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RESEARCH ARTICLE

REMOVAL OF NOISE IN PPG SIGNALS USING WAVELETS

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Abstract— ***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. . The recorded PPG signal acquired using PPG sensors are usually corrupted with Motion Artifacts (MA) due to the voluntary or involuntary movements of patient. The identification and elimination of MA has received much attention in the literature over recent years. 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 in-consistent measurements due to motion artifact which is the Gaussian random noise and fails under low perfusion states in diseased condition. In this work wavelet denoising method is used to remove the motion artifact and found to be the better method compare to the methods used traditionally in pulse oximeter.***

Key Terms: - Biomedical signals; PPG; Motion artifact; Wavelet transform; Additive White Gaussian Noise Model (AWGN)

I. INTRODUCTION

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].

Based on the fact that noise and distortion are the main factors that limit the capacity of data transmission in telecommunications and that they also affect the accuracy of the results in the signal measurement systems, whereas, modeling and removing noise and distortions are at the core of theoretical and practical considerations in communications and signal processing. Another important issue here is that, noise reduction and distortion removal are major problems in applications such as; cellular mobile communication, speech recognition, image processing, medical signal processing, radar, sonar, and any other application where the desired signals cannot be isolated from noise and distortion. The use of wavelets in the field of de-noising audio signals is relatively new, the use of this technique has been increasing over the past 20 years. One way to think about wavelets matches the way how our eyes perceive the world when they are faced to different distances[11]. In the real world, a forest can be seen from many different perspectives; they are, in fact, different scales of resolution. From the window of an airplane, for instance, the forest cover appears as a solid green roof. From the window of a car, the green roof gets transformed into individual trees, and if we leave the car and approach to the forest, we can gradually see details such as the trees branches and leaves. If we had a magnifying glass, we could see a dew drop on the tip of a leaf. As we get closer to even smaller scales, we can discover details that we had not seen before. On the other hand, if we tried to do the same thing with a photograph, we would be completely frustrated. If we enlarged the picture "closer" to a tree, we would only be able to see a blurred tree image; we would not be able to spot neither the branch, nor the leaf, and it would be impossible to spot the dew drop. Although our eyes can see on many scales of resolution, the camera can only display one at a time(12).

Basic noise theory:

Noise is defined as an unwanted signal that interferes with the communication or measurement of another signal. A noise itself is an information-bearing signal that conveys information regarding the sources of the noise and the environment in which it propagates.

1.1 Signal to noise ratio: The signal-to-noise ratio (SNR) is commonly used to assess the effect of noise on a signal. This measurement is based on an additive noise model, where the quantized signal xq[n] is a superposition of the unquantized, undistorted signal x[n] and the additive quantization error e[n]. The ratio between the signal powers of x[n] and e[n] defines the SNR. SNR generally given in a logarithmic scale, in decibels (dB)

$$SNR_{dB} = 20 * \log_{10} \frac{\sigma x}{\sigma e} \text{ …………..(1)}$$

1.2 White noise Shown in Figure 1, white noise is defined as an uncorrelated random noise process with equal power at all frequencies. Random noise has the same power at all frequencies in the range of ∞ it would necessarily need to have infinite power, and it is therefore an only a theoretical concept. However, a band-limited noise process with a flat spectrum covering the frequency range of a band-limited communication system is practically considered a white noise process[9].

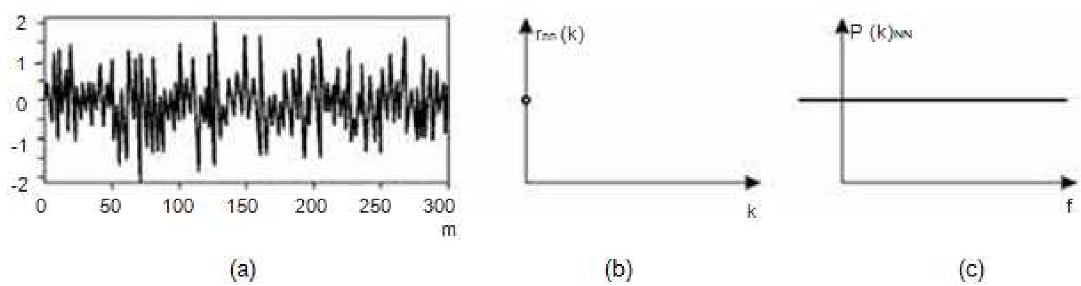

Fig. 1. Shows an illustration of (a) white noise time-domain signal, (b) its autocorrelation function is a delta function, and (c) its power spectrum is a constant function of frequency

1.3Additive White Gaussian Noise Model (AWGN)

In classical communication theory, it assumed that the noise is a stationary additive white Gaussian (AWGN) process. Although for some problems this is a valid assumption and leads to mathematically convenient and useful solutions, in practice, the noise is often time-varying, correlated and non-Gaussian. This is particularly true for impulsive-type noise and for acoustic noise, which is non-stationary and non-Gaussian and hence cannot be modeled using the AWGN assumption[13].

II. METHODOLOGY

2.1 One stage filtering: Approximations and details

For many signals, the low-frequency content is the most important part because it gives to the signal its identity. The high-frequency content, on the other hand, imparts nuance. Consider the human voice. If high-frequency components are removed, the voice sounds different, but the words are still audible and clearly recognized[4]. However, if enough low- frequency components are removed, the resulting audio signal is not clear. In wavelet analysis, approximations are the high-scale, low-frequency components and the details are the low-scale, high-frequency components of the signal. Figure 2 shows the steps for signal decomposition.

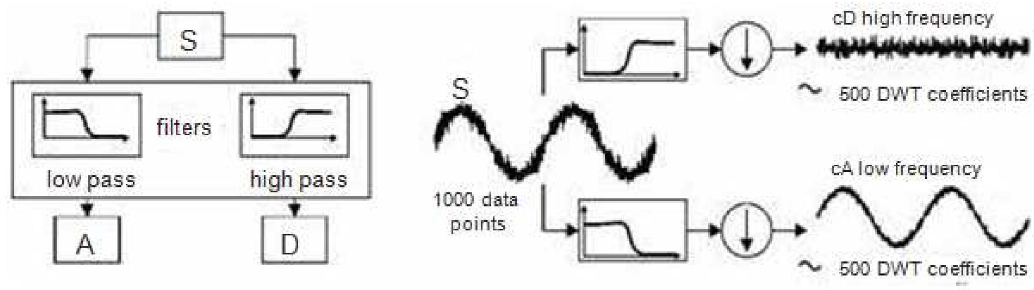

Fig.2. Show the way to decompose a signal

2.2 Multiple-level decomposition

The decomposition process can be iterated, with successive approximations being decomposed in turn, so that one signal is broken down into many lower resolution components. This is called the wavelet decomposition tree that is shown on figure 8.

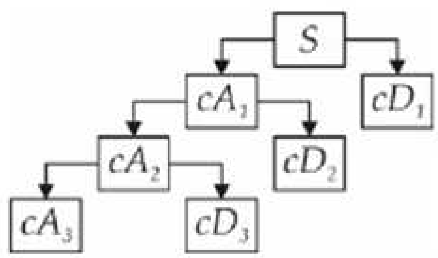

Fig. 8. Shows the process of performing, the multiple decomposition, which it is called wavelet decomposition tree

2.3 Number of levels

Since the analysis process is iterative, in theory it can be continued indefinitely. Realistically, the decomposition can proceed only until the individual details consist of a single sample or pixel. Moreover, the processes include selecting a suitable number of levels based on the nature of the signal, or on a suitable criterion such as entropy[12].

2.4 Wavelet reconstruction

Discrete wavelet transform can be used to analyze, or decompose, signals and images in a process called decomposition or analysis. Conversely, reconstruction or synthesis is the process of assembling hose components back into the original signal without loss of information. While being this transformation, it is desirable to establish its investment, i.e. to return to the original signal from the output tree. This methodology follows reasoning in the opposite direction, i.e. from the coefficients while depending on the number of levels and considering the high frequency (H') and low (L') bands that must be obtained from the reconstructed signal S, shown in figure 3. The mathematical manipulation that affects synthesis is called: the inverse discrete wavelet transforms (IDWT). In order to synthesize a signal by using Wavelet Toolbox software, we reconstruct it from the wavelet coefficients.

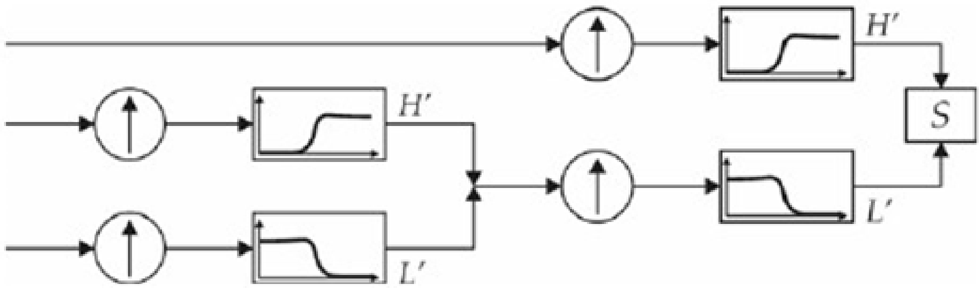

Fig 3. Show how to reconstruct a signal using wavelets

III. RESULTS 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. [2] Analysis of our proposed methodology involves filtering as well as to study the change in characteristics of the signals after the each filtering operation and calculating the Beat rate from the PPG Signal.

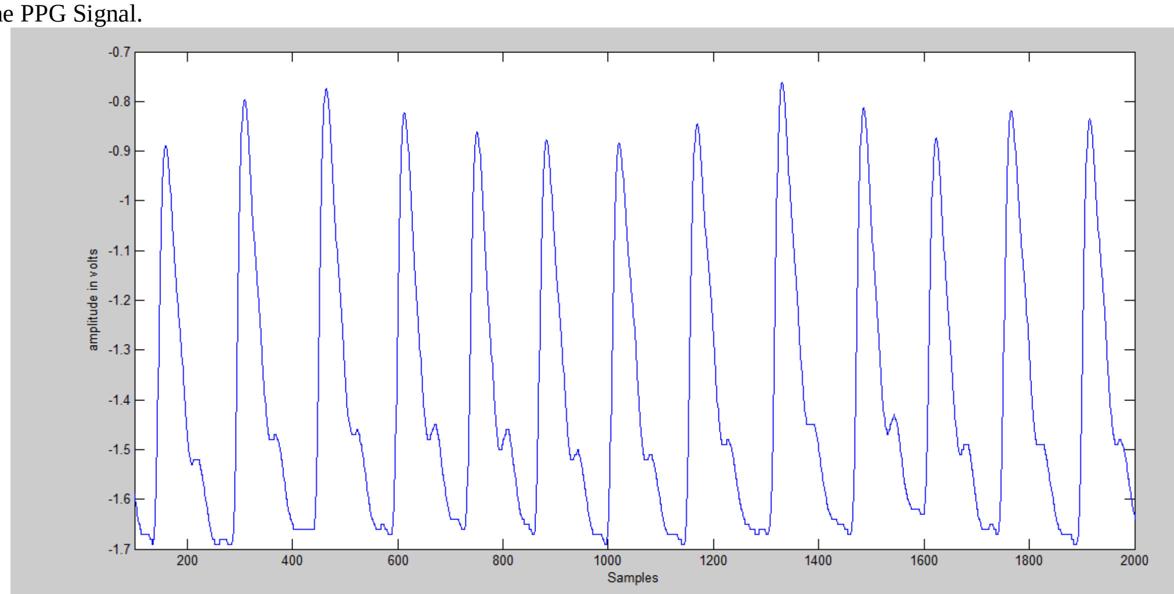

Fig4: Input PPG signal

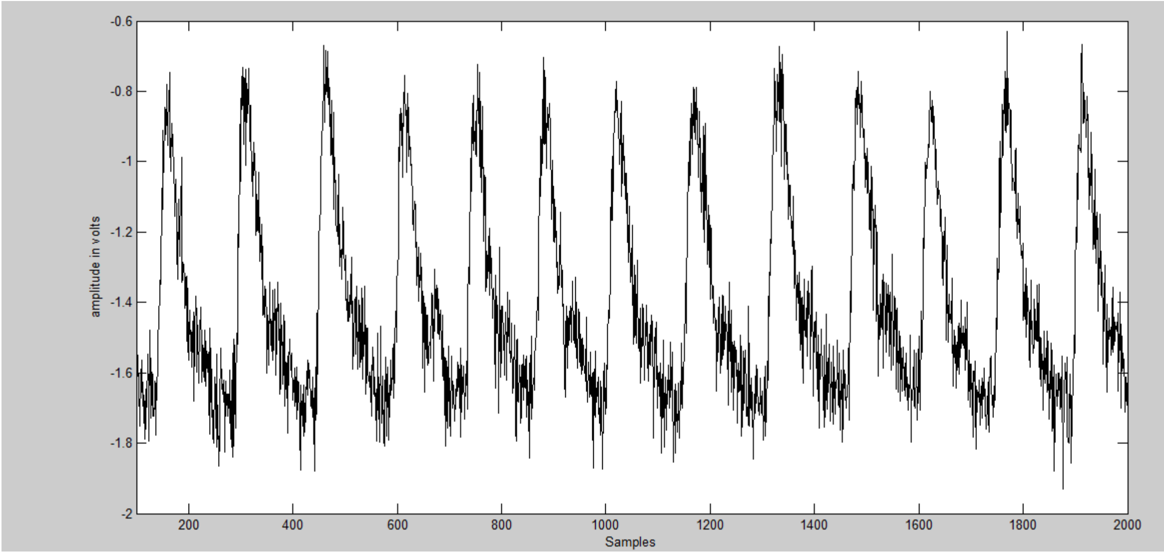

Fig5. Noisy Signal after adding Gaussian Noise

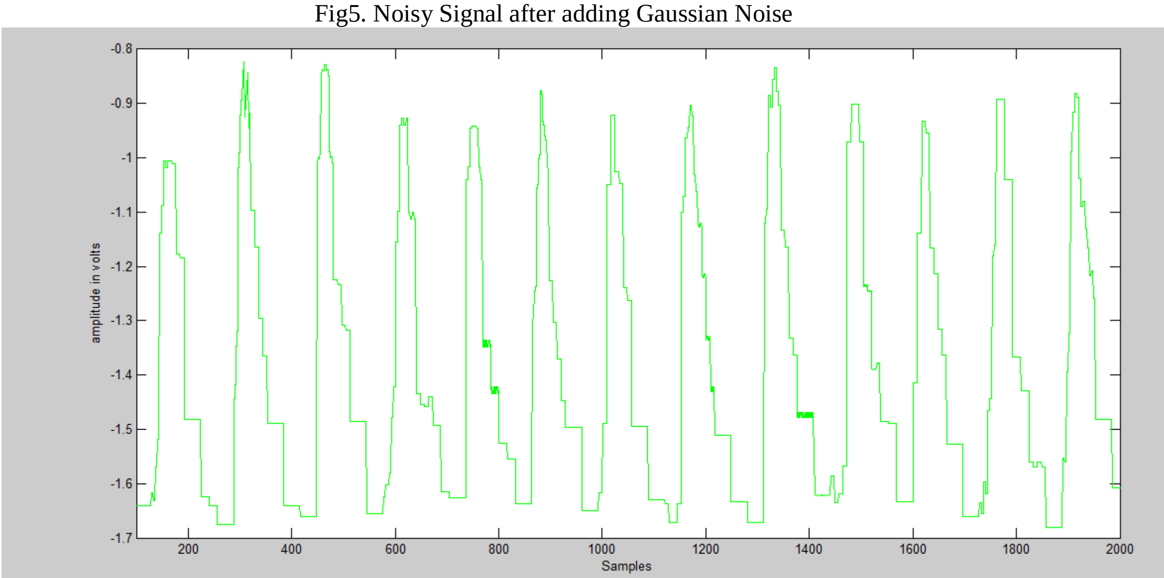

Fig6. Filtered PPG Signal by 'haar'

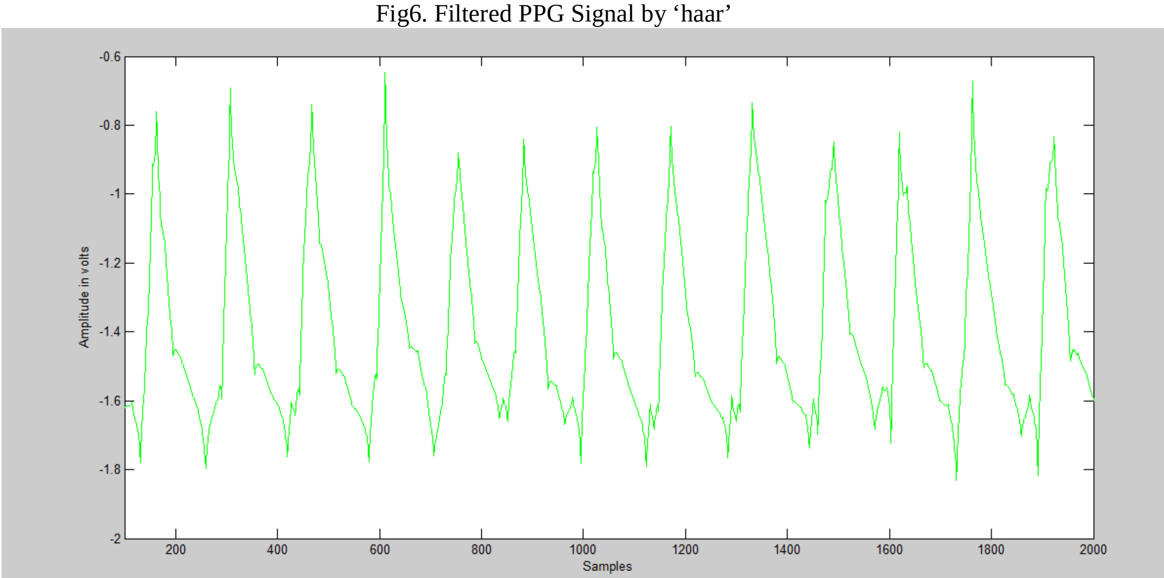

Fig7. Filtered PPG Signal by 'coif1'

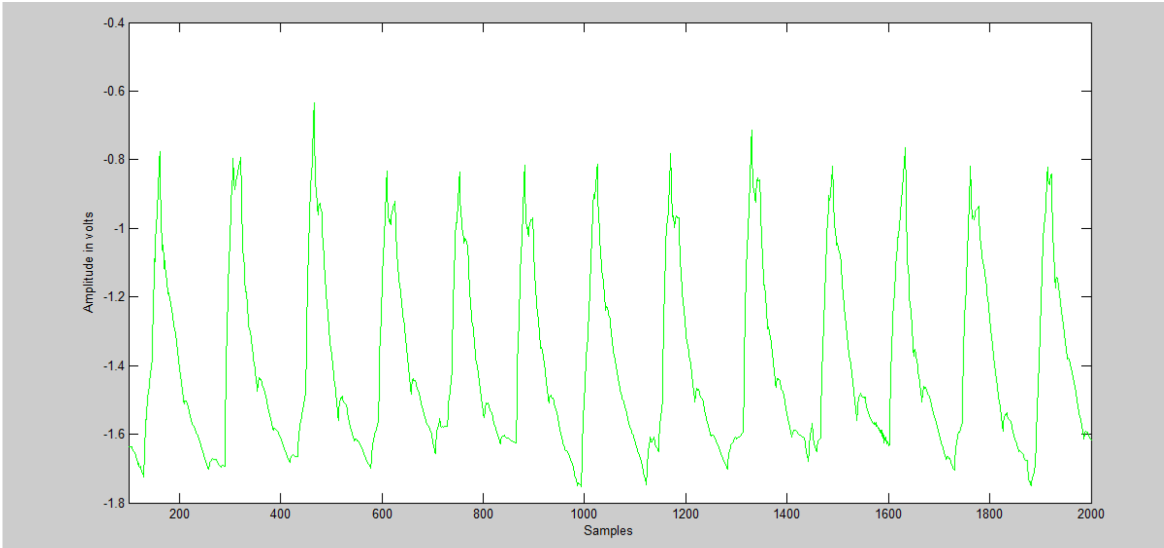

Fig8. Filtered PPG Signal by 'sym2'

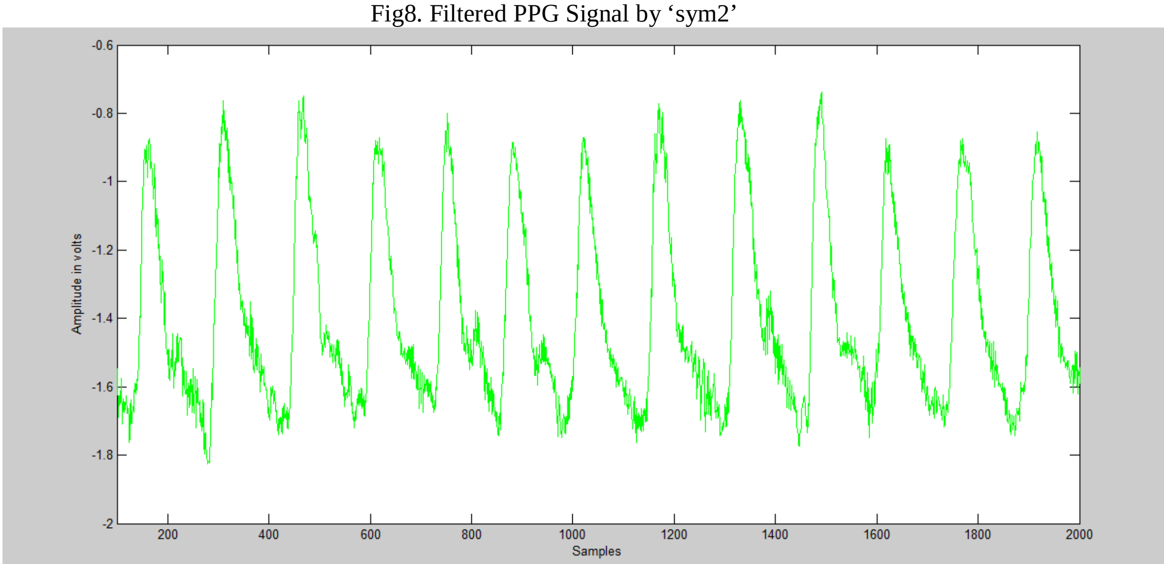

Fig9. Filtered PPG Signal by 'bior3.3'

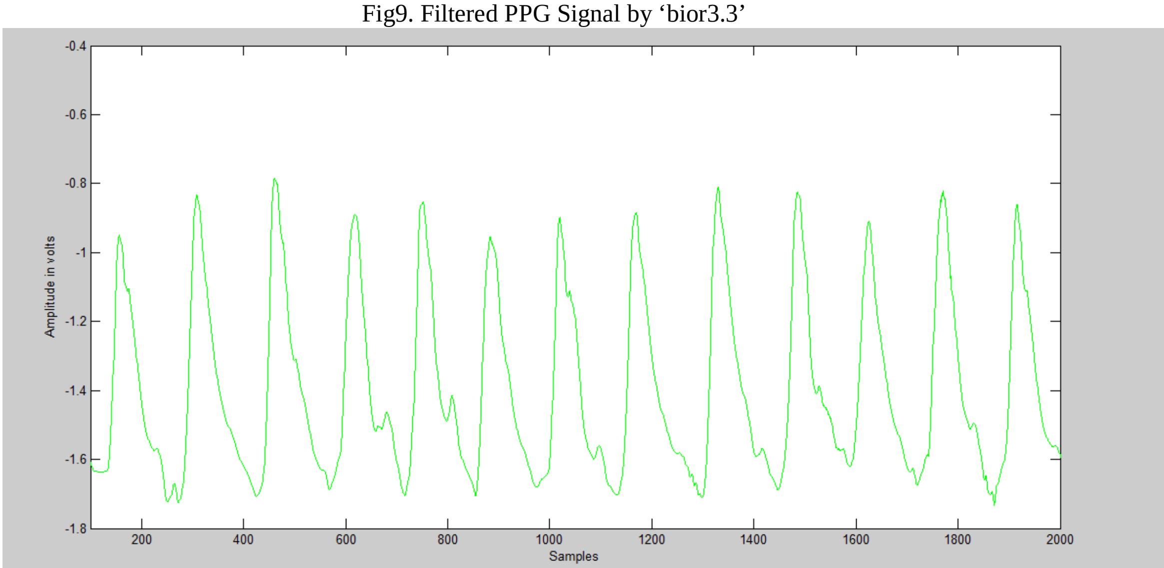

Fig10. Filtered PPG Signal by 'db4'

We have consider the db4 wavelet for filtering purpose and the Heart Rate can be calculated after de-noising process using various methods. Below tabulation (Table-1) describe the standard and mean abs deviation of the filtered signals with different wavelets approach.

Table.1

Signals	Mean	Median	Standard Deviation	Cross correlation
Input PPG Signal	1.3958	1.49	0.26935	---
Noisy PPG Signal	1.3974	1.4767	0.27813	0.6614
bior3.3-Denoised Signal	1.3972	1.4788	0.26518	0.7406
Haar- De-noised Signal	1.3973	1.4887	0.2484	0.7250
db4- De-noised Signal	1.3970	1.4691	0.25611	0.7572
sym2-De-noised Signal	1.3971	1.4831	0.2546	0.7463
coif1- De-noised Signal	1.3975	1.4913	0.25296	0.7543

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 whereas the others are less effective for our data. The mean absolute deviation of the (De-noised Signal-„db4") signal is also almost equal with the input PPG Signal[13].

IV. CONCLUSION

.The analysis can lead to identify the content of PPG signal which is different for healthy and cardiovascular patients. From the table it is clear that the original signal and db4 denoised signal are more correlated compared to other wavelets used. Hence it can be used for analyzing PPG. 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. We also investigated heart rate and respiratory rate using PPG signal.

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