A Review on Feature Extraction Techniques of Photoplethysmogram Signal

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Abstract - Photoplethysmography (PPG) signal has been used widely for detection of pulse rate from peripheral blood volume. PPG is a novel non-invasive method with the advantage of convenience and accuracy. The dichrotic notches, ectopic beats and apertures are the prominent features that can be extracted from PPG signal for computing different physiological vital parameters. In this paper, we have discussed various feature extraction techniques.

Keywords - pulse rate, dichrotic notch, ectopic beats, PPG

1. Introduction
Photoplethysmography (PPG) is the signal that measures volume of tissue blood by computing the blood volume changes throughout entire regions of the human body during each cardiac cycle. Pulse Oximeter is the medical equipment that is designed with photosensors and infrared sensors to measure the changes in volume of blood by monitoring the amount of hemoglobin saturated with oxygen. During operations and while providing anesthesia for any operation, the need of pulse oximeter is of high concern. Hence it is well equipped in different intensive care units. This non-invasive, oxygen saturation measuring device is best preferred diagnostic tool because of its advantage of real time monitoring and non-invasive nature. The usage of this device is not restricted to measurement of oxygen saturation level. It can be extended for various purposes such as screening, diagnosis, patient follow-up, and self-monitoring. The waveform of the Plethysmograph represents the activity of the heart, lungs and blood circulation. Figure 1 shows a typical PPG Signal, with 'notches'. The analysis of signal features which have clinical significance. Hence, analysis of the various features of the waveform can be helpful in diagnosing and analyzing the proper working of the heart, lungs and blood. In this paper we have discussed different feature extracted techniques to locate and display the features of the signal automatically.

Fig. 1: A typical PPG Waveform

2. Feature Extraction Techniques

Feature Extraction Technique for HR estimation from PPG signal

In PPG signal there are two significant components first component of the PPG signal is a large DC component which is due to constant flow of blood. The second component of the PPG signal is a small AC component which is due to pulsatile blood. The average heart rate is decided based on the frequency of the pulsatile component of PPG. The average heart rate of the PPG signal is 30 – 300 beats per minute, while the average signal range frequency of AC components lies 0.5 to 5 Hz. The conventional method of determining the heart rate from PPG signal is in time domain, the heart rate is calculated from the PPG signal by initially localizing the local maxima of the PPG signal. By the features extracted from local maxima, the time interval between two consecutive heart beats can be determined. The estimation of heart rate variability (HRV) can also be calculated by determining the time [1]. Instants for every peak in PPG signal to be highly oversampled, which determined the accuracy of the HRV and HR calculation. The cost of highly oversampling the PPG signal for the estimation of these parameter will be large burden on power component. The is highly compressed PPG signal used for estimating the PPG signal compressed parameter they are randomly about sub-Nyquist rate. This action of compressing PPG signal makes the analysis in time domain highly infeasible [2]. Although the oversampling PPG signal at every instant is not helpful in long process, it is necessary to used compressed signal for accurate estimation of HR and HRV. Therefore, different approaches should be proposed to use compressed signal such as least square spectral analysis. In this paper Lomb Scargle periodogram method is explained which is implemented for analysis in spectral domain [3]. From the analysis of spectrum, estimation of HR, HRV is done and clinically significant information is obtained.

Lomb-Scargle periodogram

The fourier analysis is the traditional method that is used for estimation of spectrum in frequency domain. But, fourier analysis does not work effectively for signals that are randomly sampled at different rates or sub sampled Nyquist rate. Least squares spectral fitting can be employed to troubleshoot the former disadvantage which helps to
reduce the effect of sampling at sub nyquist rate [4]. This is achieved by determining the least squares fit of sinusoidal component corresponding to the signal sampled at random rate [5]. In this section, Lomb Scargle periodogram technique is employed as the least squares fitting method.

Consider the time series \( x(t_j), j = 1, 2, \ldots, N \), \( P(\omega) \) power spectrum of the signal which is a function of frequency \( \omega \), is estimated by Lomb Scargle periodogram. \( P(w) \) is computed as shown in Equation (1).

\[
P(w)=\frac{1}{2\pi^2}\left(\frac{\sum_{j=1}^{N} (x(t_j) - \mu) \cos\omega(t_j - \tau)}{\sum_{j=1}^{N} \cos^2\omega(t_j - \tau)}\right) + \frac{\sum_{j=1}^{N} (x(t_j) - \mu) \sin\omega(t_j - \tau)}{\sum_{j=1}^{N} \sin^2\omega(t_j - \tau)}
\]

In equation (1), the symbol \( \mu \) denotes the mean of the samples of PPG signal and the symbol \( \sigma \) denotes the standard deviation of the PPG samples. The symbol \( \tau \) in equation (1) is computed as shown in Equation (2).

\[
\tan(2\omega\tau) = \frac{\sum_{j=1}^{N} \sin 2\omega t_j}{\sum_{j=1}^{N} \cos 2\omega t_j}
\]

A significant level of \( \beta \) is associated with every power spectrum of the PPG signal, which denotes the probability of power spectrum being higher or lesser than a fixed threshold value \( n \). The significance level \( \beta \) that indicates probability is computed by Equation (3).

\[
\beta = 1 - (1 - e^{-n})^k
\]

In Equation (3), the symbol \( k \) denotes the amount of frequency in terms of bins. As specified earlier, the frequency range of PPG signal lies between 0.5 to 5 Hz, which is sufficient for the periodogram estimation to be performed over this specified range. The evaluation of the amount of frequency bins purely depend upon the level of resolution required for estimation of physiological parameters such as heart rate (HR), blood pressure, respiration rate.

**Dichrotic Notch Detection**

There are different kinds of notches in the PPG signal which has high clinical importance and denotes particular physiological function of blood flow. They are divided into two types, namely flat notches and peaking notches. The prominence was the feature that was focused for locating the peaking notches in the signal. The definition was determining the prominence feature of a peak was the height of the peak which lies around the boundary of the signal. The peak takes into account only the summit that lies above the contour line and rejects the higher summit around the range. It was found that, a notch that is present in a PPG signal will considerably have a lower prominence when compared with its parent peak. The dichrotic notches was determined by applying the prominence algorithm.

The MATLAB signal processing toolbox has lot of inbuilt functions to compute specific features of a signal. The peaks function helps to identify all the peaks available in the PPG signal. The global and local peaks was computed using peak function. Among the peaks, the non-notches that was of less clinical significance was removed by applying a threshold for the prominence feature. Those peaks which failed to cross the threshold was successfully removed. Due to the evident difference prevailed between the prominence value of a true peak and prominence of a notch, the task of assigning threshold was way easier and had high accuracy.

By inverting the signal, the prominence algorithm was used for determining the notches which had downward peaks. Following this stage, the flat notches which had a least value of prominence was considered. The notch was identified as those flat notches present in each signal segment which had lengthy continuous region. These areas of longest region are signal of constant value which extended up to the valley of every segment throughout the signal.

**Aperture Detection**

The process of drastic change in the derivative value of a slope in a PPG signal that happens during the relaxation phase of cardiac cycle is called a spike. The PPG signal when observed, the most evident region which appeals as a highly distinct and separate peak throughout the signal is called an aperture. The sudden hike in the signal amplitude or the value of baseline at the initial or final point of the component is the reason for the evident distinction in the signal. Following the spike in the PPG signal this aperture is found to be appearing in the preceding waveform. These apertures vary from individual to individual that indicate a particular feature and carries clinical significance which are used for further medical analysis. By framing a suitable leniency while the aperture is defined.

**Ectopic Beat Detection**

The initial stage of localizing the aperture is the identification of spike. Depending upon the characteristics of an aperture, a range of waveform is selected. Secondly, to accurately determine the height of the signal segment, it is advisable to choose a window of smaller length. Thirdly, by sliding the window over the entire range of signal beginning from the initial point till the final sample of the signal, the quantity of heights is determined by calculating the increase and decrease in peaks for every window. There are high chances of missing the peaks due to minute difference between subsequent heights of less clinical significance. Hence, the usage of decrease function is made only when there is a high difference in the value of heights which is achieved by framing a suitable leniency while the aperture is defined [15-16].
Signal Conditioning and Feature Extraction for deriving physiological parameters

Processing procedure of the PPG signal primarily contains two parts: signal conditioning [6] and feature extraction [7]. The signal conditioning process consists of three main steps: removal of singular values, filtering of low-pass FIR and elimination of baseline drift. The extraction of signal features aims to remove all the feature points of the PPG signal, on the basis of which the physiological parameters are extracted.

Median filtering was an effective method for extracting singular values from the signal with sharp noise. Signal conditioning algorithm design. To make the signal smoother, the maximum and minimum points could be kicked off. A 5×5 median filtering template can be used which could only reduce the singular values in the signal, but not effective for the high frequency noise. So, an FIR filter was added after median filtering. For extracting time characteristics from the PPG signal, the linear phase Filter was very crucial. To remove the high-frequency noise found in the original PPG signals, a Hamming window with 21 orders was used [8]. The baseline drift was mainly caused by an artifacts of breath signal and motion. The breath signal frequency band was within 0.3~1Hz, which was superimposed with the PPG signal. Thus, conventional methods of frequency analysis were ineffective in eliminating this drift. Wavelet transformation (WT) is one of the modern tools for spectral analysis, which can not only analyse the frequency domain characteristics of the short time domain method, but can also analyse the local frequency domain time domain characteristics [9].

In order to eliminate the effect of the breath signal, an orthogonal wavelet decomposition method was suggested [10]. The main procedure was to make the signal going through a series of low-pass filter and high-pass filter. Reconstruction of the Wavelet was a reverse process. For the signal, a slowly varying variable was the baseline. It could be removed after the approximation components were deleted by reconstructing the signal.

Wavelet Approach

Wavelet analysis is one of the commonly used processing techniques for medical signals [11] and images [12]. Wavelet based automatic algorithm was developed to extract four features from PPG signal beat by beat by comparing the R-wave from ECG signal. The four features are

- **Pulse foot** is defined as the beginning of the larger components on the pulse that appears subsequent to ECG QRS complex;
- **Systolic peak** is defined as the larger peak of the incident wave on the PPG pulse;
- **Notch** is defined as the notch or valley point that exist between the systolic (contraction phase of cardiac cycle) peak and diastolic (relaxation phase of cardiac cycle) peak;
- **Diastolic peak** is defined as the larger peak of the reflected wave on the PPG pulse;

The ECG signal is read and the ear PPG signal was extracted and decomposed separately. Both the signals were reconstructed using wavelet method. The PPG signal was partitioned beat by beat based on the position of R wave in ECG signal [13].

Pulse Transit Time

The Pulse Transit Time is the feature that is extracted from PPG signal which is highly useful in measurement of blood pressure from the PPG and ECG signal. The maximal upslope point of PPG is obtained as the peak value from the first derivative of the PPG. The systolic amplitude of the PPG is foot to peak amplitude of PPG. The pulse width of PPG is taken as the full width at half the height of the systolic amplitude of PPG [14].

3. Conclusion

The Photoplethysmogram signal has been the best noninvasive photoelectric method that calculates the pulse rate by sensing the changes of blood volume through tissue. Few pre-processing techniques are employed for removal of baseline drift which is highly associated while acquiring PPG signal. In this paper, we discussed different feature extraction techniques from which physiological signals can be derived.

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