Determination of heart rate from photoplethysmogram using Fast Fourier Transform

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***Abstract*—Critical incidents can be occurred during anesthesia which may lead to death. These events can be detected using pulse oximeter; an instrument that produces photoplethysmogram, a signal represents volumetric measurement of an organ. During anesthesia, heart rate is commonly measured using photoplethysmogram. In this study, two different methods of measuring heart rate from photoplethysmogram were investigated; heart rate measurement using frequency obtained from Fast Fourier Transform analysis and peak of the time-domain signal. Results from this study shows that the heart rate measurement from Fast Fourier Transform analysis is slightly lower than that of using the second approach. Thus, the Fast Fourier Transform analysis is reliable for heart rate measurement and the algorithm proposed in this study can be embedded in pulse oximeter to provide heart rate of anesthetic patients.**

Keywords*—*photoplethysmogram; fast fourier transform; heart rate; pulse oximeter.

I. INTRODUCTION

Anesthesia is a medical intervention to control pain during surgery by using medicine called anesthetic. It can help by preventing the nerves from carrying pain signals to brain and controlling blood flow, blood pressure, heart rate and rhythm. Anesthesia uses three different types of drugs which are muscle relaxant, analgesic, and anestheticto [1]. Monitoring of heart rate during anesthesia is very important to avoid hypoxia, hypotension, and cardiac dysrhythmias [2]. There are several different ways to measure heart rate which include photoplethysmogram (PPG), electrocardiogram (ECG), and ballistocardiogram. The most frequently used instrumentation technique to measure heart rate is ECG [3]. But the complexity of the ECG procedure can be a major problem for researches during anesthesia.

The PPG can be used to detect blood volume changes in the microvascular bed of tissues because it is a simple and low-cost optical technique [4]. A PPG is obtained using a pulse oximeter with two light-emittingdiodes (LEDs) emitting red (660 nm) and infrared (940 nm) light which illuminates the skin and measures changes in light absorption [5]. The blood that is still carrying or is saturated with oxygen is measured with a clip-like device called a probe which is placed on a fingertip [6]. The differences between the oxygen-poor versus oxygen-rich hemoglobin are obtained from the comparison and calculation of the probe that consists of a light detector, microprocessor, and a light source. There are two different types of light at one side of the probe which is infrared and red. The infrared light absorbs the oxygen-rich hemoglobin and the red light absorbs the hemoglobin without oxygen[7].

Various analytical techniques to measure heart rate from PPG signal during anaesthesia have performed by researches around the world [8].However, there is no substantial research on determination of heart rate from anaesthetic patient directly from Fast Fourier Transform.

This study presents a new and simple method of measuring the heart rate from PPG of anesthetic patient using Fast Fourier Transform (FFT). The advantage of FFT is that it is able to reveal the signal frequency from the recorded signal. By using FFT, the correct heart rate measurement can be achieved once the signal frequency is obtained.

II. Method

In this work, two approaches were carried out to determine the heart rate of anesthesic patients from PPG. The first approach used the information in the time domain where the heart rate was calculated from the peak detected from the PPG signals. The second approach used information from the frequency domain where the FFT analysis was performed to obtain the frequency of PPG. Fig 1 shows the process of determining the heart rate from both approaches. In both approaches, initially FFT analysis was carried out to obtain the frequency of the signal and at the same time to ensure correct anaesthetic PPG signals were downloaded from the database.

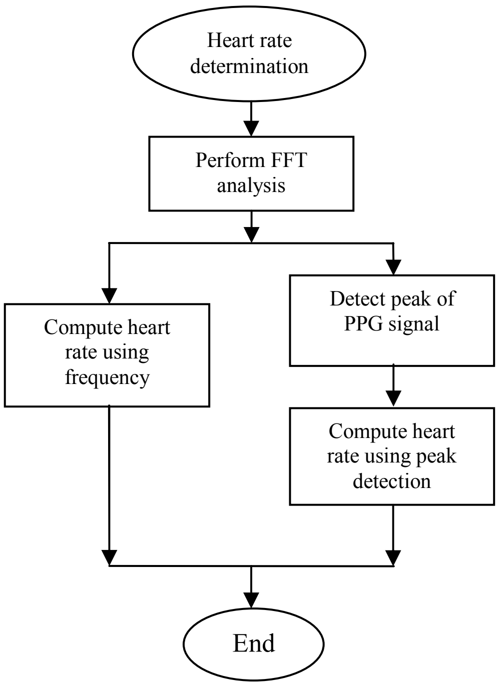

Fig. 1 Process of heart rate determination

A. *Recorded PPG data*

In this project, the PPG signals of anesthetic patients were obtained from Capnobase.org database.The PPG signals were recorded from 29 pediatric and 13 adults. The PPG signals were recorded for 8-minutes when the patients lost sensation during surgery and sampled using a sampling frequencyof 300Hz. Filtering process was applied to the PPG signals to remove noise.

B. *Determination of Heart Rate using Peak*

In common practice, the peak and location of the PPG signal was detected automatically before the number of peak was measured [9].

In this work, the peak of the PPG was initially detected automatically using a program written in Matlab. Here, the peak was detected by eliminating the unwanted peak which is below the threshold value.The threshold value was set to zero because the negative peak cannot be counted as a peak.Then, the total number of the peaks in 8 minute PPG signal was calculated. Equation (1) was then used to calculate the average heart rate.

$$\textit{Average heart rate, } HR = t_p \div 8 \tag{1}$$

where t_p is the total number of peaks in 8 minutes.Since the heart rate is expressed as beats per minute (bpm), the total number of peaks should be divided by 8 to get the heart rate in one minute.

C. *Determination of Heart Rate using FFT*

The Fast Fourier Transform (FFT) is commonly used for frequency analysis. FFT analysis converts the time domain of a signal into frequency domain. It is a faster version of the Discrete Fourier Transform (DFT) that can be applied when the number of samples in the signal is a power of two [10].The N-point DFTcan be computed using (2).

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} X_k \cdot e^{i2\pi kn/N}, \quad n \in \mathbb{Z} \tag{2}$$

where x_n is the discrete-time signal with a period of N. In order to determine the frequency of the PPG signal, FFT was computed and analysed. Once the frequency of the signal was obtained from the spectrum, the heart rate was measured from (3).

$$\textit{Heart rate} = \textit{frequency} \times 60 \tag{3}$$

III. Result

Fig. 1 shows a sample of PPG signal used in this work. The average of peaks in one second PPG signal is 1. Fig 2 shows the frequency of the signal. Note that the frequency of the PPG signal is in the range of 1.2 to 1.5 Hz.

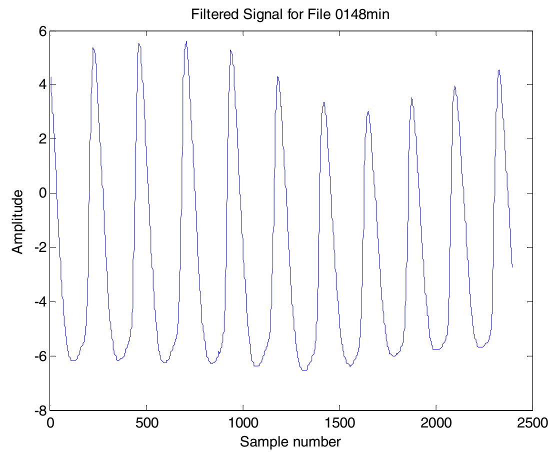

Fig. 1. Filtered PPG Signal

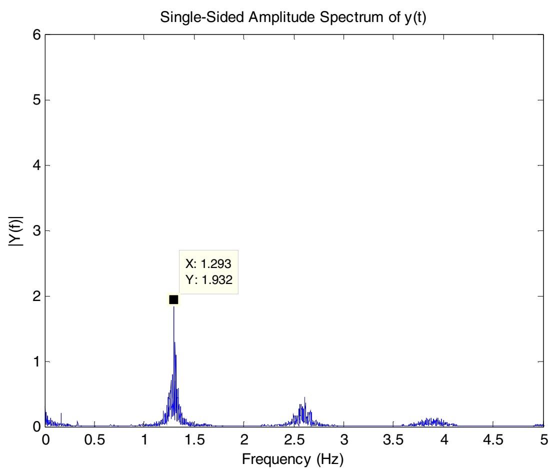

Fig. 2. FFT spectrum of the PPG signal.

Table 1 shows the heart rate obtained from both approaches for ten subjects. Using FFT, the heart rate computed from the analysis is in the range of 70 to 93 bpm whereas using peak, the average heart rate is in the range of 71 to 93 bpm. It is obvious that there is a small difference between the heart rate obtained from FFT analysis and the peak. For example, the frequency for subject 0148_8min is 1.29s, which produces heart rate of 77.4 bpm using FFT analysis. For the same subject, the total number of peak is 623, which gives the average heart rate of 77.8bpm. The heart rate measured by using FFT algorithm is lower compared to the average heart rate computed using peak. The different in the heart rate measurement is due to the accuracy of the frequency measurement from the spectrum. Since the difference is considered as small, it can be said that FFT analysis can be used to measure the heart rate.

TABLE I. HEART RATE OBTAINED FROM BOTH APPROACHES

File	Heart Rate from FFTanalysis		Heart Rate from Peak	
	Frequency (Hz)	*Heart Rate (bpm)*	*Total No. of peaks*	*Average Heart Rate (bpm)*
0121_8min	1.22	73.2	578	72.5
0123_8min	1.45	87	710	88.75
0125_8min	1.293	77.4	626	78.25
0133_8min	1.17	70.2	568	71
0134_8min	1.21	72.6	577	72.13
0142_8min	1.55	92.5	740	92.5
0148_8min	1.29	77.4	623	77.8
0313_8min	1.22	73.2	587	73.38
0322_8min	1.22	73.2	589	73.63
0330_8min	1.24	74.4	599	74.88

IV. CONCLUSION

A simple technique to measure heart rate from PPG signal of anesthetic patient has been described in this paper. The results obtained from this study shows that the heart rate produced from FFT analysis is lower than that obtained from peak. However, since the difference between the heart rate obtained from both methods is considered as small, it can be concluded that the FFT analysis can be used to measure heart rate from PPG of anesthetic patients.

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