ECG is shown in Fig. 1.

The whole system equations was designed to work on 3.3 V single power supply. Thus the ICs used were AD8630 quad op-amp and AD8226 instrumentation amplifier. Voltage limiting devices on each input lead were used to protect the equipment from high electrostatic discharge due to improper handling of the instrument. The parallel diode arrangement was used at the input stage. So the diodes clip any voltage of the magnitude more than absolute value 0.7V. The ECG acquired was contaminated with motion artifacts as the subject was constantly moving. Thus an adaptive filtering technique was employed in MATLAB to remove the artifacts

The triaxial accelerometer ADXL335 provides the reference signal to the adaptive filter. It measures acceleration with a minimum full-scale range of ±3 g. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. It contains a polysilicon surface-micromachined sensor and signal conditioning circuitry to implement open-loop acceleration measurement architecture. The output signals were analog voltages that are proportional to acceleration.

The accelerometer signals were too small in magnitude to be used directly and hence were amplified using instrumentation amplifier AD8226. The ECG output and the accelerometer signals were given to the ADC of microcontroller MSP430. The architecture of MSP30 combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. MSP430 has ultra-low power consumption of 1.3 µA in standby mode. The sampling rate was set as 500 Hz. The micro-controller used the serial communication port (baud rate: 115,200) to connect to a Bluetooth module (LMX9838). The signals were thus transferred to the PC using Bluetooth and processed in MATLAB using LMS algorithm. The block diagram of entire system is shown in Fig. 2.

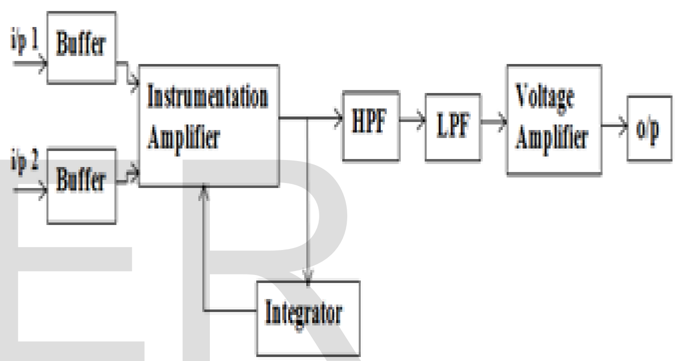

Fig. 1. Block Diagram of Stress ECG

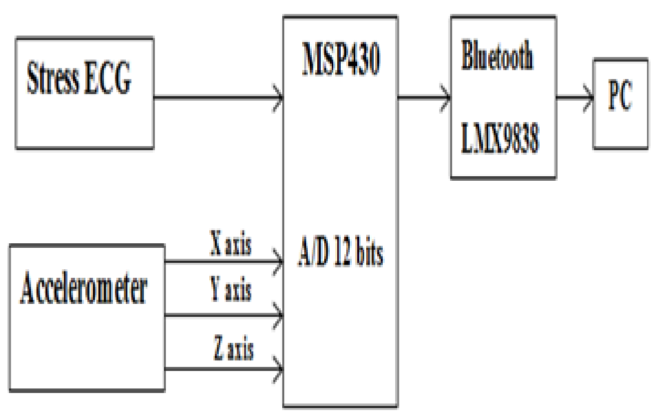

Fig. 2. Block Diagram of Entire Designed System

3 Results

The Graphical User Interface (GUI) for displaying ECG and accelerometer signals is developed using Lab Windows CVI as shown in Fig. 3.

Channel 1 (CH-1) shows the ECG output whereas CH-2, CH- and CH-4 displays X-axis, Y-axis and Z-axis output of

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accelerometer.

Provisions have been made to measure the time and number of samples. The triaxial signals of the accelerometer can be seen in above figure where the Y-axis signal represents crabwise motions, the X-axis signal represents forward and backward motions and the Z-axis signal represents up and down motions.

The captured stress ECG and the accelerometer signals were taken in MATLAB for further processing. Accelerometer signal provides the reference input for adaptive filter. Least Mean Square (LMS) algorithm was used to reduce the motion artifacts and obtain a clean ECG signal.

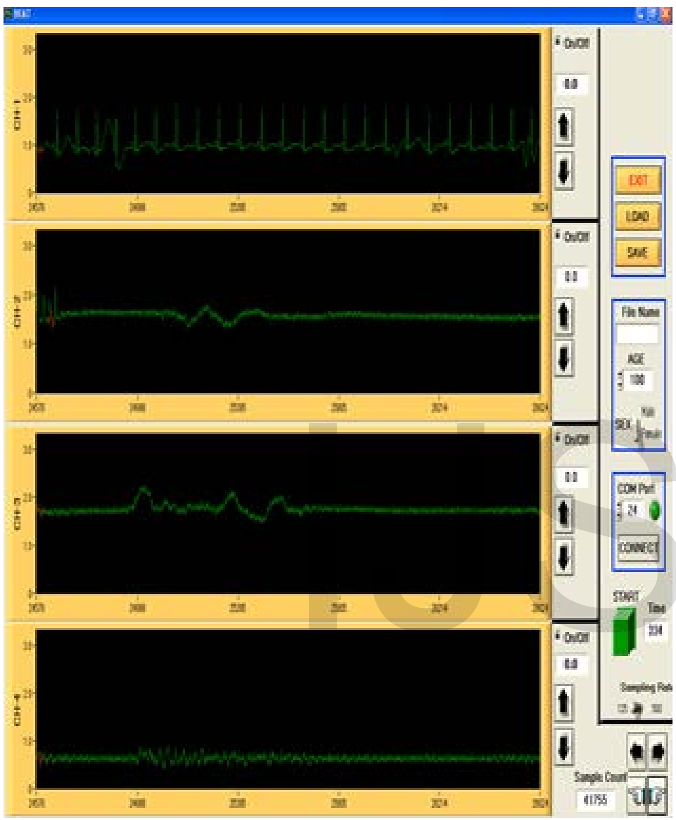

Fig. 3. GUI Developed for the Designed System

The output after processing is shown:-

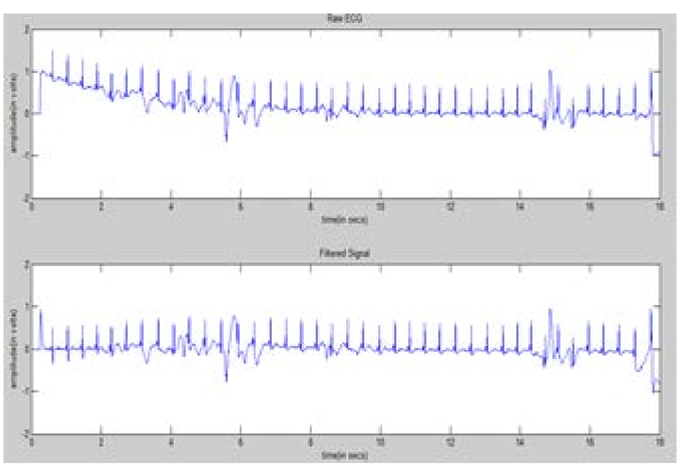

Fig. 4. MATLAB Output after Processing

4 Discussion

An adaptive filter always needs references to filter the redundant signals that do not belong to the blind signal process. If the reference inputs and redundant signal had a higher correlation, the performance of the filter would be better. Motion artifacts belong to the transient baseline change caused by a change in the electrode-skin impedance with electrode motion. The adaptive filter is a nonlinear-phase high-pass filter when the reference input is a constant. This explains why the adaptive filter did not remove all motion artifacts from the acquired ECG.

Because the adaptive filter is a non-linear phase filter, the filtered ECG signal will have some distortion at P-wave and T-wave. The adaptive filter used the LMS algorithm to adjust the coefficients of the filter for minimizing mean square error. Thus the amplitude of the filtered ECG may be slightly less than the acquired one. But the SNR of the filtered ECG signal could be raised.

Future scope involves on-line processing of acquired data in MATLAB using algorithm like NLMS, RLS which provides more accuracy than LMS.

5 Conclusion

The aim of the designed system is to provide an economical, portable, compact and simple to operate device. It can be used to acquire clean ECG removing the motion artifacts in health care centers and clinics. The ECG obtained can then be used to detect coronary artery diseases. Thus using exercise testing, ischemic conditions are detected and treated to prevent infarction or other serious complications.

In this paper, hardware system is designed to acquire ECG during treadmill exercise and the acquired ECG is processed in MATLAB using an algorithm which used an accelerometer to measure the signal of the vibrations or movement of the trunk as the reference inputs. The optimal weight of the adaptive could be adjusted using LMS algorithm. LMS has certain advantages as being a simple algorithm with minimal complexity and requires less computational time.

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References

[1] R A Wolthuis, V F Froelicher, A Hopkirk, J R Fischer and N Keiser, "Normal electrocardiographic waveform characteristics during treadmill exercise testing", *Circulation Journal of American Heart Association*, 1979.

ISSN 2229-5518

[2] Jonathan Hill, Adam Timmis, “Exercise Tolerance Testing”, *British Medical Journa*l Volume 324, 4 May 2002.

[3] T. FULLER, M. A. Ed., PA-C, A. MOVAHED, M .D, F.A.C.C, Current “Review of Exercise Testing: Application and Interpretation”, *Clinical Cardiology* 10, 189-200 (1987).

[4] Wolthuis RA, Froelicher VF, Fischer J, Triebwasser J, “A new practical treadmill protocol for clinical use”, *American Journal of Cardiology* 39: 697, 1977.

[5] Mary Anne D. Raya, Student Member, IEEE, and Luis G. Sison', Ph.D, Member, IEEE, “Adaptive Noise Cancelling of Motion Artifact in Stress ECG Signals Using Accelerometer”, *Proceedings 01 the Second Joint EMBWMES Conference* Houston, TX, USA October 23-25 2002.

[6] Shing Hong Liu, “Motion Artifact Reduction In Electrocardiogram Using Adaptive Filter”, *Journal of Medical & Biological Engineering*, Volume 31 No 1, 2011.

[7] PS Hamilton, MG Curley, RM Aimi, C Sae-Hau E.P. Limited, Somerville, USA, “Comparison of Methods for Adaptive Removal of Motion Artifact”, *Computers in Cardiology* 2000;27:383-386.

[8] B.Widrow, J.R.Glover, J.M.McCool, J.Kaunitz, C.S.Williams, R.H.Hean, J.R.Zeidler, E.D.JrandR.C. Googlinb, “Adaptive noise cancelling: principles and applications”, *Proc. IEEE*, 63: 1692-1716, 1975.

[9] N.V.ThakorandY. S.Zhu, “Applications of adaptive filtering to ECG analysis: Noise Cancellation and Arrhythmia Detection”, *IEEE Transactions in Biomedical Engineering*, 38:785-794, 1991.

[10] S. W. Yoon, S. D. Min, Y. H. Yun, S. Lee and M. Lee, “Adaptive motion artifacts reduction using 3-axis accelerometer in E-textile ECG measurement system”, *Journal of Medical System*, 32: 101-106, 2008.