Cardiac Irregularity Detection Using Photoplethysmogram Signal

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***Abstract*—In this study, photoplethysmogram (PPG) based heart abnormality detection method was proposed. PPG signals utilized were obtained from MIMIC II Waveform Database, Version 3 Part 1 with sampling frequency of 250 Hz with the duration of 10 seconds each. The feature of the PPG signals were then extracted using MATLAB and the distances between successive minimum troughs as well as the area of Cardioid graphs of PPG signals were calculated and evaluated to differentiate the normal and abnormal PPG signal. Based on the experimentation results, distances between minimum trough and the area of the Cardioid graphs of abnormal PPG signals are larger than the normal segments. Therefore, the results show the proof-of-concept of the proposed heart abnormality detection technique and suggest a better alternative to the current techniques.**

***Index Terms*—Photolethysmogram; Heart Abnormalities; Cardioid.**

I. Introduction

Cardiovascular disease (CVD) or also known as heart disease is caused by disorders of the heart and blood vessels, and includes coronary heart disease (heart attacks), cerebrovascular disease (stroke), raised blood pressure (hypertension), peripheral artery disease, rheumatic heart disease, congenital heart disease and heart failure [1]. Since 1950s, CVD is the leading deaths cause worldwide. The latest statistics from World Health Organisation (WHO) as of March 2013 shows that it was estimated that 17.3 million people died from CVDs in 2008, representing 30% of all global deaths [2]. Based on these records, it was estimated that 7.3 million of deaths were due to coronary heart disease and 6.2 million deaths were due to stroke [2]. It is estimated that about 600,000 people die of heart diseases in the US every year [4], accounting for one in every four deaths, with coronary heart disease being the most common killer, accounting for over 385,000 deaths annually.

Figure 1 shows that in the 34-49 year old age group, the rate of men dying from CVD is 249% more often than women. In the 50-69 year age group, men die 261% more. Statistics in Canada also shows that in every 7 minutes, someone dies from heart disease or stroke [3]. In the year 2008, it had been declared that of all cardiovascular deaths, 54% were due to ischemic heart disease, 20% to stroke and 23% to heart attack. In addition, the Conference Board of Canada claims that the heart disease and stroke costs the Canadian economy more than $20.9 billion every year in physician services, hospital costs, lost wages and decreased productivity [3]. It had been reported that Canadian acute care hospitals handled almost three million hospitalizations admit in 2009-2010. In the year 2007, 1.3 million Canadians or 4.8% out of the Canadians populations were reported of having heart disease.

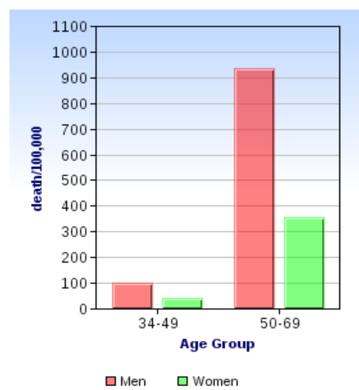

Figure 1: CVD Mortality Rate in Canada [3].

Similarly, heart disease is also the leading cause of death in Malaysia, according to Datin Dr Liew Yin Mei, the Medical Director of the Heart Foundation of Malaysia [7]. In the year 2009, statistics from the Ministry of Health estimated that one in four deaths in government hospitals was associated to either heart attacks or strokes. Dr Liew added that local statistics show that heart disease risk factors, such as obesity, hypertension, diabetes and high cholesterol levels are on the rise. In Malaysia, one in four women dies of a heart attack [5], a trend that has remained consistent over the last decade. The total number of deaths attributed from heart disease is reportedly 2.5 times higher than that of all types of diseases combined.

The worry comes when the WHO had predicted that by 2030 there will be more than 23.3 million deaths annually from CVDs which indicates that we will need a better and faster system to detect cardiac irregularities and identify which class of disease they belong to. High mortality level that root from heart diseases will stunt the economic growth of a country. The failure to identify a person with heart disease faster may risk the person’s chance to live longer. Therefore, this paper will propose a more efficient and quicker technique to detect heart irregularities by using Cardioid based graph approach.

The remaining sections in this paper are structured as follows; the next section will review the related works on heart abnormalities classification technique. Later, Section 3.0 elaborates more on the method of the study which includes the data collection procedure, pre-processing, feature extraction and the classification mechanism. After that, in Section 4.0, the performance of our proposed system is discussed. Last but not least, in Section 5.0, the study is concluded based on the experimentation and results in the previous section.

II. LITERATURE REVIEW

A. Fundamental of PPG Signal

Photoplethysmogram (PPG) signals is obtained using pulse oximeters to monitor the blood pressure which are non-invasive devices. Figure 2 (a) shows how the PPG is measured and Figure 2 (b) shows the received signals [8].

Figure 2 (a): Fingertip is attached with pulse oximeter to monitor the blood pressure [8].

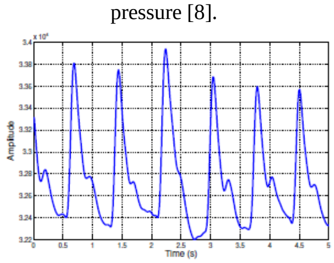

Figure 2 (b): The PPG signals obtained.

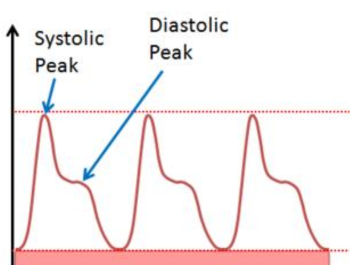

Figure 3: Systolic and diastolic peaks of PPG signals

The heart pumps the blood to all areas of human body by the arteries. Blood pressure is pushed against the walls of the arteries. Systolic pressure is where the maximum blood pressure occurs when the heart is pumping in and diastolic pressure is at the lowest blood pressure when the heart is resting. Figure 3 shows the location of systolic and diastolic peaks on PPG signals. The waveform imitate the fluctuations in blood volume which is triggered by blood vessel expansion and contraction [9].

B. Related Work

In the past decades, there exists a variety of methods introduced to determine the heart's activity. The most widely used technique is analysing the ECG signal. From the ECG readings, a medical practitioner is able to identify abnormalities in the heart waveform.

Bolanos et al. [10] explored the potential use of PPG signal in determining HRV and how it relates to ECG-derived HRV in healthy individuals. This study was performed on two healthy individuals, 1 male and 1 female with ages of 24 and 25 respectively. The data were recorded for 5 minutes and 3 times per subject. In order to derive and compare different measures from both ECG and PPG signal, autoregressive (AR) modelling, Poincare' plots, cross correlation, standard deviation, arithmetic mean, skewness, kurtosis, and approximate entropy (ApEn) were used. The results show that the correlation coefficient deviate only 1% in the first subject and 5% in the second subject from a correlation coefficient of 1 which indicates almost perfect match between the repeated tests. The Pointcare' plots of average PPG HRV and average ECG HRV shows that the heart rate intervals cluster together in common region which indicates that PPG signal provided equivalent HRV data as derived from the ECG data.

Rubins et al. [11] performed a study which shows that PPG method may have the potential to discover and evaluate arterial heart diseases related with increasing arterial stiffness. Digital volume pulse (DVP), pulse cycle duration (T), augmentation index (AIx), reflection index (RI) and transit time of reflected wave (RTT) were assessed in every heartbeat cycle. A total of 174 volunteers participated in this study which consists of three main groups. The first group comprises of 46 healthy subjects of age range between 23 to 35 years old, whereas the second group involves 26 healthy subjects of age range between 63 to 76 years old. On the other hand, the third group is made up of 102 patients with age range between 60 to 80 years diagnosed with cardiovascular disease. The measurements were conducted in room temperature in a sitting position for 1 minute continuously. The results show a clear dissimilarity between the three subject groups. For older and patients with cardiovascular disease, AIx showed higher values as compared with healthy young subjects. The values of RTT decreased for higher pulse rate (or lower T) and showed lower values for patients with cardiovascular disease. Standard deviation of RTT shows greater value for patients in the third group. This study shows that all parameters are in one way or another related to each other and has the potential to be used in primary vascular diagnostic.

Bonissi et al. in [8] suggest the continuous identification method based on PPG signals. As mentioned in [9], pulse oximeter is sensitive to the user's movements. Therefore, it is crucial to find a technique which can solve this problem. They study implemented a basic automated approach to remove unwanted samples which is low in quality. For signal processing, high pass Butterworth filter is applied and the feature were extracted using modified Pan Tompkins algorithms. Based on the study, the experiment shows that, by using specific algorithm that is maximum cross-correlation, the accuracy of the biometric identification can be increased. The results also show the accuracy of the proposed method after being tested within different time period which suggests PPG signals have sufficient distinctiveness to be applied in biometric recognition techniques. However, according to this study, the feature analysis gives low durability and can be improved if continuous enrollment method is adopted.

However, based on our knowledge, the previous works were incapable of identifying heart diseases using Cardioid based graph technique. The function of this approach is to identify individual which can be further expanded in the domain of classifying heart diseases due to the consistency of abnormal heart morphology and visible abnormal cardiac irregularities detection using Cardioid based graph method. Thus, in this study, we will propose of using Cardioid based graph to detect and identify heart abnormalities by using PPG.

III. Methodology

Figure 4 summarizes the proposed identification system which consists of the Data Collection, Pre-processing, Feature Extraction and Classification stages. Each stage will be elaborated further in the next sub-sections.

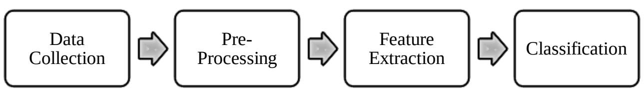

Figure 4: The proposed method used for PPG based heart abnormality detection technique

A. Data Collection

In this study, PPG signals were obtained from Physionet, which is an online public database with a sampling rate of 250 Hz. A total of 10 PPG signals with both normal and abnormal waveform are selected from MIMIC II Waveform Database, Version 3, Part 1 which consists of physiological signals of patients from intensive care units suffering with various types of heart abnormalities.

B. Pre-processing

Raw PPG signals contains a lot of undesirable signals for instances noise and baseline wandering which is produced by the contiguous environment during PPG signal acquisition. For the pre-processing stage, Butterworth filter which is a low pass filter is used to filter out these unwanted signals. The filter is a form of signal processing technique intended to have as flat a frequency response as possible in the pass band and also denoted to as a maximally flat magnitude filter. The choice of Butterworth as a filter is because it results in smooth, monotonically decreasing frequency response.

C. Feature Extraction

The next step is feature extraction, which is separated into two steps, PPG segmentation and the plotting of Cardioid based graph.

i. PPG Segmentation

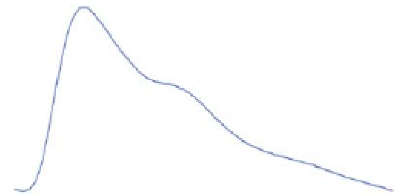

Figure 5: One cycle of a PPG signal.

Segmentation is a process to identify the starting point and the ending point of PPG signal. This process is very essential to find the distance between successive troughs and to plot the Cardioid based graph of PPG signals. Figure 5 shows one complete cycle of a PPG signal.

ii. Cardioid Based Graph

After the PPG signal is segmented, Cardioid based graph is plotted using the MATLAB software. In order to guarantee the accuracy of the classification stage, this step must be done accurately. PPG waveform can be denoted as x(t) as shown in Equation 1.

$$x(t) = \{x(1), x(2), x(3), \ldots, x(N)\} \quad (1)$$

where, x(t) = PPG signals and,
N = the total number of PPG complexes for a given period

In order to attain the points to plot the Cardioid, the PPG complexes are then differentiated as in Equation 2.

$$y(t) = x(n) - x(n-1) \quad (2)$$

where, $t = 1, 2, 3 \ldots (N - 1)$ and,
y(t) = The differentiated PPG data set.

A closed loop graph is then generated based on a scattered XY graph after obtaining the vectors of x and y. The x-axis represents the amplitude of the PPG signals, whereas y-axis represents the differentiated PPG data set. Once the Cardioid based graph has been plotted, the time series representation is lost and a closed loop is formed as depicted in Figure 6.

D. Classification

Classification stage is very significant where we can distinguish between normal and abnormal PPG signal. Based on the segmented PPG signal, the distance between troughs are calculated and based on the Cardioid based graph, the area of the Cardioid loop is computed.

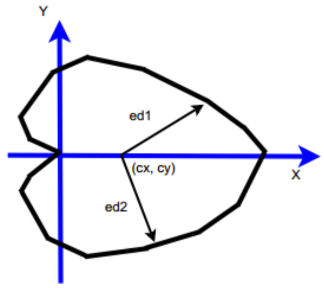

Figure 6: Cardioid based graph [12].

IV. Results And Discussion

In this section, the experimentation and result using the proposed identification system as shown in Figure 3 is described in detail. To briefly recap, the stages involved are Data Collection, Pre-processing, Feature Extraction and Classification stages. Figure 7 shows the raw PPG signal which is taken from the Physionet. As can be seen, the raw PPG signal is inconsistent in shape indicating the presence of normal and abnormal signals.

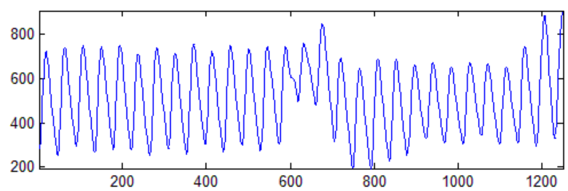

Figure 7: Raw PPG signal

In order to ensure that the signal is noise-free, the signal is then filtered using Butterworth filter. Figure 8 shows the results. The PPG signal is at the same horizontal axis. The purpose of filtering is to remove the undesirable noise such as baseline wandering produced from the movement of the body. Besides that, it is also to boost the accurateness of the quality of PPG signals. This step fulfils the second stage which is Pre-processing.

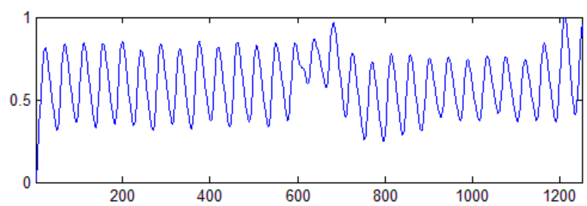

Figure 8: PPG signal after being filtered

Then, the signal is segmented to differentiate the normal and abnormal heartbeats. The purpose of this step is to calculate the differences between normal and abnormal heartbeat. Then, the distance between troughs of the segmented PPG signal is determined using MATLAB as shown in Figure 9. After this stage, the Cardioid based graph is plotted. Figures 10, 11, 12and 13 show the segmented PPG signals with the results of its area. These results are for Subject 1.

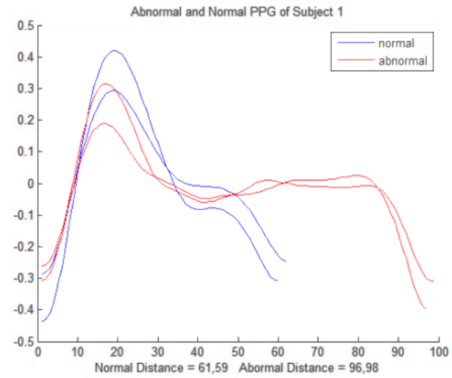

Figure 9: Segmented PPG signals with their distances between troughs for Subject 1

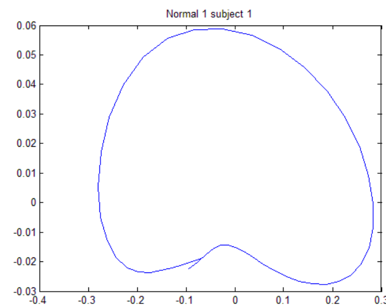

Figure 10: Normal PPG signal for Subject 1

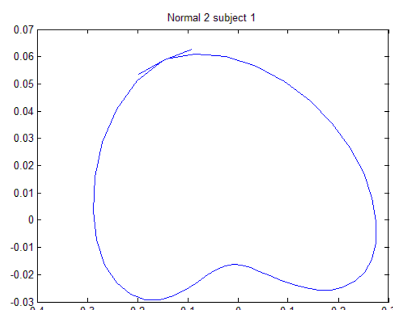

Figure 11: Normal PPG signal for Subject 1

To ensure the accuracy of the results, the segmented PPG signal in Figure 9 and its Cardioid graphs in Figure 14 are overlapped. The red lines indicate the abnormal beats and the blue line represents the normal beats. As we can observe, the distance between successive minimum troughs and the size of Cardioid graphs of abnormal beats are bigger when compared to normal beats.

Tables 1 and 2 reflect the outcomes of the distance of successive minimum troughs and area of Cardioid based graph for the entire subject tested. As can be observed, the values of the distance for normal heartbeat are smaller than the abnormal beat. Correspondingly, the similar results are true for area of Cardioid graphs. The values for normal heartbeat are lesser as equated to the abnormal heartbeat.

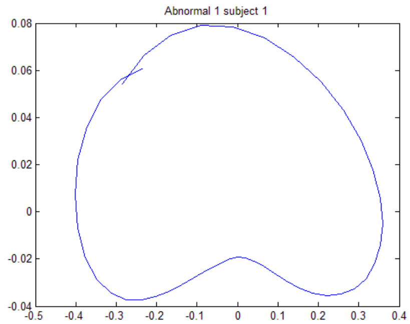

Figure 12: Abnormal PPG signal for Subject 1

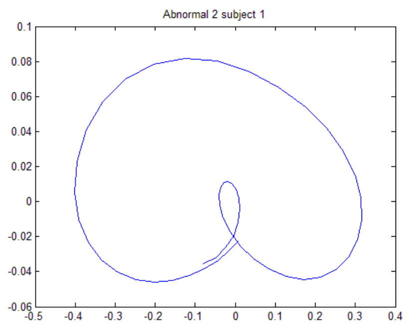

Figure 13: Abnormal PPG signal for Subject 1

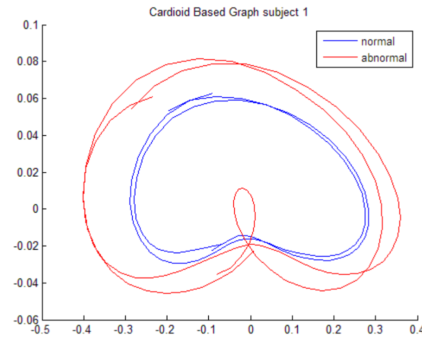

Figure 14: Cardioid Based Graph for Subject

Normal heartbeat is produced when the heart condition is stable where there is no fluctuation due to heart abnormality. Thus, the value of the distance between troughs and area will be higher when the heart abnormality arises.

V. CONCLUSION

Thus to conclude, in this study, we managed to validate an effective and precise Cardioid based graph PPG heart abnormality classification technique. In the statistical method, the distance and area values of abnormal heartbeat double the value of a normal heartbeat. All of these statistical parameters indicate the reliability of the proposed system to classify the heart abnormality. For future work, we would like to examine this technique by using real PPG data and improve the classification method in order to extemporize the accuracy of the technique.

Table 1
Distance between successive minimum troughs and average differences between normal and abnormal

Subject	Normal 1	Normal 2	Abnormal 1	Abnormal 2	Average differences between normal and abnormal
Subject 1	61	59	96	98	37
Subject 2	61	51	117	141	73
Subject 3	58	45	103	107	53.5
Subject 4	58	56	153	112	75.5
Subject 5	55	50	95	112	51
Subject 6	50	65	101	96	41
Subject 7	76	63	102	97	30
Subject 8	54	54	83	87	31
Subject 9	53	56	147	84	61
Subject 10	53	50	104	85	43

Table 2
Area of the Cardioid Based Graph

	Normal 1	Normal 2	Abnormal 1	Abnormal 2
Subject 1	0.037393	0.038774	0.067024	0.071853
Subject 2	0.104600	0.105520	0.267520	0.156680
Subject 3	0.124050	0.033255	0.298340	0.255740
Subject 4	0.024943	0.242950	0.397600	0.444700
Subject 5	0.043298	0.053438	0.136300	0.127360
Subject 6	0.039636	0.053700	0.115970	0.100830
Subject 7	0.058710	0.025651	0.186520	0.161920
Subject 8	0.064972	0.090144	0.188570	0.134840
Subject 9	0.138500	0.181330	0.271980	0.366390
Subject 10	0.021164	0.025704	0.087022	0.064642

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