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ICA based System with WPT for Removal of Motion Artifacts in Photoplethysmogram (PPG) Signal.

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***Abstract*— The optical sensors are used very commonly in the area of non-invasive diagnosis recently. The reason for this is their salient features like, simple construction, low cost, easy to use, relatively inexpensive nature etc. PPG sensor is one among the wide variety of optical sensors available, and is used to measure the blood volumetric changes occurring in the various parts of the body. PPG signal contains rich source of information related to cardio-pulmonary system. But the major problem associated with the signal is the motion artifacts and power line interference causing corruption in the original PPG signal. Various techniques are available in order to overcome this problems associated with PPG. In this a system technique which combines both Wavelet Packet Transform (WPT) and Independent Component Analysis (ICA) is proposed and evaluated. In order to analyze each system, the cross correlation between the pure PPG signal with de-noised signal is calculated along with SNR.**

Keywords—PPG Signal, AWGN, WPT, ICA.

I. INTRODUCTION

Photoplethysmography is a technique used for measuring the blood volume changes in an organ optically. PPG signal can be used as an indicator of the cardiac activity. It can be seen that the peaks of the PPG signal coincides with the R peak of the ECG signal [1]. And it can be used to detect several biological disorders like arterial obstructions, cardiac diseases etc.

There are two different methods of obtaining PPG waveforms: transmission PPG and reflection PPG [2]. In transmission type, light is emitted into the tissue and a light detector is placed in the opposite side of the tissue to measure the transmitted light. However in the reflection type, the light source and the light detector are both placed on the same side of a body part. Then the reflected light is measured by the detector.

The most common noise sources associated with PPG are the ambient light, electromagnetic coupling from other electronic instruments and other motion disturbances. Among the wide range of noise sources interfering with the PPG signal, the motion artifacts caused by the movement of the patient is very difficult to remove. Also the presence of power line interference is a prominent noise in PPG. This work focuses on the removal of motion artifact and power line interference from the corrupted PPG signal which enables to interpret the signal more easily and and accurately.

Various approaches are used to adjust and process motion-corrupted measurements. The first method that was used for removal of MA was Fourier series. But PPG signal being a quasi-periodic and non-stationary signal it was not possible to use Fourier series directly [3]. Periodic moving average filter which takes into consideration the quasi periodicity of the PPG signal was later introduced[4]. This method works well for the removal of intermittent noise, but cannot remove the MA of large amplitude or one that occurs suddenly. Later it is found that wavelet can be used for the removal of MA in PPG signal [5]. In this Gaussian noise added with the PPG signal is removed using different mother wavelets. It can be seen that Daubechies (db4) wavelet functions shows much efficient result compared to other wavelets.

The usage of Independent component analysis described in [6] shows that the motion artifacts can be reduced by exploiting the quasi-periodicity of the PPG signal and the independence between the PPG and the motion artifact signals. This method makes use of a pre-processor and ICA. Since it does not require prior knowledge of the system it is very useful for MA removal but its disadvantage is that it considers that all source signal component pairs as mutually independent. Singular Value Decomposition (SVD) is a mathematical tool that can be used for the removal of MA in PPG signal [7]. Multi-Scale Principal Component Analysis makes use of the de-correlation ability of Principal Component Analysis [8]. It can be seen that the MSPCA performs better than basic wavelet processing.

Adaptive filters can also be used for the removal of MA affected PPG signal [9]. This method makes use of a synthetic reference signal for adaptive filtering purpose. This reference signal is generated from input PPG signal itself. It can be seen that using Fixed-interval Kalman filter along with adaptive filter provides better result than adaptive filter used alone [10].

Recently ICA along with wavelet transform is used more commonly to remove MA affected PPG signal. Most recent studies used ICA with dual tree continuous wavelet transform for this purpose [11]. This ICA based improved DTCWT (I^2 DTCWT) proved to perform better than DTCWT modified with Hilbert transform. Even though this method seems much efficient its disadvantage is that it has higher computational complexity than many other techniques. Our Proposed De-noising Method removes the motion artifact and is less sensitive to variability.

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The rest of the paper is arranged as follows: section II gives a short description on PPG. Section III describes about proposed system. Finally simulation results are shown in section IV .

II. SHORT DESCRIPTION ON PPG SIGNAL

A PPG signal consists of an AC component and a DC component [14]. The pulsatile portion of the PPG signal is the AC component and is obtained when light passed through the arterial blood. The DC component or non-pulsatile portion is caused the absorption of light by blood in veins, bones and tissues. This signal contains important informations about the heart rate variability, blood pressure, respiration etc.

The Photoplethysmography signal used to measure pulsatile arterial flow contains information about the cardiac cycle. A pulse of the PPG waveform can be split into two phases. The first rising edge, which is the systolic upstroke time is called the anachrotic phase. Next falling edge is the catacrotic phase which is characterized by the diastole. The dicrotic notch observed in the catacrotic phase is due to the sudden closing of the aortic valve which results in retrograde flow and increase of blood volume in the arteries for a short period. Fig. 1 shows the typical PPG waveform and its characteristic parameters, where x is the amplitude of the systolic peaks and y is the amplitude of the diastolic peak. Different parameters of a PPG signal include Systolic Amplitude, Stiffness index, Crest time, Pulse Width, Pulse Area, and Peak to Peak Interval.

A. Advantages and Limitations of PPG

PPG offers several advantages over other in-vivo optical methods. Since it uses inexpensive optical sensors which are rugged, needs less maintenance it is an ideal ambulatory device as the power consumption is very low. A range of clinically relevant parameters like heart rate, respiratory rate and respiratory induced intensity variations (RIIV) etc. can be obtained from PPG signal.

Among the various limitations associated with PPG signal Motion Artifacts caused due to poor contact to the fingertip by the photo sensor is a major problem. Variations in temperature and bias variations in the instrumentation amplifiers can sometimes cause baseline drift as well. Power line interference can also cause disturbance in the signal. Usually the main cause of motion artifacts is the vibrations or movement of the subject.

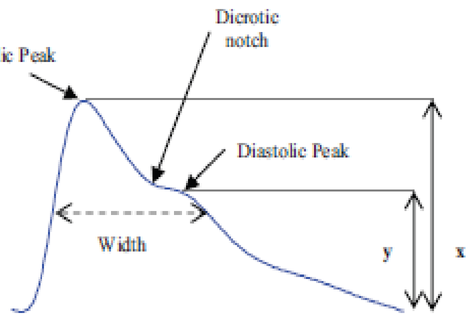

Fig. 1. A Typical Waveform of PPG.

III. THE PROPOSED SYSTEM

The proposed system consists of Wavelet packet transform followed by Independent component analysis. The input for this system is PPG signal which contains MA. In order to obtain this signal, additive white Gaussian signal and sine waves with certain frequencies are added to the pure PPG signal. The Fig. 2 shows how the noise is added to the PPG signal using Simulink. In this a random signal is added to the sine waves generated by the signal generator. Low frequency signal (0.1 Hz -0.35Hz) as well as 50 Hz power line interference and its harmonics are obtained using these blocks. The performance of the proposed system is compared with WPT and ICA system by taking into consideration the cross-correlation between the de-noised signal and pure PPG signal as well as SNR.

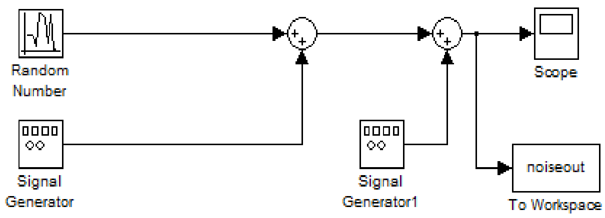

Fig. 2. Generation of PPG Signal containing MA.

A. Removal of MA using WPT

The PPG signal obtained using pulse oximeter is affected by various factors like MA, skin pigmentation, ambient light effect etc. The frequency of noise due to MA is 0.1 Hz or more and the range of useful PPG signal is 0.5 Hz -4 Hz. The superimposition of unwanted noisy signal over wanted PPG signal creates major problem in signal processing. In this section the capability of WPT to remove the noise content in PPG signal is verified.

In recent years, wavelet analysis is used as a major tool for the removal of noise or motion artifacts in biological signal processing. DWT divides the signal into approximates (low frequency) and details (high frequency) components. The disadvantage of DWT is that the wavelet transform is applied only to low frequency components .i.e., only approximates are passed through low pass and high pass filters in different levels. But when it comes to wavelet packet transform approximates as well as details is passed through low pass and high pass filters in each level. This provides a better control over the signal. WPT enables us to select a tree which is best suitable for the signal processing. The steps of wavelet packet transform are: Signal decomposition, Computation of the best tree, Thresholding (For each level an appropriate threshold is selected for detail coefficients) and Signal reconstruction. MA reduced PPG will be combining original approximate coefficients and modified detail coefficients from level 1 to N.

B. Removal of MA using ICA

Independent component Analysis (ICA) is a computational tool which is used in signal processing. ICA separates a multivariate signal into its additive subcomponents, assuming that these subcomponents are non-Gaussian and are statistically independent from each other. It is special case of blind source separation and cocktail party problem i.e., listening to a person's speech in a noisy room is an example of this application. ICA assumes that unrelated signals are generated by different physical processes.

In ICA in order to find the independent components the statistical independence of the estimated components are maximized. The independence of components is obtained by minimization of mutual information or maximization of non-Gaussanity. It can be stated that in order to separate independent signals from their mixtures it is required to make linear signal transformation as non-gaussian. This is idea is derived from making use of the central limit theorem. Before applying any measure for non-gaussanity the signal is normalized. Kurtosis and entropy are used for measuring the non-gaussanity of a system.The pre-processing steps for ICA is centring, whitening and dimensionality reduction. Whitening is used to ensure that all dimensions are treated equally before the algorithm is run. The algorithms for performing ICA include infomax, Fast ICA, JADE etc.

Fast ICA is a fixed point ICA algorithm which uses higher order statistics for the recovery of independent sources. Fast ICA estimates independent components one by one using deflation approach or simultaneously using symmetric approach. Fast ICA makes use of simple estimates of Negentropy based on the maximum entropy principle.The Fast ICA toolbox is made use in order to remove the MA in PPG signal..

C. Removal of MA using WPT-ICA system

The ICA is usually incorporated with various transforms like Wavelet transform, Dual tree continuous wavelet transform etc in order to improve the performance of the system. The proposed system incorporates wavelet packet transform with ICA in order to improve the performance of ICA.

The steps involved in WPT-ICA can be described as:

Step 1: The input PPG signal is decomposed using Wavelet Packet Decomposition.

Step 2: The Best tree suitable for de-noising is selected using best tree algorithm.

Step 3: Thresholding is done after selecting appropriate threshold level.

Step 4: Signal is reconstructed using Wavelet Packet Reconstruction.

Step 5: The reconstructed signal is given as input to the Fast ICA toolbox.

Step 6: After performing ICA in the toolbox the independent components that are present in the input signal is obtained. This obtained signal contains PPG signal with no or very less amount of artifacts.

IV. Simulation Results

The performance of the proposed system is evaluated by giving the generated MA affected PPG signal as the input to the system. The output obtained after doing WPT-ICA is shown in the Figures below. The proposed system is evaluated using cross-correlation between the original noise free PPG signal and output signal and SNR. Cross-correlation shows the similarity between two signals. A higher value of cross-correlation means how well the noise is removed from the PPG signal. The tables below show the comparison of WPT, ICA and WPT-ICA.

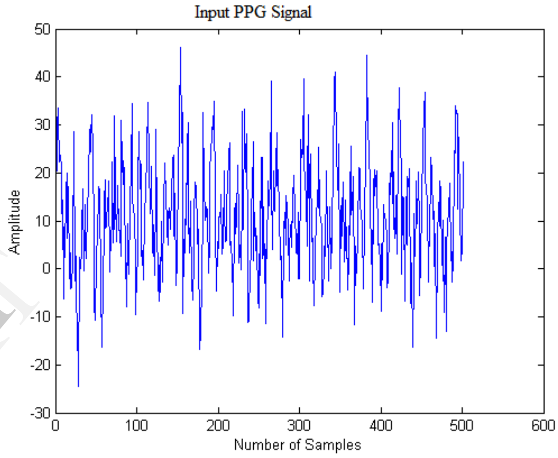

Fig. 3. Input PPG Signal containing Power line interference.

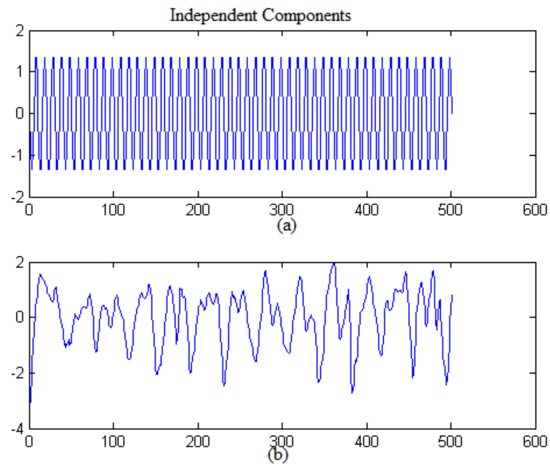

Fig. 4. Output of WPT-ICA (Power line interference)

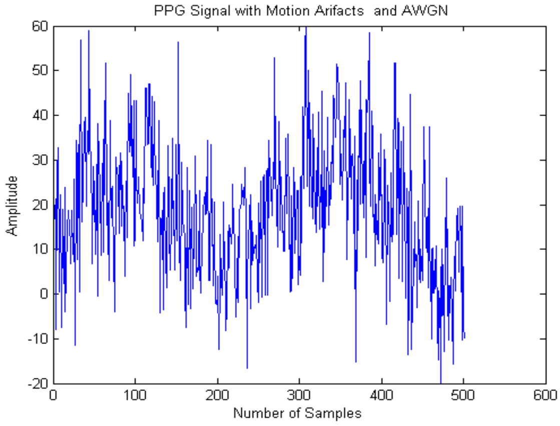

Fig. 5. Input PPG Signal containing Motion Artifacts

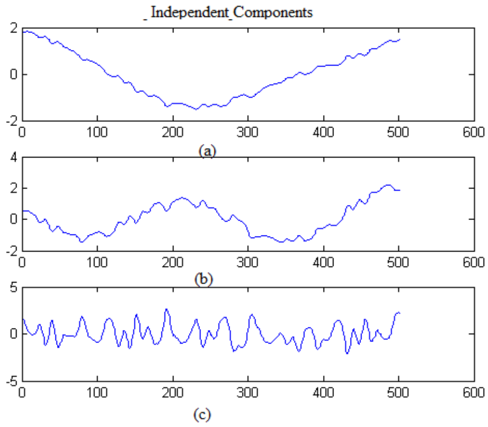

Fig. 6. Ouput of WPT-ICA (Motion Artifacts)

TABLE I. EXPERIMENTAL RESULT S (MOTION ARTIFACTS)

Parameter	SNR(in dB)	Cross Correlation
WPT	-5.5917	0.8721
ICA	14.3959	-0.9170
WPT-ICA	14.3959	-0.9470

TABLE II. EXPERIMENTAL RESULT S (POWER LINE INTERFERENCE)

Parameter	SNR(in dB)	Cross Correlation
WPT	-1.6730	0.9582
ICA	14.3959	0.8481
WPT-ICA	14.4046	0.9412

V. CONCLUSION

Photoplethysmography (PPG) has been widely used in many biomedical applications such as pulse oximetry, detection of varicose veins etc. The performance of the system which combines WPT and ICA performance well in case AWGN is present along with motion artefact and power line interference. The results show that the WPT system can remove AWGN present in the PPG signal almost completely when no MA or power line interference is present. And in case of ICA the noises except AWGN can be well removed by separating the independent components present in the PPG signal. The WPT-ICA system effectively removes all the noises present in the signal disregards to whether AWGN is present or not. That is, using ICA along with WPT provides better control over the signal. As advancement to the current work, FFT or other techniques can be added to the proposed system to remove the effects of cardiac signal on the PPG signal.

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