Photoplethysmogram (PPG) Signal Analysis And Wavelet De-Noising

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***Abstract*—The use of optical sensors is nowadays very common in the area of non-invasive diagnosis. This is mainly because of their salient features like, simple construction, low cost, easy to use, relatively inexpensive nature etc. Photoplethysmography (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, causing corruption in the original PPG signal. The aim of this study is to know in deep about the different parameters of PPG signal. Peak and transition points of the pulse signal are determined as a part of pulse wave analysis. Wavelet transform is now commonly used in a wide variety of signal processing applications. In this work wavelet de-noising is used for removing AWGN from the PPG signal. Various mother wavelets are studied and the performance of them are evaluated based on the cross correlation with the original signal.**

Keywords—PPG signal; AWGN; wavelet transform; mother wavelet; wavelet de-noising.

I. INTRODUCTION

Blood flow measurements can be used to estimate the blood volume changes in different parts of the body. Such blood volume measurements are of great importance in clinical applications which can be used to detect several biological disorders like arterial obstructions, cardiac diseases etc. Instruments used for measuring blood volume changes are called Plethysmographs and the technique is called Plethysmography. The idea behind this technique is that blood absorbs more infrared light than the remaining tissues.

A PPG signal consists of an AC component and a DC component. The pulsatile portion of the PPG signal is the AC component and is obtained when light passes through the arterial blood. The DC component or non-pulsatile portion is caused the absorption of light by blood in veins, bones and tissues [1]. This signal contains important information about the heart rate variability, blood pressure, respiration etc.

Pulse Oximetry (PO) is the process of non-invasive way of determination of the peripheral oxygen saturation (SpO2) of blood and pulse rate, which is used to assess most basic body functions, based on the analysis of photoplethysmographical (PPG) signal pulses. The most common noise sources associated with PO 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. Due to the persistent motion of the person whose PPG is measured, the signal may be distorted and the pulsatile component is no longer identified from it. This work focuses on the removal of motion artifact from the corrupted PPG signal which enables to interpret the signal more easily and accurately.

Various approaches are used to adjust and process motion-corrupted measurements. These approaches are generally divided into time and frequency domain methods. Time range processing is requires less processing power and has efficient computation [2]. Fast Fourier transform (FFT) analysis of pulse signals can be used to reduce the effect of motion artifact on the required signal. However, FFT analysis performs poorly for quasi-periodic data sets [3]. Various studies show that adaptive filters can be used to eliminate in-band noise [4]-[6]. But, in order to use adaptive filter technique, a reference signal is needed and it requires an additional hardware setup. In order to reduce intermittent noise in PPG signal Periodic Moving Average Filter (PMAF) can be used but this does not remove motion of large amplitude or one that occurs suddenly. In 2012, M. Raghu Ramand and Venu Madhav proposed an approach for motion artifact reduction in PPG signals based on AS-LMS Adaptive Filter. But this also requires a reference signal which is a disadvantage [7]. Our Proposed Wavelet de-noising method removes the motion artifact and is less sensitive to variability.

II. STUDY ON PPG SIGNAL

Photoplethysmographs that measure the blood volume saturation are commonly worn on the finger. But in some cases it is placed on head i.e., the ear nasal septum and forehead. This is because shock, hypothermia etc. can reduce the amount of blood that flows to the finger tips. This will result in a PPG without a clear cardiac pulse.

There are two different methods of measuring PPG waveforms: Transmission PPG and Reflection PPG [8]. 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. As only a limited amount of light passes through the organ tissue the transmittance PPG is applicable only to a body parts such as the finger or the ear lobe.

However in the reflection type, the light source and the light detector are both placed on the same side of a body part.

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Then the reflected light is measured by the detector. Since the reflected light is measured, this can be used at any part of the body.

In this work PPG signal obtained from a commercially available transmission type pulse oximeter was used for processing.

A. *Waveform representation of PPG*

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. Systolic amplitude gives an indication of the pulsatile changes in the blood volume, which also depends on the stroke volume. Stiffness index which depends on the height and age of a person is also related to the time delay between systolic and diastolic peaks. Crest time is an important parameter in the identification of cardiovascular diseases. It is the time duration from the base of PPG waveform to its peak. These parameters of PPG signal are used in various time domain processing methods like peak detection, Transition points calculation etc.

B. *Advantages 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. PPG signal contains rich source of information related to cardio-pulmonary system. 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. Usually the main cause of motion artifacts is the vibrations or movement of the subject.

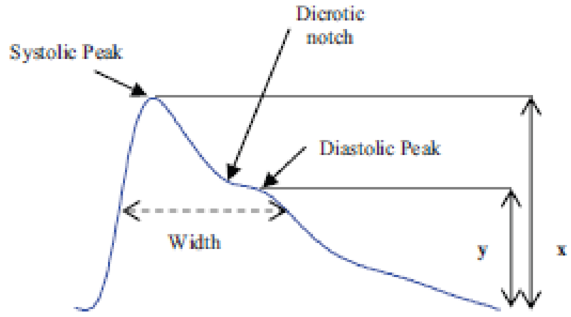

Fig. 1. *A typical waveform of PPG*

III. TIME DOMAIN PROCESSING

Time domain processing of PPG signal includes the calculation of peaks of the signal and also the transition points within the signal. For the processing of physiological signals, it is necessary to detect the peaks. Even though there are a variety of peak detection algorithms most of them requires the selection of an appropriate threshold value. Peaks are maximum value between two consecutive local minima. Once the peaks are detected the distance between the peaks can be used for the calculation of heart rate and other important parameters related to cardiovascular system.

The peak detection algorithm was used to detect the systolic peak of all the acquired PPG signals .The algorithm used for peak detection is as follows: Initially the peaks of the signal are calculated by the use of ‘findpeaks’ function in Matlab. Since both systolic and diastolic peaks were detected, a particular threshold value is set so that only systolic peaks detected.

Algorithm for the calculation of transition points works as follows:

1. Initially store the values of input PPG signal in a vector (say a).

2. Store the positions, where a(i)>a(i-1) to a vector b.

3. Store the positions, where a(i)<a(i-1) to a vector d.

4. Sort the vectors b and d and store it in another vector so as to show the positions where transition occurs.

IV. WAVELET DE-NOISING

A. *Discrete wavelet transform (DWT)*

Even though Fourier Transform is the commonly used tool for frequency analysis, it will not work well when the signal used is non- stationary. Since most of the physiological signals are non-stationary in nature, Fourier transform doesn’t work well.

Different methods are available to extract both time and frequency information from a waveform. Wavelet transform divides a waveform into segments of scale. It describes the properties of a waveform that changes over time[9]. Discrete wavelet transform (DWT) is the wavelet transform with its wavelets are discretely sampled. Also it has better temporal resolution over Fourier transform [10].

PPG signal can be used as an indicator of the cardiac activity of a person, so it is very important to get the parameters of PPG signal clear without noises and artifacts. DWT effectively reduces noise better than continuous wavelet transforms (CWT) as it is a faster algorithm. DWT transforms a data vector into a numerically different vector of the same length. DWT have hierarchical set of wavelet functions as its basic function. The DWT splits the signal into low frequency component and high frequency component, each having half of original length. The low frequency component is also known as smooth information and the process is performed again on this component, breaking it up into low-low and high-low components and it is repeated several times. The high frequency component is also known as difference information. As the wavelet transform obeys reconstruction theorem it can also be used to reconstruct a noise free signal from its high and low frequency components [11].

Various mother wavelets can be used for decomposition and reconstruction of the signal. The different mother wavelets used in this work for wavelet de-noising are haar wavelets, daubechies wavelets and symlet wavelets.

The steps for de-noising method are shown in Fig 2. Initially wavelet decomposition is performed over the noisy input signal. After decomposing the signal into different wavelet coefficients, an appropriate threshold value and thresholding method is selected. Then de-noised signal is obtained by taking the IDWT of the corresponding signal so that an artifact free PPG signal is obtained.

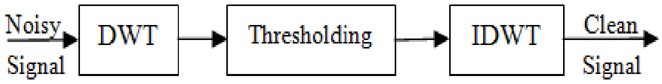

Fig. 2. *Wavelet de-noising based on DWT-IDWT*

V. Results And Discussion

In the process of the current work, the collected PPG signal is analyzed sequentially. At the first stage AWGN noise is added to the input PPG signal to make it noisy and after that the filtering operation is performed by using wavelet transformation (DWT) approach where three different wavelets i.e. haar, db4, Sym3, being used to study about the filtering process. The performance of different mother wavelets is evaluated by calculating the cross correlation of the original signal and De-noised signal.

The following figures show the results of peak detection and transition points calculation. Once the peaks are detected, the P-P interval can be utilized for heart rate calculation.

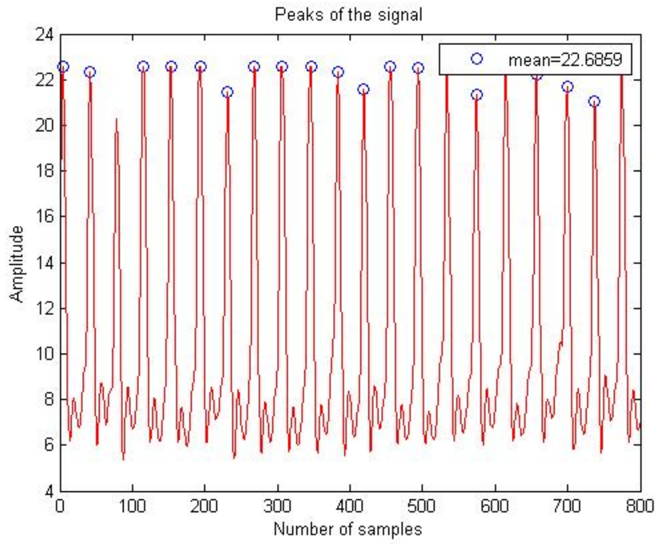

Fig. 3. *Results of peak detection*

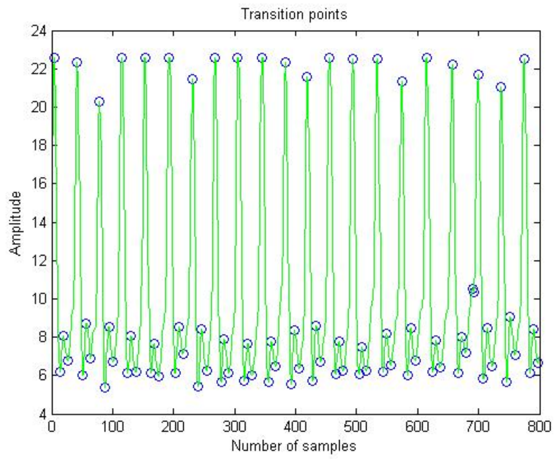

Fig 4 . *PPG signal corrupted by AWGN noise*.

The following figures show the results of wavelet de-noising. Since the PPG signal used for this work is obtained from a commercially available pulse oximeter, it is less corrupted by noise. So AWGN noise is added to it to obtain the signal corrupted by artifacts. Figure 3 and 4 shows the input PPG signal and signal corrupted by AWGN noise. AWGN noise having signal to noise ratio of 5db is used for producing a PPG signal with motion artifact.

Table1 shows the statistical parameters associated with de-noised signal obtained by using different mother wavelets. Based on the cross correlation values obtained, it is clear that the performance of db4 wavelet is better compared to the others as it gives good correlation value with the input signal after de-noising.

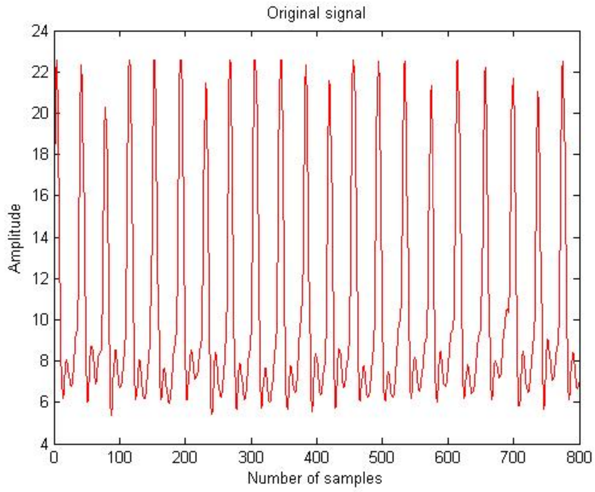

Fig. 5. *Input artifact free PPG signal*

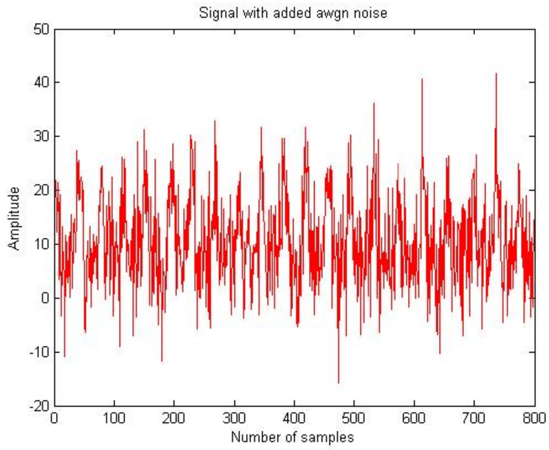

Fig .6 . *PPG signal corrupted by AWGN noise.*

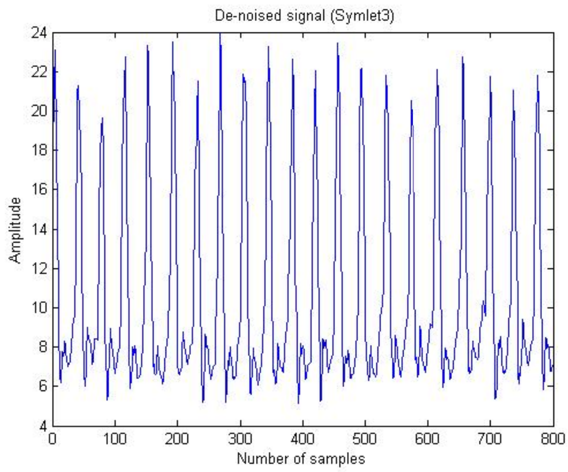

Fig. 7 .*De-noised signal using sym3 wavelet*

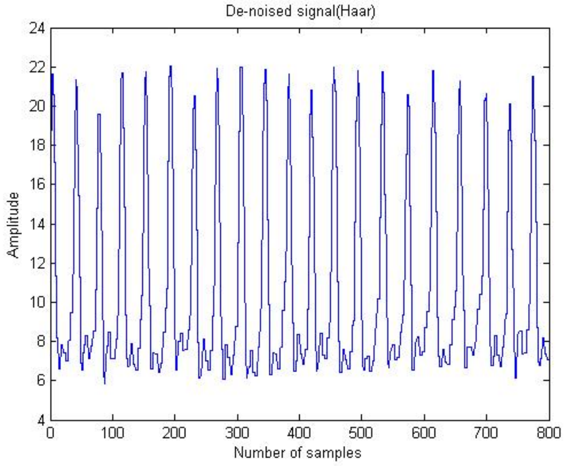

Fig.8. *De-noised signal using haar wavelet*

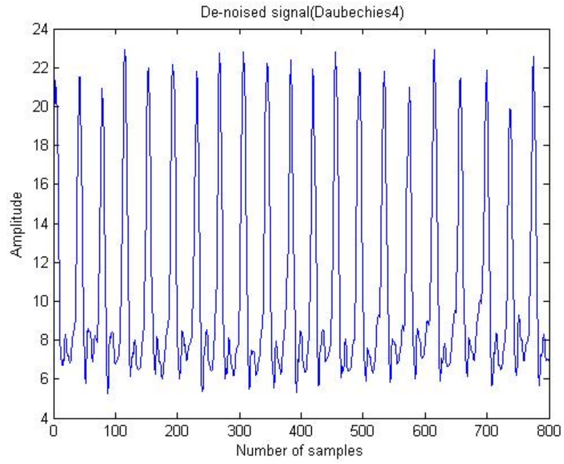

Fig .9. *De-noised signal using db4 wavelet*

TABLE1: EXPERIMENTAL RESULTS

Wavelet type	Mean	Std Deviation	Cross Correlation
sym3	10.512	4.909	.9987
haar	10.504	4.854	.9978
db4	10.506	4.962	.9991

Since Bio-signal processing can be used for understanding complex biological processes it is rapidly developing and is used in variety of areas. Daubechies (db4) wavelet functions are a powerful time-frequency approach when applied to PPG Signal shows efficient results compared to other wavelets. The signal reconstruction is more accurate in db4 whereas the others are less effective for our data.

VI. CONCLUSION

This work deals with the detailed study of PPG signal in which, the important parameters associated with the PPG signal, signal components, advantages and disadvantages of PPG etc. are studied. Since the most important problem associated with the pulse signal is the unwanted interferences associated with it, an approach for de-noising the signal based on wavelets is performed. Different mother wavelets are used for evaluation and the mother wavelet with the best performance is identified.

VII. FUTURE WORK

Due to the difficulty of obtaining a real-time PPG signal with significant artifacts we have done de-noising on synthetic signal. The future work includes the detailed analysis of the influence of various other sources of noise in the real-time PPG signal, and elimination of the same from obtained signal.

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