EMPIRICAL MODE DECOMPOSITION BASED SIGNAL DENOISING AND HEART RATE ESTIMATION FROM PPG SIGNAL.

[1]Tripti R Kulkarni, [2]Dushyanth N D
[1]Dept. of Electronics & Communication Engg, Dayananda Sagar Academy of Technology and Management, Bangalore, India
[2]Dept. of Electronics & Communication Engg, K S School of Engineering and Management, Bangalore, India

Abstract
Photoplethysmography (PPG) signals can be used to extract Heart rate. PPG signal are highly non stationary signals and also they are heavily affected by the noise components. Quality of the PPG signal is very important to decide the accuracy of the heart rate estimation. The method proposed in this paper uses a novel technique using Empirical Mode Decomposition (EMD) to improve the signal quality and heart rate estimation using wavelet-based method. The method is tested and evaluated with Highly reliable and widely used open source PPG-BP Database, the heart rates can be accurately estimated from PPG signals using the proposed method as compared to existing methods.

1. Introduction

Heart rate is the number of times one's heart beats per minute. PPG signals are recorded using a PPG Sensor. PPG sensor consists of a photodiode and a light-emitting diode (LED), by illuminating the skin with this LED change of blood volume is recorded as PPG signals. The heart rate can be extracted by analyzing these PPG signals. The pulse-to-pulse interval and pulse rate of the PPG signal are highly correlated with the R-R interval from ECG and the heart rate [1-2]. PPG signal is relatively nonstationary and possibility of interference of noise is more while collecting the signal. A lot of research is being done in the field of heart rate extraction and denoising of PPG signal [3-4]. This work mainly focuses on two concepts they are, Noise removal from PPG signal and peaks detection in PPG signal for heart rate estimation. The rest of the paper is organized as follows; details of the EMD based Noise removal from PPG signal is explained in Section 2. Algorithm for peaks detection in PPG signal for heart rate estimation is explained in Section 3 and conclusions are put forward in Section. 4.

2. Noise removal process from PPG

Highly reliable and widely used open source PPG dataset such as PPG-BP Database [5] is used for the evaluation of the algorithms developed in this paper. PPG-BP Database contains 657 data records from 219 subjects. The raw PPG signal is shown in Figure 1, poor signal quality is the main reason for inaccurate estimation of heart rate. So, before using these signals for heart rate

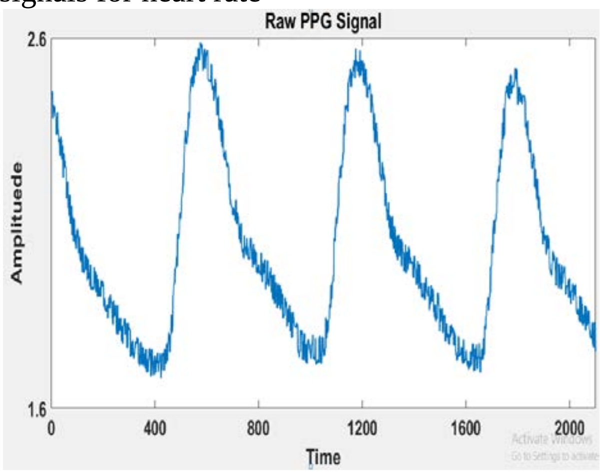


Figure 1. Recorded raw PPG signal

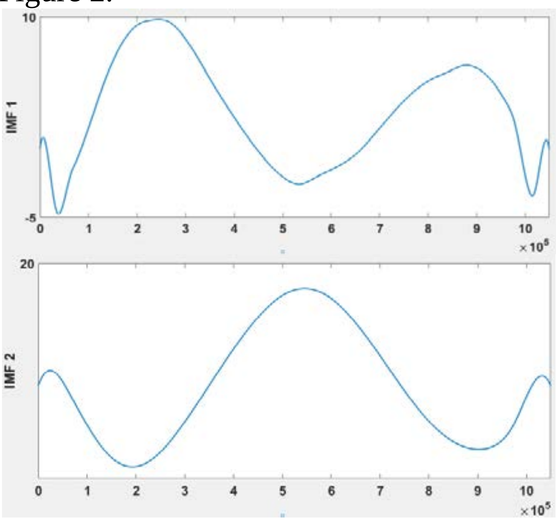
estimation, preprocessing is performed to eliminate noises. Generally, linear filtering methods such as the Wiener filtering [6] are used to eliminate noise in a signal, because these filters are easy to design and implement. However, when signals contain impulses of short duration and sharp edges these filters are not so effective. Recent work on signal quality estimation, uses the manually selected features like, Root Mean Square of the Successive Difference of peak-to-peak intervals (RMSSD), spectral analysis , Shannon entropy (ShE), dynamic time warping for shape analysis, and Poincaré plot analysis (PPA)[7], in detecting optimal signal quality index (SQI) to distinguish high-quality PPG signals from poor or corrupted signals. In many situations these methods are limited in their ability to remove motion artifacts.

To overcome the above mentioned limitations of linear filtering, nonlinear filtering methods based on Continues Wavelet Transform (CWT) have been proposed [8]. The limitations of CWT based method is that, here the wavelets basis functions are fixed, but these PPG signals are nonstationary, and hence wavelets may not match these real PPG signals. For analyzing data from nonlinear and nonstationary process, recently empirical mode decomposition has been introduced [9] for analysis of signas. In EMD the basis functions are derived from the signal itself this is the main advantage of using the EMD for signal analysis. In this paper a signal denoising for PPG signal is done using EMD.

In empirical mode decomposition method nonlinear and non stationary signal is decomposed into oscillatory components called Intrinsic Mode Functions (IMFs) and a residual function $r_c(t)$ (equation 1) using a process referred to as sifting.

$x(t) = \sum_{i=1}^{c} IMF_i(t) + r_c(t)$ -------- (1)

$IMF_i(t)$, i = 1, . . . ,C are called Intrinsic Mode Functions and $r_c(t)$ is a residual, the IMFs and residuals of the PPG signal is as shown in Figure 2.



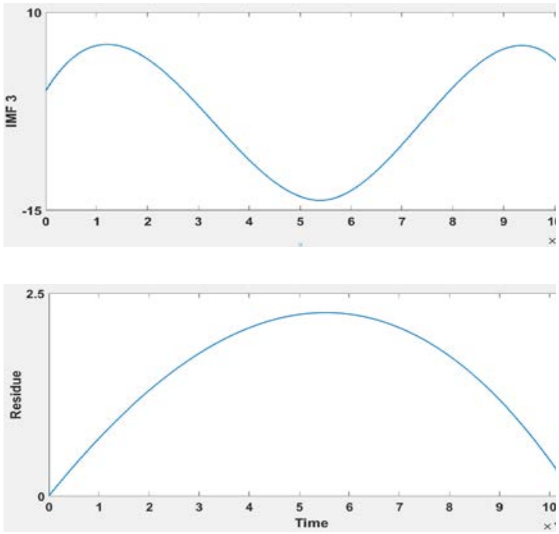


Figure 2 IMFs and residuals of the PPG signal.

Intrinsic Mode Function

Intrinsic mode functions are a new class of functions in order to find instantaneous frequency using empirical mode decomposition process. An IMF should satisfy the following two conditions:

(i) Number of zero crossings and number of extrema must be equal or at most it differs by one.

(ii) Mean value of the envelope which is obtained by joining all local minima and the envelope which is obtained by joining all local maxima, must be zero.

In EMD method when a signal is decomposed the important structures are often concentrated on lower frequency components (last IMFs). Thus, the recovered signal is reconstructed with only few IMFs that are signal dominated.

Finally the signal y(t) is reconstructed using the (C − k + 1) selected IMFs (equation 2)

$$y(t) = \sum_{i=k}^{c} IMF_i(t) + r_c(t)$$

k=2, …., c ….(2)

The recovered noiseless PPG signal y(t) is as shown in Figure 3.

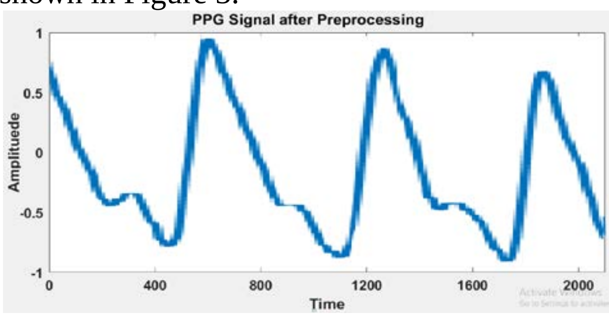


Figure 3. Recovered signal after preprocessing.

3. Peak detection for heart rate estimation

Heart rate is calculated by counting the number of systolic peaks per minute. Therefore it is required to count the systolic peaks in the PPG signal. In the field of PPG, traditional methods to locate the local maximum point were based on derivative approach [10]. Shin et al. [11] developed a method based on an adaptive threshold for improved peak detection in PPG waveforms. Liu et al. [12] designed an algorithm based on the fuzzy logic discriminator for heart rate estimation with improved accuracy. In this paper we use hybrid wavelet-based method for peak detection this can effectively extract the heart rate in comparison existing methods [13]. The results of peak identification in PPG signal is as shown in Figure 5, the results showed that using hybrid wavelet method peaks identification quality is optimized and also measurement accuracy improved compared to existing methods.

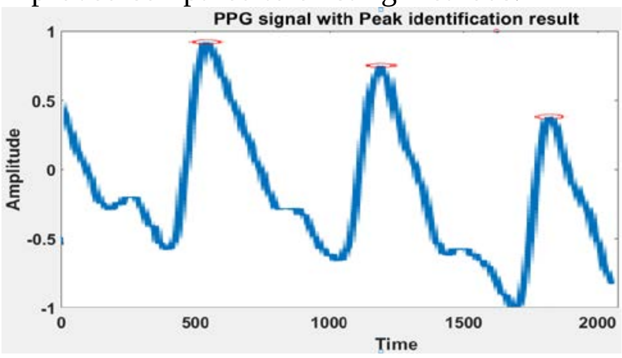


Figure 5. Peak identification in PPG signal

4. Conclusions

In this paper a new signal filtering scheme, empirical mode decomposition for denoising PPG signal is presented. This filtering method is simple and fully data-driven. The method does not require any user parameters setting. Results obtained for the PPG signals indicate that our method is effective for noise removal. A hybrid wavelet method was proposed for heart rate estimation. This method can estimate the heart rate more accurately with the error rate less than 6%.

References

1. Z. Zhang, ``Photoplethysmography-based heart rate monitoring in physical activities via joint sparse spectrum reconstruction," *IEEE Trans. Biomed. Eng.*, vol. 62, no. 8, pp. 1902_1910, Aug. 2015.
2. A. Temko, ``Accurate heart rate monitoring during physical exercises using PPG," *IEEE Trans. Biomed. Eng.*, vol. 64, no. 9, pp. 2016_2024, Sep. 2017.
3. S. Lu, H. Zhao, K. Ju et al., “Can photoplethysmography variability serve as an alternative approach to obtain heart rate variability information?” Journal of Clinical Monitoring and Computing, vol. 22, no. 1, pp. 23–29, 2008.
4. A. Sch¨afer and J.Vagedes, “How accurate is pulse rate variability as an estimate of heart rate variability? A review on studies comparing photoplethysmographic technology with an electrocardiogram, ”International Journal of Cardiology, vol. 166, no. 1, pp. 15–29, 2013.
5. Liang, Y., Liu, G, Chen, Z & Elgendi, M. Figshare https://doi.org/10.6084/m9.figshare. 5459299 (2017).
6. J.G. Proakis and D.G. Manolakis, Digital Signal Processing: Principles, Algorithms, and Applications (3rd edition), Prentice-Hall, 1996.
7. Elgendi, M., “Optimal signal quality index for photoplethysmogram signals”. Bioengineering 3, 21 (2016).
8. D.L. Donoho, ”De-noising by soft-thresholding ” IEEE Trans. Inform. Theory, vol. 41, no. 3, pp. 613-627, 1995.
9. N.E. Huang et al. ”The Empirical Mode Decomposition and the Hilbert spectrum for nonlinear and nonstationary time series analysis,” Proc. Royal Soc. London A, vol. 454, pp. 903-995, 1998.
10. L. Galeotti, C. G. Scully, J. Vicente, L. Johannesen, and D. G. Strauss, “Robust algorithm to locate heart beats from multiple physiological waveforms by individual signal detector voting, ”Physiological Measurement, vol. 36, no. 8, article no. 1705, pp. 1705–1716, 2015.
11. H. S. Shin, C. Lee, and M. Lee, “Adaptive threshold method for the peak detection of photoplethysmographic waveform” Computers in Biology and Medicine, vol. 39,no. 12, pp. 1145–1152, 2009.
12. S.-H. Liu, K.-M. Chang, and T.-H. Fu, “Heart rate extraction from

photoplethysmogram on fuzzy logic discriminator ”Engineering Applications of Artificial Intelligence, vol. 23, no. 6, pp. 968–977, 2010.

13. Suyi Li, Shanqing Jiang, Shan Jiang, Jiang Wu, Wenji Xiong, and Shu, “Diao1 A Hybrid Wavelet-Based Method for the Peak Detection of Photoplethysmography Signals”, Hindawi Computational and Mathematical Methods in Medicine Volume 2017, doi.org/10.1155/2017/9468503.