IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 4, Issue 5, May 2016

Data Processing of Ballistocardiogram Signal using Adaptive Filter

Nitesh[1], Manjula B.M.[2]

PG Scholar, Department of ECE, Nitte Meenakshi Institute of Technology, Bangalore, India [1]

Associate Professor, Department of ECE, Nitte Meenakshi Institute of Technology, Bangalore, India [2]

Abstract: Ballistocardiogram is a non-invasive method used to detect the health of heart. Ballistocardiography (BCG) is a plot of repetitive motion of human body arising from the ejection of blood into the blood vessel. BCG is used to detect the Cardiac Output which is defined as "The amount of blood pumped by the heart in a minute". BCG Signal is obtained from the sensors placed near the aorta which is the main artery, originating from left ventricle of extending down to the abdomen. BCG is found to be the promising method to detect the cardiovascular diseases. The data obtained from the sensors contains vibrations due to respiration, body movements and other disturbances. They are eliminated using pre-processing block. Thus obtained signals will have noise which is filtered using the RLS and LMS adaptive filters and the MAE, MSE and PSNR for these filters are calculated. LMS adaptive filter is found to have better noise suppression compared to RLS filter. The hardware Co-simulation of LMS filter is performed. The area, power and delay of these circuits are tabulated.

Keywords: Ballistocardiogram, Seismocardiography, Electrocardiography, Piezoelectric sensor, Signal processing.

I. INTRODUCTION

Biomedical signals involves in the observation of physiological activities of organisms, gene, protein and cardiac rhythms. Extracting significant information from biomedical signals is referred to as biomedical signal processing. Different biomedical signals involved in the detection of heart health are Electrocardiography (ECG), Ballistocardiography (BCG) and Seismocardiography (SCG) etc.

ECG is the widely used technology to record the electrical activity of heart for a period of time using the electrodes placed on patient's body. The electrodes detect the small electrical changes on the skin surface that arise from the heart muscle during each heartbeat. Ten electrodes are placed on the patient's chest surface. The overall magnitude of the heart's electrical potential is measured and is recorded for a specific period of time.

SCG is the measure of local vibrations of the chest wall in response to the heartbeat. The sensor used here is an accelerometer which is placed on the chest wall. SCG was first observed in 1961 and was first used in 1991[2]. It was abandoned due to the advent of MRI, ECG, etc.

BCG is another promising technology which measures the recoil forces of the body in reaction to the cardiac ejection of blood into the blood vessels with each heartbeat.

It is used to detect the malfunctions of heart and the quality of sleep. BCG was first discovered in 1800s and in 1877 J. W. Gordon's explained the reason for fluctuation of the needle on a weighing scale is due to the rhythm of the heart. Gordon explained that the cause was ejection of blood into the aorta, comparing the recoil to "a ball propelled from a gun "[1].

BCG is a non-invasive method used to measure the health of heart by making patient lie on bed/ chair in supine position. Here no wires/sensors are placed on the patient's body. The EMFi sensor is integrated in bed or chair. Another method is by inserting optic fiber in the mattress and the fiber length is changed by the heart and breathing activity [3]. BCG records the body movements such as (1) Head to foot deflection, (2) Aentero-posterior vibrations and (3) Cardiac ejection. In bed/ chair based BCG systems head to foot deflection is measured. It is preferable to use microgravity environment for the measurement of BCG [2].

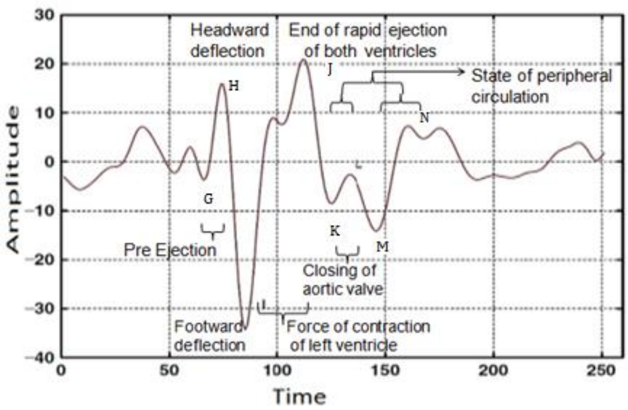

Fig. 1: Typical BCG waveform

BCG wave represents repetitive motions of the human body due to the sudden ejection of blood into the blood vessels from the heart, with frequency 1-20 Hz. The BCG signal consists of eight points (G, H, I, J, K, L, M and N) as shown in Fig.1. The H wave is associated with contraction of heart is an upward deflection which is small. During heart disease amplitude its amplitude might become large, equal or exceeding the height of the J wave. The peak J corresponds to the end of rapid ejection of blood by both the ventricles. I-J amplitude is the force of contraction of left ventricle and I-J period reflects the contractility. The K and L wave reflects deceleration of blood flow and closing of the aortic valve. Diastolic wave (KL and MN) reflects the peripheral circulation. The influence of arteries wall stiffness and peripheral resistance has greater influence on the diastolic waves [6].

II. BCG MEASURING TECHNIQUES

Placing the sensor in precise location is of greater importance. BCG measured at the head will not be the same as the BCG measured at the foot. BCG measurement can be done in three different ways [2], namely

• **Wearable BCG Systems**
Here the sensor with three axis measuring capability is placed in the body by using adhesives, plastic mounting or textiles and the BCG is measured. [8]

• **Weighing Scale BCG**
Here weighing machines with the capability of measuring the BCG, body weight and motion artifacts were built. The measurement is susceptible to motion artifacts and floor vibrations. The main disadvantage of this technique is that the patient can stand on weighing scale without any vibration/distortion for a maximum of 30-60 seconds.

• **Bed based BCG**
Here the BCG is evaluated when the patient is at sleep. This method is used to evaluate the quality of sleep and sleep related disorders. The pressure sensor is placed in the mattress or film type sensor in the legs of the bed, EMFi sensor and piezoelectric sensor in the mattress pad to measure BCG signal. Array of sensor is preferred over single sensor to improve robustness. Here electrodes are not attached on the patient's body, which is the main advantage over ECG.

III. DESIGN APPROACH

The Block diagram of the proposed system is shown in figure 2. The hardware used in the measurement of BCG signal consists of following main parts: sensor pad and an analog signal processing circuit. The BCG signal is synchronously sampled on measuring card and the samples are stored.

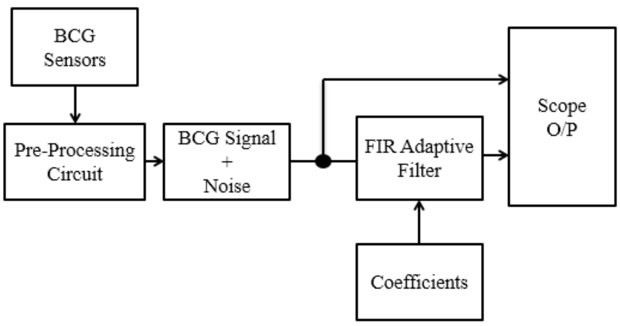

Fig. 2: Block diagram of the proposed system

A. *Sensor*

Sensors such as EMFi sensor (electromechanical film sensor) and accelerometer can be used to acquire the BCG signal [6].

• EMFi sensor: The EMFi sensor measures ballistic forces from the heart and converts them to electric pulses. The person is made to rest on the sensor pad in supine position. The sensor pad has very high sensitivity and therefore it BCG is measured using it. During the measurement a person lies with his back on the pad.

• Accelerometer: Another method to measure the forces generated by the heart is to measure the tiny displacements of the skin by attaching an acceleration sensor, called accelerometer, directly onto the skin of the patient.

B. Analog signal pre-processing circuit

The analog BCG from piezoelectric pad is pre-processed before it is sampled. The analog circuit consists of three parts: an impedance separation, a low pass filter (LPF) and an amplifier. The input resistance of the sensor pad is determined before it is passed through the LPF. The voltage follower circuit is used for impedance separation. Then it is passed through the low pass passive filter with the cut-off frequency 30 Hz. LPF is followed by a non-inverting amplifier with adjustable gain.

The electric circuit of analog pre-processing block is as shown in Fig. 3 [7].

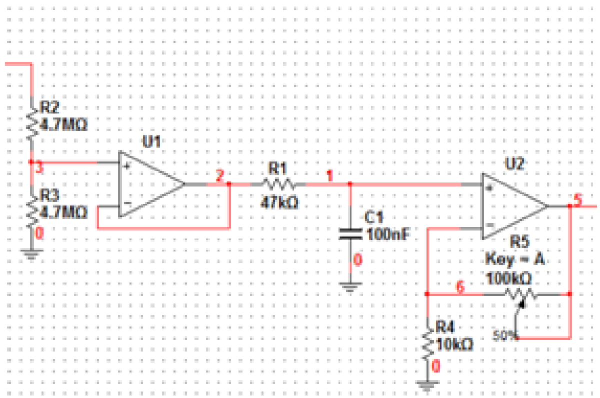

Fig. 3: Analog pre-processing block

C. FIR Adaptive Filter Block

The BCG sample a healthy individual is obtained. It consists of noise signal. The noise signal can be removed using filters to obtain the pure BCG signal. FIR filters are used because of their simplicity, robustness in design.

White Gaussian noise along with interference is added to the BCG signal to obtain noisy BCG signal. The obtained signal is fed through a FIR filter designed using System Generator platform.

The output obtained from the designed filter is shown in figure 4.

FIR filter does not suppress noise effectively. Better results can be obtained using adaptive filters.

IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 4, Issue 5, May 2016

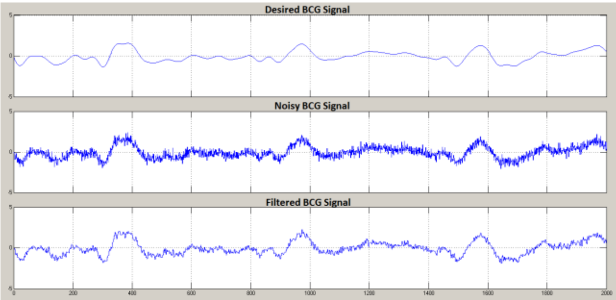

Fig. 4: Response of FIR filter

Adaptive filters are the computational devices that iteratively models the relationship between the input and output signals. An adaptive filter adjusts the filter coefficients according to the adaptive algorithm. A typical adaptive filter block is shown in fig. 5.

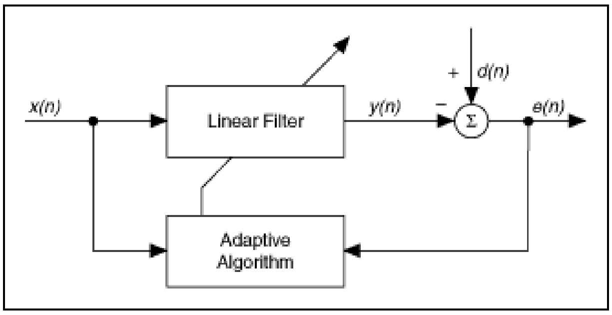

Fig. 5: Block diagram of a typical adaptive filter

Where x(n) is the input signal at time n
y(n) is the output signal
d(n) is the desired signal
e(n) is the difference between d(n) and y(n)

Adaptive filter updates the filter coefficients using the following equation:

$$w(n+1)=w(n)+\mu\, e(n)\, x(n) \qquad (1)$$

Where μ is the step size of the adaptive filter, w(n) is the filter coefficients vector, and $\vec{u}(n)$ is the filter input vector and

$$e(n) = d(n)–y(n) \qquad (2)$$

The adaptive algorithm adjusts the coefficients of the linear filter iteratively to minimize the power of $e(n)$.

The noisy BCG signal is fed to different adaptive RLS and LMS filter as shown in figure 6. The response of RLS and LMS filters is as shown in figure 7. The Mean Squared Error (MSE), Mean Absolute Error (MAE) and Peak Signal to Noise Ratio (PSNR) are calculated for both RLS and LMS filters and the results are tabulated in Table 1 respectively.

The MSE and MAE values are less for LMS filter compared to RLS filter. The LMS filter has high PSNR compared to RLS filter. Hence LMS filter is more suitable than RLS filter. Thus LMS adaptive filter block is implemented using System Generator which is discussed in the next section.

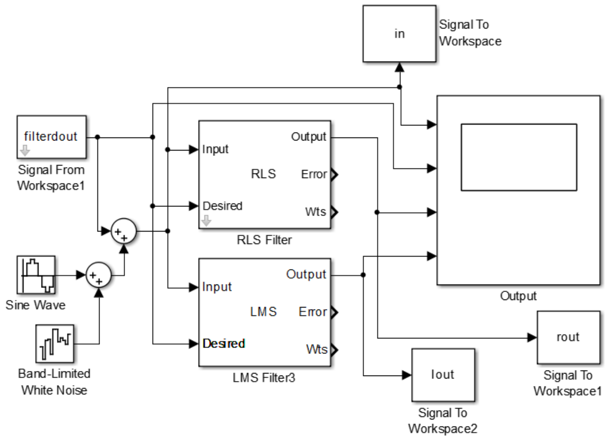

Fig. 6: Simulink model of RLS and LMS filters

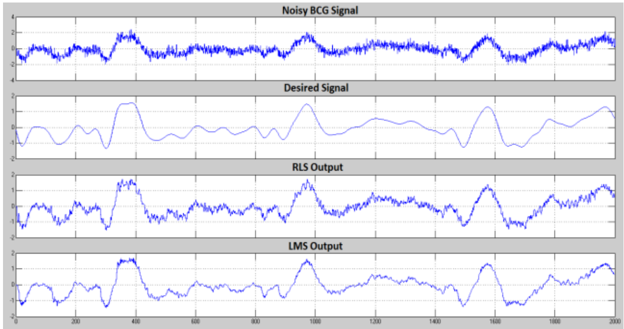

Fig. 7: Response of RLS and LMS Adaptive filters

Table 1: MAE, MSE and PSNR for LMS and RLS filters

Parameter	RLS	LMS
Mean Absolute Error [MAE]	0.2345	0.1539
Mean Squared Error [MSE]	0.0857	0.0397
Peak Signal to Noise Ratio [PSNR]	15.095	21.980

IV. SYSTEM DESIGN

The adaptive filter block is implemented using adders, multipliers and delay elements. It is implemented for 3, 6 and 8 taps. The filter with 8 tap has better noise suppression compared to lower order taps.

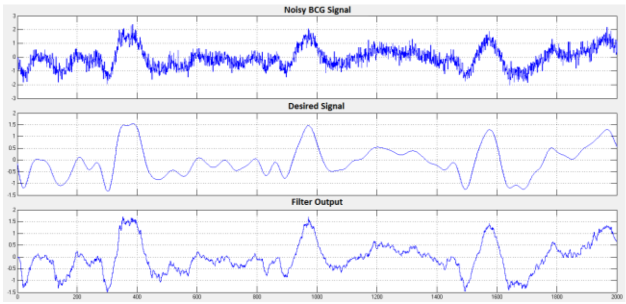

Fig. 8: Response of LMS Adaptive filter of order 6

The Noisy BCG signal is fed to the designed LMS filter and the corresponding output is shown in figure 8.

V. RESULTS AND DISCUSSIONS

The System Generator based adaptive filter design is implemented in Virtex II Pro FPGA board and the

IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 4, Issue 5, May 2016

hardware software Co-simulation is performed as shown in figure 9. The results are as tabulated in Table 2.

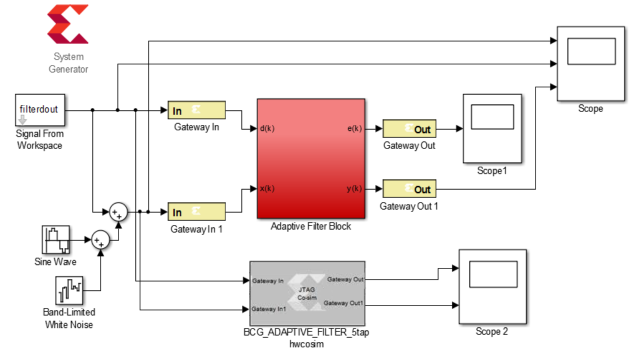

Fig. 9: Hardware Co-simulation of LMS Filters

Table 2: Synthesis summery of LMS adaptive filter

Filter Order	8 Tap	6 Tap	3 Tap
No. of Slices	289	195	106
No. of Flip flops	233	140	67
No. of LUTs	429	332	185
No. of IOs	82	82	82
Dynamic Power (mW)	319	303	292
Total Power (W)	1.178	0.938	0.926
Max Delay (nS)	2.625	2.343	2.312

VI. CONCLUSION

Ballistocardiogram signal is filtered using RLS and LMS adaptive filters and their MAE, MSE and PSNR are calculated. LMS adaptive filter gives better noise suppression compared to RLS adaptive filter. A LMS adaptive filter was implemented using system generator for different filter order. The filtered output is similar to the desired signal with filter order of 8. Hardware Co-simulation is performed and the results are tabulated.

REFERENCES

[1] Andreaw D. Wiens "A Novel System Identification Technique for Improved Wearable Hemodynamics Assessment" IEEE Journal of biomedical Engineering, Vol. 62, No. 5, May 2015.

[2] Omer T. Inam, Mozziyar Etemadi and N=John Zenetti, Jens Tank, Irina Funtova and G. Kim Prisk "Ballistocardiography and Seismocardiography: A Review of Recent Advances" IEEE Journal of biomedical and Health Informatics, Vol. 19, No. 4, July 2015.

[3] Jakub Parak "Heart Rate Detection from Ballistocardiogram"

[4] Andrew D. Wiens, Liviu Klein and Omer T. Inan "Towards Continuous Noninvasive Assessment of Ventricular Function and Hemodynamics: Wearable Ballistocardiography" IEEE Journal of biomedical and Health Informatics, Vol. 19, No. 4, July 2015.

[5] Bharath Kurumaddali , Ganesan Marimuthu, Mayur Venkatesh.S "Cardiac Output Measurement Using Ballistocardiogram" The 15th International Conference on Biomedical Engineering, IFMBE Proceedings 43, 861 DOI: 10.1007/978-3-319-02913-9_222, © Springer International Publishing Switzerland 2014.

[6] R.Uhashini , S.Dhanalakshmi , R.Vasanthi "A Survey on the Scope of Cardiac Arrhythmia Classification using BCG" International Journal of Innovative Research in Technology & Science(IJIRTS), Volume 2, Number 36.

[7] Deuchar, D. C. Ballistocardiography. British Heart Journal 1967,vol. 29, no. 3, p. 285 – 288.

[8] A. Noordergraaf, G.H. Pollack, "Ballistocardiography and Cardiac Performance", J Bibl. cardiol. Fasc., 1967, vol. 19, p.1-6.