ANALYSIS OF PHOTOPLETHYSMOGRAPHIC SIGNALS OF CARDIOVASCULAR PATIENTS

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Abstract - **In this paper, we present the results of the spectral analysis of photoplethysmography (PPG) signals for normals and patients with various cardiovascular disorders. Photoplethysmography is a non-invasive technique that measures relative blood volume changes in the blood vessels close to the skin. The PPG signal of 10 subjects was recorded from the earlobes. Five of the subjects were critically ill patients (2-Atrial Flutter, 3-Post Myocardial Infarction) and the remaining five were normals. The spectral analysis indicates that the contents of the PPG signal are different for normals and cardiovascular patients. We also investigated Heart Rate Variability (HRV) using the PPG signal. These results show that PPG can be used to analyze cardiovascular disorders and supplement existing methods of analyzing HRV.**

Keywords **- Photoplethysmography, Heart Rate Variability, Biomedical Signal Processing.**

I. INTRODUCTION

Photoplethysmography is a non-invasive technique that measures relative blood volume changes in the blood vessels close to the skin. In recent years, it has developed into a popular non-invasive method for assessing mean arterial blood pressure and oxygen saturation (Pulse Oximeter). In this report we present the PPG signal as a marker for cardiac activity. The measurement of blood volumetric changes in the skin perfusion by means of PPG depends on the fact that blood absorbs infrared light many times more strongly than the remaining skin tissues.

PPG has several advantages. It uses simple inexpensive optical sensors that need little maintenance. The device is compact and is portable. Hence it can be used in all types of environments. The simplest PPG sensor consists of an infrared LED and a photo detector placed in a small plastic housing. The sensor is applied to the skin by means of a double-faced adhesive ring. The sensor can be either of transmitting type or reflecting type. Here we have used a transmission type sensor. Using an optical fiber to transmit and receive the light can modify the PPG sensor head. With this modification, simultaneous measurements of PPG signal with MRI, ECG, EEG probes can be done without any electromagnetic interference problems.

The PPG signal has been used to study the Autonomic control of the cardiovascular system [1], [2]. It has shown that in normal subjects, the PPG signal peaks coincide with the R peaks of the ECG [3]. This result has lead to the present study of whether the PPG signal reflects the cardiac activity and R-R interval variability in the case of abnormal subjects.

II. METHODOLOGY

The PPG signal from the patients and the normals was recorded at the intensive care unit in supine position from the left and right ear lobes. The mean age of all the subjects was 36. The duration of the recording was 15 minutes. The outputs of the two PPG sensors were digitally sampled at a sampling rate of 40Hz and stored for further analysis.

The subjects studied were 5 normals and 5 patients (2-Atrial Flutter and 3-Post Myocardial Infarction (MI)). The Atrial Flutter patients were on Anti-Arrhythmic (T.Diltiazien 90mg/day) and Anti-Coagulant (T.Lanoxin – 0.25mg/day) drugs. The post MI patients were on Nitroglycerine drips. The normals were non-smokers and were not on any drugs or drug-trials.

III. PREPROCESSING

The data was filtered using a butterworth low pass filer of order 8 (cutoff - 7 Hz) to remove any high frequency noise that might be present in the signal. Figure 1a shows the raw PPG signal and Fig. 1b shows the filtered PG signal.

The very low frequency components contained in a signal are sometimes an artifact caused either by the instruments used to acquire the signal or the movement of the subject, which shifts the PPG signal up or down. The PPG sensor is also very sensitive to these shifts. These low frequency components smear the power spectrum of the PPG signal and can affect the results. Furthermore, the PPG signal consists of a quasi DC signal that corresponds to changes in the venous pressure. While it is the arterial blood volume changes that have a direct bearing on cardiovascular dysfunction. This quasi DC signal needs to be removed and the signal was detrended before being subjected to analysis. A linear detrending was applied to the PPG data. All the preprocessing and analysis was done in MATLAB.

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Abstract

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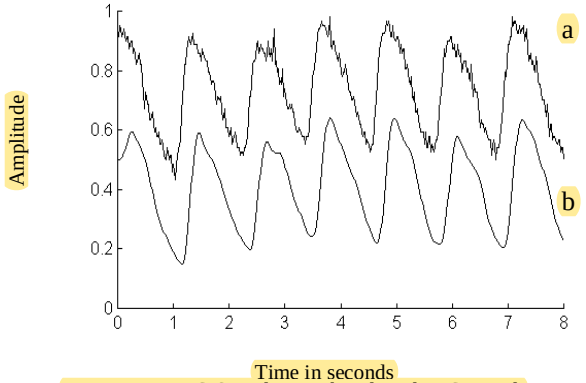

Fig 1a. Raw PPG Signal. Fig 1b. Filtered PPG signal.

IV. Spectral Analysis

FFT spectral analysis was performed on the data and was found to have many spurious peaks. The normals typically have a peak around 0.1 Hz and 1-1.5 Hz. Fig. 2.0 shows the FFT spectra for a normal subject.

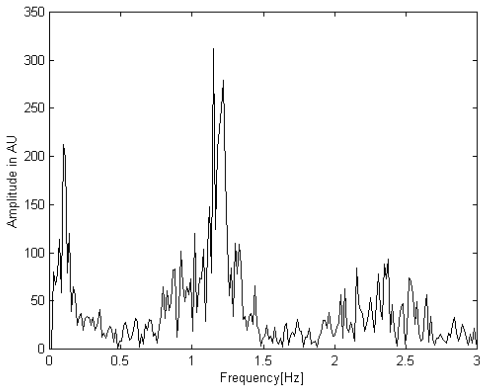

Fig 2 FFT Spectra for a Normal Subject

To remove the spurious peaks, non-parametric spectral analysis was performed on the PPG data. The power spectral density (PSD) estimate was computed using the Welch method. By employing the standard "PSD" function available Matlab 5.3. The PSD estimate showed similar frequency contents as the FFT, but devoid of the spurious peaks as seen in Fig. 2. The 1 Hz component is stronger than the 0.1 Hz components and the ratio of their magnitudes was 7:2. Fig. 3 shows the PSD for a normal subject.

The PSD also shows a small hump at about 2-2.5 Hz, which is the higher harmonic of the cardiac component. Fig. 4a and Fig. 4b shows the PPG signal of the Atrial Flutter and Post MI patient. It can be seen from Fig. 4a that the PPG signal picks up the flutter waves. Fig. 5a and Fig. 5b shows the PSD estimate for the atrial flutter and Post MI patient respectively.

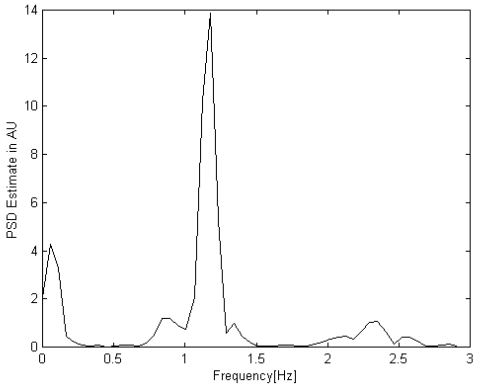

Fig 3 PSD Spectra for normal subject

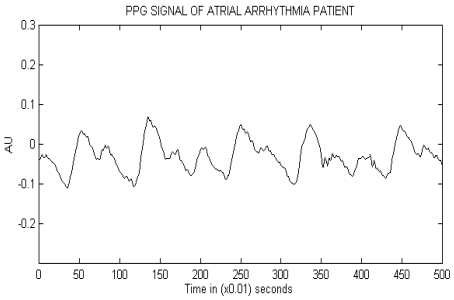

Fig 4a PPG signal of atrial flutter patient

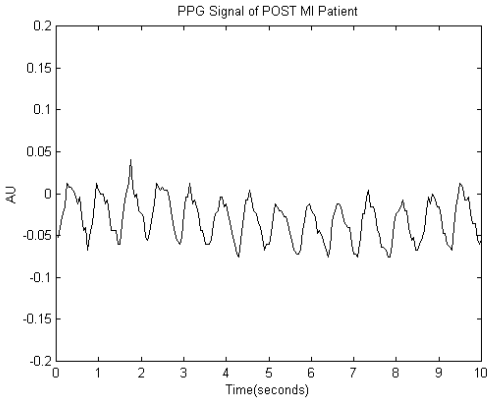

Fig 4b PPG signal of Post MI patient

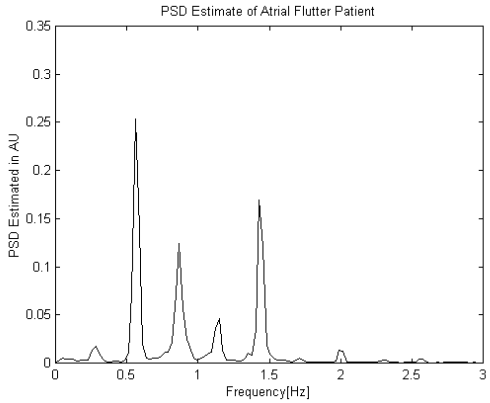

Fig 5a PSD Estimate of atrial flutter patient

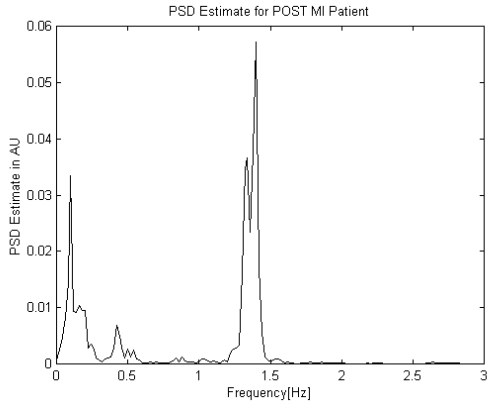

Fig 5b PSD Estimate of POST MI Patient

The PSD estimate for atrial flutter patients has prominent components at 0.6 Hz, 0.8 Hz and the cardiac component. The 0.6 Hz and the 0.8 Hz components are respectively the 'two' and 'three' flutter waves [8] seen in the PPG signal as shown in Fig 4a. The PSD estimate of post MI patients indicates the presence of two low frequency rhythms of 0.1 Hz and 0.25 Hz apart from the cardiac component (1 Hz). The ratio of amplitudes of cardiac component and the 0.1Hz component is nearly 2:1.

V. HEART RATE VARIABILITY

The study of HRV has proven to be a reliable marker for a wide range of cardiovascular disorders. It is widely known [4], [5] that the HRV spectrum comprises of two peaks, one corresponding to the sympathetic component of the heart rate and the other corresponding to the parasympathetic component. From the ECG signal, the HRV spectrum is calculated by measuring the time intervals between instantaneous R-R peaks and taking a frequency transform of the obtained time series. However, R peak detection by itself is computationally intensive and needs a signal averaged ECG, which would suppress transients and variability in the R-R intervals. Thus the observed HRV needs to be validated. We seek this validation by using the PPG signal. By using a similar technique used for ECG signals, we calculate the time differences between two PPG peaks and obtain the HRV spectrum from the PPG signal for all 10 subjects.

Figure 6 show the HRV spectrum of the normal subject derived from the PPG signal. Here two prominent peaks – one centered at 0.1 Hz and the other centered at 0.3 Hz are observed. These respectively correspond to the sympathetic component and the parasympathetic component of the heart rate. To obtain a smoother curve, parametric estimation using Burg method with an order 8 is used. The linear trends in the time difference are removed by using 100 point moving average detrending algorithm.

Figure 7 and Fig. 8 show the HRV spectrum for the atrial flutter patient and post MI patient respectively.

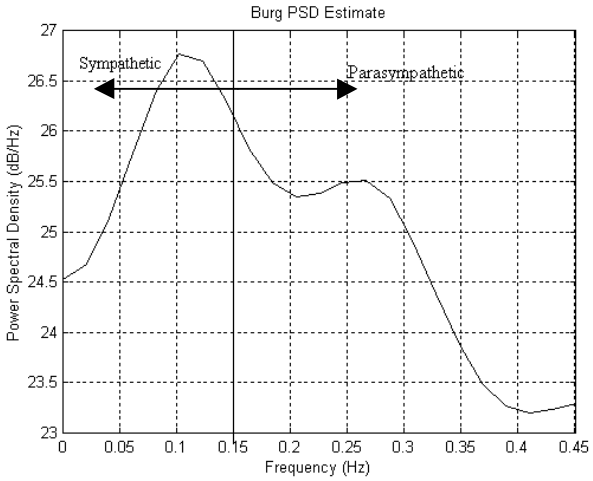

Fig 6 HRV Spectrum for a Normal Subject

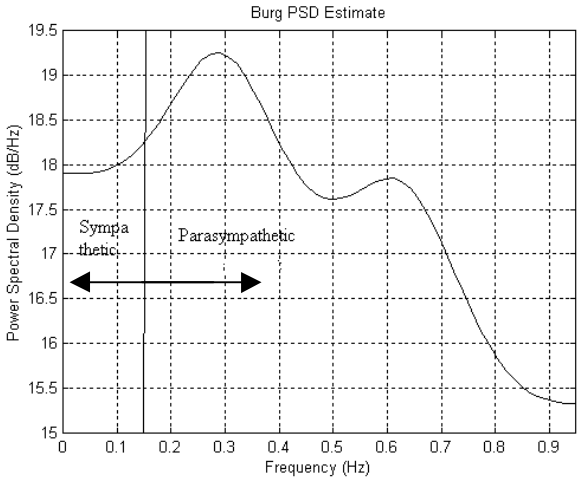

Fig 7 HRV Spectrum of an Atrial Flutter Patient

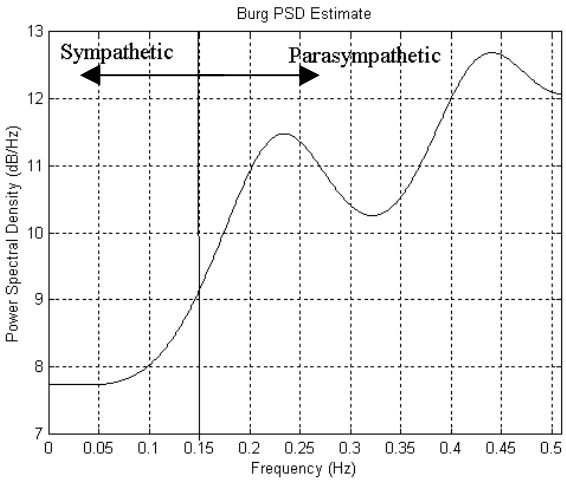

Fig 8 HRV Spectrum for POST MI Patient

VI. Discussion

By comparing Fig. 3, 5a and 5b, it is clear that the PSD estimate of the PPG signal is different for normals and cardiovascular patients. With these results, it is certain that the PPG signal contains information about the cardiac activity.

From Fig. 6 it is clear that the PPG signal reflects the HRV spectrum for normal subject in agreement with [6]. Figure 4a shows the PPG signal of a Patient with Atrial Flutter. The PPG signal usually has two and three flutter waves in between two PPG peaks. This was consistently seen during the period of measurement. These are very clear in the PSD Estimate of Fig. 5a where 0.5Hz corresponds to the 2-flutter wave component, 0.8Hz corresponds to the three-flutter wave component and the 1.5Hz corresponds to the cardiac component. Figure 7 shows the HRV spectrum for Atrial flutter patient. In contrast to the HRV spectrum of the normal subject shown in fig 6 we see two components i.e. 0.3Hz and 0.6Hz for the Atrial flutter patient.

From Fig. 8, we see that the HRV spectrum for the Post MI patient shows a peak at 0.2-0.3Hz and no significant peak at 0.1-0.15Hz, indicating absence of sympathetic pacing of the heart. This was seen for all 3 Post MI patients. A similar HRV spectrum for ECG signal has been reported in [7] and is in good agreement with Fig. 8.

VII. Conclusion

Photoplethysmography (PPG) has been widely used in many biomedical applications such as Pulse Oximetry, detection of varicose veins, muscle pump test etc. We have performed spectral analysis on the PPG signals from normals and patients with cardiovascular disorder. The results show that the spectral contents differ between normals and patients. We also obtained the HRV spectrum for normals and patients and here too there was a significant difference. These results show that PPG can be an alternative diagnostic tool to study the cardiovascular system and especially heart rate variability. Future work can aim to study the effects on different ailments on the sympathetic and the parasympathetic nervous systems using PPG in conjunction with ECG.

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