

# Noise Cancellation of PPG Signals using Wavelet Transformation

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**Abstract** – Analysis of Biomedical signals in efficient manner can lead to finding out critical diseases and for the patient treatment it will be helpful. Now a day's Analysis of bio-signals in the clinical point of view is gaining wide range of application. Photoplethysmography is a non-invasive technique that measures relative blood volume changes in the blood vessels close to the skin. We present the results of analysis of photoplethysmography (PPG) signals having motion artefacts which are as like Gaussian noise in nature. This paper discusses a methodology to analysis the significance of different wavelets application such as db4, bior3.3, coif1, sym2, haar in removing the motion artefacts. We applied the haar wavelet (level-5) for compressing the signals and to derive the residuals of both the input & output filtered signals, so as to study the change in standard deviation and mean abs deviation. The abs mean deviation of input signal was 50.05 and the De-noised PPG signal was found 48.33 with db4 wavelet. In our case the db4 wavelet is showing better result than the other wavelets. De-noised Signal helps to study large artery damage and any abnormality in the cardiovascular disease which is one of the common causes of high mortality rate.

**Keywords** – Biomedical Signals, motion artefacts Photoplethysmography, Wavelets, Standard Deviation and Mean Abs Deviation.

## I. INTRODUCTION

The discrete wavelet transform has a huge number of applications in science, engineering, mathematics and computer science. Most notably, it is used for signal coding, to represent a discrete signal in a more redundant form, often as a preconditioning for data compression. Practical applications can also be found in signal processing of accelerations for gait analysis [1], in digital communications and many others.

The PPG waveform was first described in the 1930s. Although considered an interesting ancillary monitor, the "pulse waveform" never underwent intensive investigation. Its importance in clinical medicine was greatly increased with the introduction of the pulse oximeter into routine clinical care in the 1980s. Its waveform is now commonly displayed in the clinical setting. Active Research efforts are beginning to demonstrate a utility beyond oxygen saturation and heart rate determination. Future trends are being heavily influenced by modern digital signal processing, which is allowing a re-examination of this ubiquitous waveform. Key to unlocking the potential of this waveform is an unfettered access to the raw signal, combined with standardization of its presentation, and methods of analysis. Human skin plays an important role in various physiological processes including thermoregulation, neural

reception, and mechanical and biochemical protection. The heart-generated blood-pressure waves propagate along the skin arteries, locally increasing and decreasing the tissue blood volume with the periodicity of heartbeats. The dynamic blood volume changes basically depend on the features of the heart function, size and elasticity of the blood vessels, and specific neural processes. Therefore direct monitoring of skin blood pulsations may provide useful diagnostic information, especially if realized non-invasively.

Optical technologies are well suited for non invasive monitoring of skin blood pulsation. Radiation of the red to near infrared spectral region penetrates several millimeter under the skin surface. Skin blood pumping and transport dynamics can be monitored at different body location (e.g. fingertip, earlobe, and forehead) with relatively simple and convenient PPG contact probes. Simultaneous data flow from several body locations the multi channel PPG technique increases the reliability of clinical measurements also allowing us to study heart beat pulse wave propagation in real time and to evaluate the vascular blood flow resistance an important physiological parameter for vascular diagnostics. Pulse wave analysis helps to study diabetes & arthritis & it is unique for each individual so it would also give unique identification as biometric identification [4]. Pulse wave analysis also helps to study large artery damage& an abnormality in the cardiovascular disease which is one of the common causes of high mortality rate.PPG analysis emphasizes the importance of early evaluation of the diseases [5].

## II. METHODOLOGY

Reflection PPG method uses the back scattered Optical signals for analysis of skin blood volume pulsation [2]. In the transmission method, an optical signal change according to its absorption at the pulsation as oxygenated allows red wavelength more and deoxygenated blood allows infrared wavelength. It employs the principle that oxygenated blood is bright red. Whereas reduced or deoxygenated blood is dark red so combination of red and near infrared LED's and photo sensors can be used to monitor the colour of blood [2]. In case of the contact and noncontact PPG, in which both are has nearly same potential only difference in the amplitude of the received signal and clarity. In the noncontact PPG signals are not so cleared as compared to contact type PPG. The second issue concerns the dynamic range of the detected signal. The detected pulsatile (AC) signal is very small compared to the non-pulsatile (DC) signal as shown in figure1. The third issue is ambient light artifact. The detector will

receive increased ambient light due to the probe separation from the tissue bed. Introducing close packaging of finger bed with detector could reduce this effect. [6]

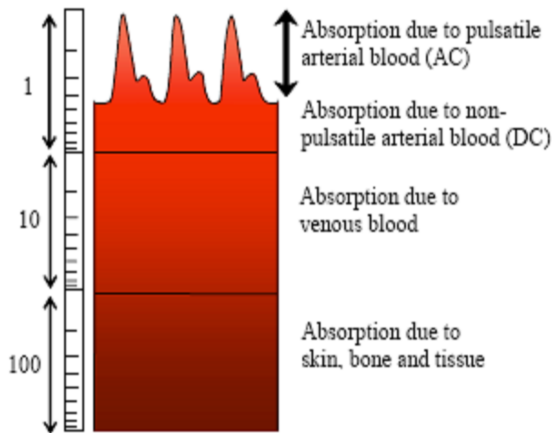


Fig.1. Breakdown of the component of the detected PPG signal

Photoplethysmography (PPG) is a non-invasive method of studies of the blood volume pulsations by detections and temporal analysis of the tissue back-scattered or transmitted optical radiation. It provides a quality assessment of changes in cutaneous blood volume. Traditionally, signal processing for Pulse-Oximeter (PPG waveforms) consisted of a time domain Weighted Moving Average (WMA) of source absorption ratios to compute blood oxygenation. This method however, suffers from inconsistent measurements due to motion artifact which is the Gaussian random noise and fails under low perfusion states in diseased condition.

Fast Fourier transform (FFT) analysis of pulse Oximeter signals have been shown to reduce the negative impact of motion artifact, alternate hemoglobin states, and low blood volume. However, FFT analysis has shown to perform poorly for quasi-periodic data sets [3]. Our Proposed Wavelet De-noising Method which described below shows a motion artifact free and less sensitive to variability. [10]

### III. WAVELET DENOISING

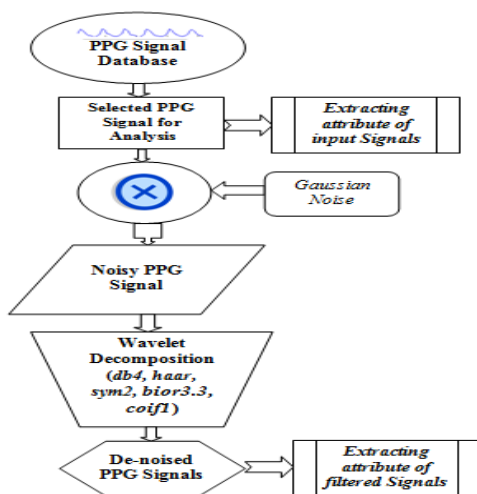


Fig.2. Block diagram of main stages of this work

The block diagram (Fig.2) shows the process of our current work where the collected PPG signal is analyzed sequentially. At first stage we added Gaussian noise in the input PPG signal to make it noisy and after that we have performed the filtering operation by using wavelet transformation (DWT) approach where five different wavelets i.e. haar, db4, sym2, coif1, bior3.3 being used to study the filtering process.

#### PPG Database

The database is prepared by downloading PPG signals from PhysioBank ATM and recording PPG signals from Heart/Pulse Rate Measurement Trainer (ST2357) at Medical Instrumentation Lab of SMIT.

#### a. Extracting attribute of Signal

Here we have applied 'haar' wavelet with level-5 for Compression by Global thresholding using balance sparsity-norm. After compression we extract the residuals i.e. histogram, cumulative histogram, autocorrelations, FFT- Spectrum of the signals along with its standard deviation and mean abs deviation. (Table-1)

#### • Average absolute deviation and Standard Deviation

The average absolute deviation or simply average deviation of a data set is the average of the absolute deviations and is a summary statistic of statistical dispersion or variability. It is also called the mean absolute deviation (MAD),

The equation for MAD is as follows:

$$MAD = 1/n \sum (|e_i|), \text{ where } e_i = F_i - D_i$$

The standard deviation of a random variable, statistical population, data set, or probability distribution is the square root of its variance. It is algebraically simpler though practically less robust than the average absolute deviation.

#### b. Wavelet Transforms in Signal Decomposition

A transform can be thought of as a remapping of a signal that provides more information than the original. The Fourier transform fits this definition quite well because the frequency information it provides often leads to new insights about the original signal. Fourier analysis provides a good description of the frequencies in a waveform, but not their timing. However, the inability of the Fourier transform to describe both time and frequency characteristics of the waveform led to a number of different approaches. None of these approaches was able to completely solve the time-frequency problem. Timing information is often of primary interest in many biomedical signals. A wide range of approaches have been developed to try to extract both time and frequency information from a waveform. Basically they can be divided into two groups: time-frequency methods and time-scale methods. The wavelet transform can be used as yet another way to describe the properties of a waveform that changes over time, but in this case the waveform is divided not into sections of time, but segments of scale [7]. In numerical analysis and functional analysis, a discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled. As with other wavelet transforms, a key advantage it has

over Fourier transforms is temporal resolution: it captures both frequency *and* location information. [8]

The **Haar wavelet** is a sequence of rescaled "square-shaped" functions which together form a wavelet family or basis. Wavelet analysis is similar to Fourier analysis in that it allows a target function over an interval to be represented in terms of an orthonormal function basis.

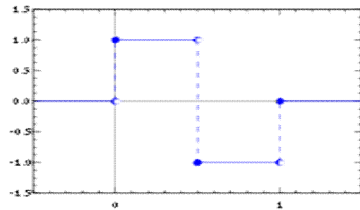


Fig.3. The Haar wavelet

*Coiflets* are discrete wavelets designed by Ingrid Daubechies, at the request of Ronald Coifman, to have scaling functions with vanishing moments. The wavelet is near symmetric, their wavelet functions have  $N/3$  vanishing moments and scaling functions  $N/3-1$ , and has been used in many applications using Calderón-Zygmund Operators.

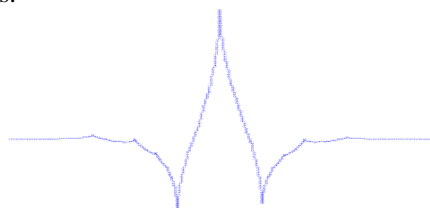


Fig.4. Coiflet with two vanishing moments

Both the scaling function (low-pass filter) and the wavelet function (High-Pass Filter) must be normalised by a factor  $1/\sqrt{2}$ . A **biorthogonal wavelet** is a wavelet where the associated wavelet transform is invertible but not necessarily orthogonal. Designing biorthogonal wavelets allows more degrees of freedom than orthogonal wavelets.

The **Daubechies wavelets** are a family of orthogonal wavelets defining a discrete wavelet transform and characterized by a maximal number of vanishing moments for some given support. With each wavelet type of this class, there is a scaling function (called the *father wavelet*) which generates an orthogonal multiresolution analysis. Daubechies wavelets are chosen to have the highest number  $A$  of vanishing moments, (this does not imply the best smoothness) for given support width  $N=2A$ , and among the  $2^{A-1}$  possible solutions the one is chosen whose scaling filter has extremal phase. The wavelet transform is also easy to put into practice using the fast wavelet transform. Daubechies wavelets are widely used in solving a broad range of problems, e.g. self-similarity properties of a signal or fractal problems, signal discontinuities, etc.[9]

#### IV. RESULT ANALYSIS

To verify our DWT algorithm for Noise removal, we have used the PPG Signals where Gaussian noise is added with the input PPG Signal. Then different wavelets such as *db4*, *bior3.3*, *coif1*, *sym2*, *haar* are applied to the noisy

PPG Signal. After that the filtered signals are analyzed. Aspects that have been carefully considered are: The logic and arithmetic involved in the data acquisition and the analysis of the PPG signals and the nature of the information to be stored. [9][10]

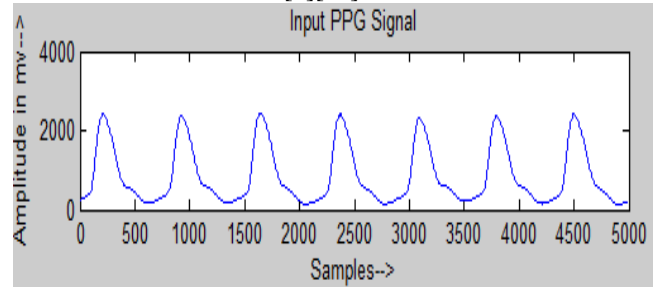


Fig.5. Input PPG Signal

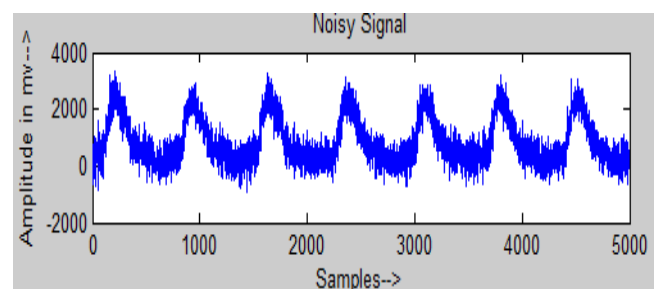


Fig.6. Noisy Signal after adding Gaussian Noise

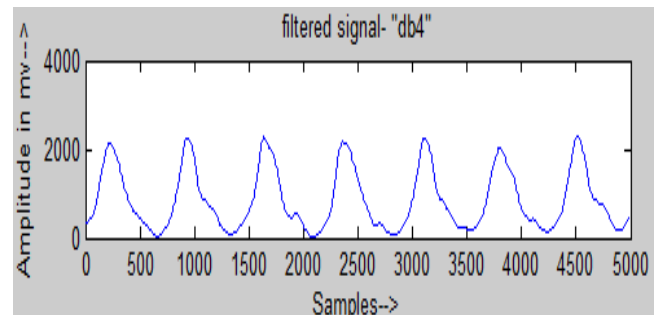


Fig.7. Filtered PPG Signal by 'db4'

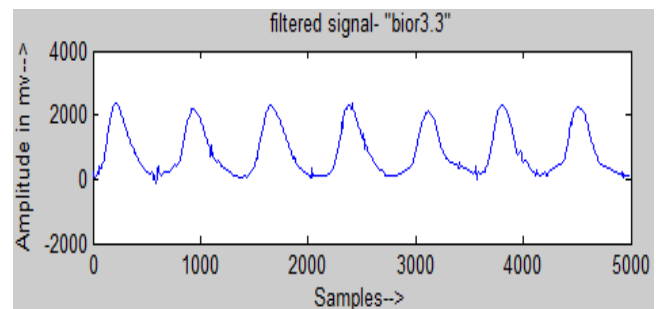


Fig.8. Filtered PPG Signal by 'bior3.3'

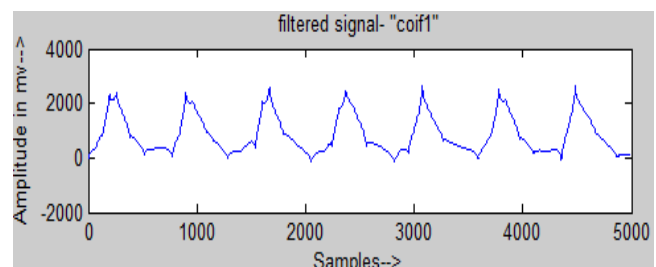


Fig.9. Filtered PPG Signal by 'coif1'

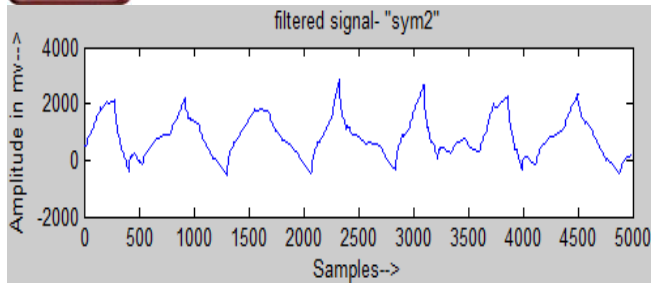


Fig. 10. Filtered PPG Signal by 'sym2'

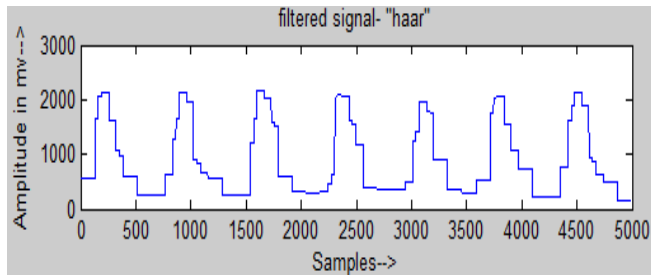


Fig. 11. Filtered PPG Signal by 'haar'

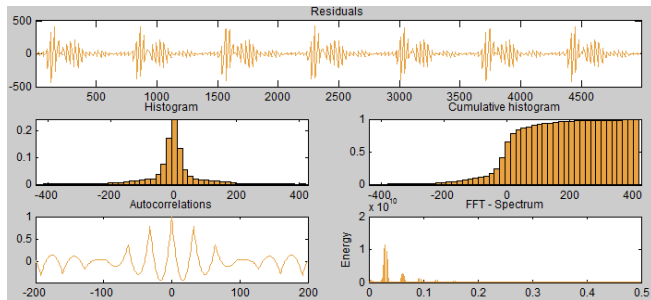


Fig. 12. Residuals of input PPG Signal

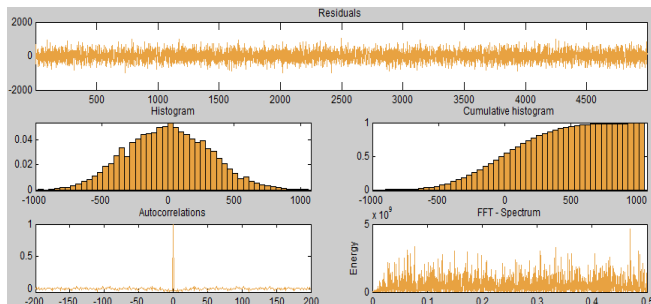


Fig. 13. Residuals of Noisy PPG Signal

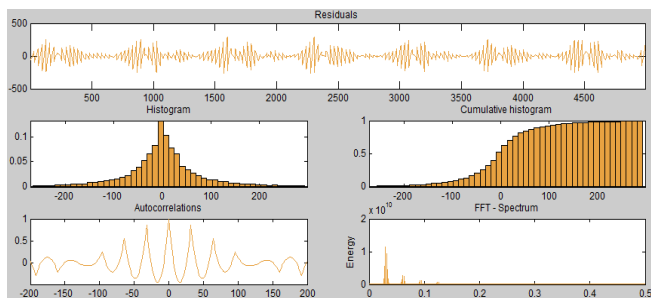


Fig. 14. Residuals of Filtered PPG Signal (Applying db4 wavelet)

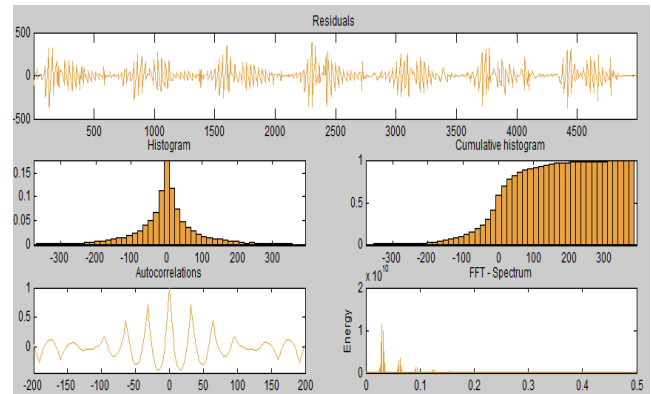


Fig. 15. Residuals of Filtered PPG Signal (Applying bior3.3 wavelet)

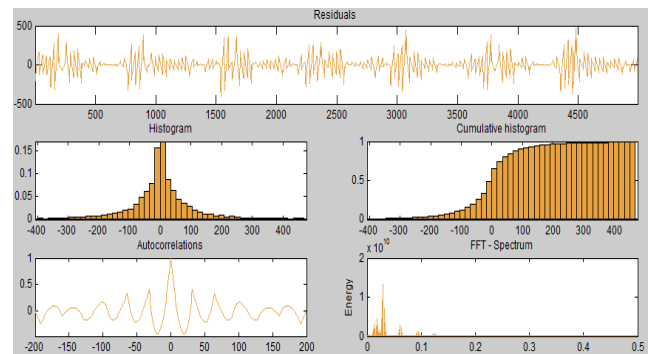


Fig. 16. Residuals of Filtered PPG Signal (Applying coif1 wavelet)

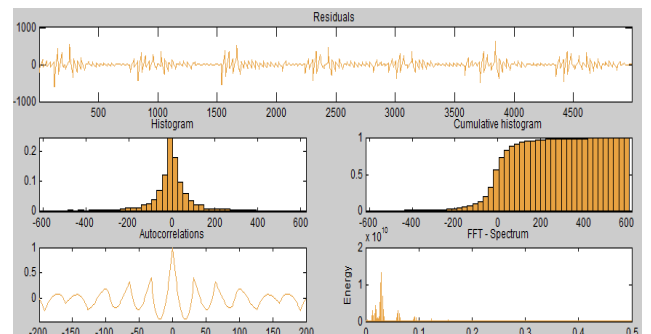


Fig. 17. Residuals of Filtered PPG Signal (Applying sym2 wavelet)

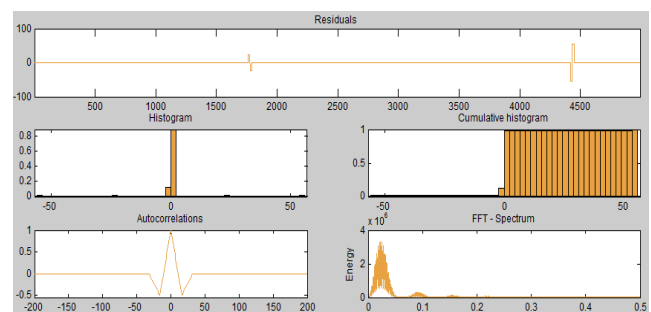


Fig. 18. Residuals of Filtered PPG Signal (applying haar wavelet)

Analysis of our proposed methodology involves filtering as well as study the change in characteristics of the signals after the each filtering operation. We have also analyzed residuals for ach signal with bior3.3, coif1, sym2, haar &

db4 which includes histogram, cumulative histogram, autocorrelations, FFT- Spectrum (Fig12-18) and the standard deviation and mean abs Deviation (Table-1) also calculated. The comparison studies have been made with all the wavelets used and the respective standard & mean abs deviation is tabulated.

Table 1. Standard & Mean Abs Deviation

Signals	Standard Deviation	Mean abs Deviation
Input PPG Signal	84.53	<b>50.05</b>
Noisy PPG Signal	311.6	251.1
De-noised Signal-‘db4’	69.47	<b>48.33</b>
De-noised Signal-‘bior3.3’	80.99	54.25
De-noised Signal-‘haar’	4.837	0.5065
De-noised Signal-‘coif1’	89.13	59.16
De-noised Signal-‘sym2’	90.5	55.94

Biosignal processing has been rapidly developing, increasing the understanding of complex biological processes in a wide variety of areas. Wavelet transform (Daubechies, 1991) , Daubechies (db4) wavelet functions is a powerful time frequency approach which has been applied to PPG Signal and it shows efficient results as compare to other wavelets. The Signal reconstruction is more accurate in db4 where as the others are less effective for our data. The mean absolute deviation of the (De-noised Signal-‘db4’) signal is also almost equal to the input PPG Signal.

### V. CONCLUSION

Five different wavelets are utilized for this purpose. Based on the smoothness and symmetric nature of the wavelets, the PPG signals are analyzed. The standard and mean abs deviation of each signal is calculated and in our case it is Daubechies wavelet (db4) which is better suited for present condition. Analyzing PPG signals carefully can give us information related to diabetes and arthritis patient, because in their case there is a difference in the pulse shape changes as a function of disease which can be well observed visually. In the diabetic patients PPG waveform shows very small dichrotic notch & slope is less, where as arthritis patients PPG waveform shows very sharp slope and no dichrotic notch were observed. The Further research will be carried out in analyzing PPG signal to detect Heart rate and respiration rate.

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