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VENTRICULAR ARRHYTHMIAS CLASSIFICATION AND ONSET DETERMINATION SYSTEM

Mohd Afzan Othman*, Norlaili Mat Safri, Noraini Zakaria

Department of Electronic and Computer Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

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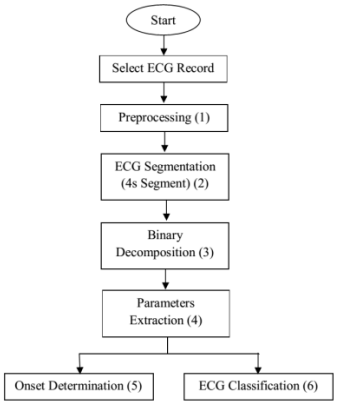
*Corresponding author
afzan@utm.my

Graphical abstract



Abstract

Accurately differentiating between ventricular fibrillation (VF) and ventricular tachycardia (VT) episodes is crucial in preventing potentially fatal missed interpretations that could lead to needless shock to the patients, resulting in damaging the heart. Apart from accurately classifying between VT and VF, the predetermination of the onset of the ventricular arrhythmias is also important in order to allow for more efficient monitoring of patients and can potentially save one's life. Thus, this research intends to focus on developing a system called Classification and Onset Determination System (CODS) that is able to classify, track and monitor ventricular arrhythmias by using a method called Second Order Dynamic Binary Decomposition (SOD-BD) technique. Two significant characteristics (the natural frequency and the input parameter) were extracted from Electrocardiogram (ECG) signals that are provided by Physiobank database and analyzed to find the significant differences for each ventricular arrhythmia types and classify the ECGs accordingly (N, VT and VF). The outcome from these ECG extractions was also used to locate the onset of ventricular arrhythmia that is useful to predict the occurrence of the heart abnormalities. All the ECGs analysis, parameters extraction, classification techniques, and the CODS are developed using LabVIEW software.

Keywords: Ventricular arrhythmias, ventricular fibrillation, ventricular tachycardia, arrhythmia classification, arrhythmia prediction, ECG

Abstrak

Ketepatan dalam membezakan antara penyakit Fibrilasi Ventrikel (VF) dan Takikardia Ventrikel (VT) adalah amat penting bagi menghalang sebarang penyalah tafsiran yang boleh menyebabkan pesakit dikenakan kejutan elektrik yand tidak sepatutnya dimana membawa kepada kerosakan jantung. Selain daripada ketepatan pengklasifikasian antara VT dan VF, masa berlakunya aritmia ventrikular juga penting dalam pemantauan pesakit yang lebih efisen. Maka, penyelidikan ini memfokuskan kepada pembangunan system yang digelar Classification and Onset Determination System (CODS) yang berupaya mengklasifikasi, mengesan dan memantau aritmia ventrikular berasaskan kaedah Second Order Dynamic Binary Decomposition (SOD-BD). Dua ciri penting (frekuensi semulajadi dan parameter masukan) diekstrak daripada isyarat elektrokardiogram (EKG) yang diperolehi daripada Physiobank bagi tujuan penganalisaan dan mencari perbezaan yang signifikan bagi mengelaskannya kepada N, VT dan VF. Hasil daripada proses ini seterusnya digunakan dalam menentukan bilakah masa bermulanya ventrikular aritmia dimana ianya berguna untuk meramalkan berlakunya abnormalisasi jantung.

Kata kunci: Aritma ventricular, fibrilasi ventricular, takikardia ventricular, klasifikasi aritmia, ramalan aritmia, EKG

1.0 INTRODUCTION

World Health Organization (WHO) has reported that more than 17.3 million people died from cardiovascular diseases (CVD) in 2008 [1]. From 17.3 million, over 80% of CVD deaths take place at low- and middle-income countries. This does not disqualify Malaysia from that list, in which the CVD mortality rates ranged from 239-362 death per 100,000 residents in males and 181-281 death per 100,000 residents in females [1]. In Malaysia particularly, the CVDs become the number one killer (Mei, 2010) and mortality numbers keep increasing every year [2].

Due to this reason, we had decided to carry out a study on CVD. This study will concentrate on arrhythmias because some of the arrhythmias are life threatening and require immediate treatment. Arrhythmia is a type of CVDs that is defined as a group of conditions in which the electrical activity of the heart is irregular that could result in the heart beating too fast or too slow than normal. During an arrhythmia, the heart is unable to pump enough blood and oxygen throughout the body. This less efficient pumping of blood and oxygen by the heart will cause lungs, brain and organs unable to work properly and shutdown or damaged.

Among of these arrhythmias, ventricular fibrillation (VF) is considered as a life threatening ventricular arrhythmia that craves for emergency treatment. VF is portrayed by chaotic contractions of the heart's ventricles, resulting in arrested cardiac pump function that can be fatal unless corrective measures are taken immediately. VF can only be treated by an electric defibrillator that delivers an electrical shock to the chest to restore the heart into normal sinus rhythm [3]. However, if ventricular tachycardia (VT) is misinterpreted as VF, the patient will receive unnecessary shock that could damage the heart. On the contrary, if VF is misclassified as VT, that will lead to sudden cardiac arrest which is life threatening. Thus making the correct and prompt detection of VT and VF is of utmost importance.

Therefore, in this study we want to develop a system that is not only capable of classifying the types of VT and VF correctly but could predetermine the onset of ventricular arrhythmias as well, so that the corrective measure can be taken promptly in order to prevent a sudden cardiac arrest.

2.0 PROJECT BACKGROUND

The introduction of automated system for arrhythmia analysis gives a fresh air in medical fields especially in diagnosing the abnormalities of the heart. Physicians no longer need to sit and read hundred thousand of ECG data in order to locate the fiducially points and calculate the parameters in order to determine whether the ECG shows any sign of cardiac disease or not. This will prevent the physicians who are always susceptible to overlook abnormal cycles due to mental fatigue after they have to interpret such large amount of data. Thus it helps to reduce the burden of physicians and improves the detection accuracy as well.

Despite the previous proposed methods by other researchers showing promising results in term of sensitivity and specificity, a few drawbacks have been identified to improve the accuracy of detection [7, 9]. Some of the proposed techniques are too complicated to be materialized in real time. For the discrimination of ventricular VT and VF signals, the detection time becomes the key factor to determine the patient's fate. According to Minami *et al.,* (1999), the time delay due to the detection of VT/VF signals must be as short as possible; otherwise, the patient is at risk of death. If the proposed technique is too complex, the processing time will be too long to be effective.

In the meantime, some of the previous methods only discriminate between normal sinus rhythm (N) and VF signals, without testing for VT [3-5]. VF must be accurately identified and discriminated from VT and N signals to prevent needless shock to the patient that could damage the heart. The accuracy of the detection technique must be as high as possible to prevent misinterpretation or false detection, which would have fatal consequences to the patient.

Albeit, some of the previous methods show promising results in discriminating between ventricular arrhythmias (V), VT and VF but they are only concentrating on recognition of the ECG arrhythmia patterns. Recognition of the signal only is not the best way to stop patient from having sudden ventricular arrhythmias attack that will lead to sudden cardiac arrest. Thus it is important to have an algorithm not only could classify between ventricular arrhythmia types but also capable to determine the onset of the ventricular arrhythmias in order to allow for more efficient monitoring of patients and can potentially save one's life.

In recent study by our group, we had proposed a new detection technique based on second order dynamic binary decomposition (SOD-BD) technique in which it studies the oscillatory behaviour patterns of cardiac contraction from the ECG signals and at the same time extract values of the parameters that determine the nature of their behaviour [7]. ECG signal consists of P, Q, R, S and T waves that represent the contraction activities of heart muscles, i.e. atriums and ventricles. Thus by using the SOD-BD algorithm, three parameters (the natural frequency, the damping coefficient and the input parameters) were extracted. These parameters could represent the behaviour pattern of ECG and determine the nature of their behaviour. In this study, we found that, the SOD-BD was capable of completely discriminating between normal rhythms and VT and VF episodes without any false detections and also distinguished VT and VF episodes from one another with a recognition sensitivity of 94.1% and 95.2% for VT and VF, respectively [7].

Thus, the significance of this research is to develop a system that not only could classify N, VT and VF

segments accurately but also could track the behaviour of ECG signals that is useful for cardiac monitoring as well. The developed system will replicate the current ECG device, not only to acquire the ECG signals, but to allow for more efficient monitoring of patients in which it can determine the onset of occurrence of ventricular arrhythmia by studying the alteration behaviour patterns of ECG signals. Thus it can potentially save one's life once VT or VF suddenly occurs, since we can take corrective measures immediately.

3.0 METHODOLOGY

The development of the system comprises those following steps:

- ECG data preprocessing
- Parameters extraction (natural frequency (ω), damping coefficient (ζ) and external input (υ)) using SOD-BD
- ECG classification
- Ventricular arrhythmia onset detection

3.1 ECG Data Processing

ECG data processing consists of two processes, one is ECG normalization and the other one is ECG filtering.

3.1.1 ECG Normalization

Since in this study three different types of Physiobank databases is used [8], thus some care need to be exercised when combining different database to the same analysis. Below are the lists of factors that need to be taken into considerations:

- Number of channel.
- Sampling rate.
- Gain.

3.1.2 ECG Filtering

A raw ECG signal is usually contaminated with noise, which affects the ability of certain ECG recognition system to recognize ECG signal patterns. Example of ECG noise include muscle noise, artefacts due to electrode motion, power line interference, baseline wander and T waves with high-frequency characteristics similar to QRS complex. Thus a filtering process is necessary to discriminate between these noises. The filtering process works as follows:

(i) First, the mean value is subtracted from ECG signals.
(ii) Second, a moving average filter of order 5 is applied to eliminate high-frequency noise, such as muscle noise.
(iii) Finally, a bandpass Butterworth filter with a pass band from 1-30 Hz will be used. A pass band from 1-30 Hz is chosen because the power spectra of normal sinus rhythm, ventricular tachycardia and ventricular fibrillation signals are reported to be within this range [3, 6].

3.3 Parameter Extraction using SOD-BD

The SOD-BD technique is a fusion of binary decomposition with second order dynamic methods [7]. The ECG segments are converted into binary pulses, b_1, b_2, b_3,..b_n (n is the number of data points) of 0-1, which were defined as follows:

$$b_n = \begin{cases} 1 & x_i > v \\ 0 & x_i \le v \end{cases} \quad [1]$$

where;
b_n is binary pulse (n = 0,1, 2, ... n).
x_i is the ECG data sample (i = 0,1, 2, ... n).
v is the threshold.

A second order dynamic is a reduced-order agent model that can be used to describe the oscillatory behaviour of a system by monitoring the behaviour patterns of semantic concept.

The output pattern of a simple second order dynamic system is defined by three parameters: natural frequency (ω), damping coefficient (ζ) and external input (υ). But in this system, we will only extracts two parameters (natural frequency and input parameters) from the second order dynamics technique, since from our finding only these parameters shows significant differences between N, VT and VF [7]. The details on the SOD-BD technique can be found in Othman *et al.,* 2013.
Parameter extraction equation for natural frequency, ω is as follows:

$$\omega_k^2 = \frac{x''(n).x''''(n) - x'''^2(n)}{x'(n).x'''(n) - x''^2(n)} \quad [2]$$

where,
n is number of sample (n = 0,1,2,…n)
k is number of coefficient (k = 0,1,2,… k)

Parameter extraction equation for input parameter, υ;

$$u(n) = \omega_k^{-2}.x''(n) + 2.\zeta_k.\omega_k^{-1}.x'(n) + x(n) \quad [3]$$

3.3 ECG Classification

The classification is based on the two parameters extracted previously, i.e. ω and υ. The threshold values are set for these parameters [7]. If the certain value falls in between, over or below these thresholds, then we can classify the types of ECG segments whether it is N, VT and VF.

Figure 1 The VI's front panel of CODS

3.4 Ventricular Arrhythmia Onset Detection

Tracking the change in behaviour of the ECG signals is essential especially when monitoring people who have cardiac arrhythmia disease. From this monitoring, we can expect what would happen next when suddenly there are slight changes in behaviour of the ECG signals. This alteration of ECG signals, either in pace form (from slow to fast) or in shape form (from normal to abnormal) can be useful to determine the onset of any abnormalities of ECG signal. Due to this reason, in the development of the system, we are trying to determine the onset of ventricular arrhythmia by calculating the rate of change of the parameters that are extracted from the second order dynamic and calculating the extracted parameters to heart rate ratio as well. We employed the differentiation technique to the extracted parameters to calculate the rate of change as follows:

$$m = \frac{\Delta y}{\Delta x} \quad [4]$$

where *m* is slope, Δ is abbreviation for change in time, *y* is the extracted parameters while *x* is the time in seconds.

Apart from that, the relationship between extracted parameters and heart rate ratio is calculated as well in order to find ratio between those two. The extracted parameters to heart rate ratio are defined as follows:

$$ratio_{parameter:hr} = \frac{extracted\ parameter}{beat\ per\ minute} * 15 \quad [5]$$

Since the heart rate is computed based on the number of heart beats per minute, so it is necessary that the extracted parameters are multiplied by 15 in order to have the estimation of the extracted parameters for 60s of segment as well because the segment duration used in the analysis is only 4s epoch.

4.0 RESULTS AND DISCUSSION

Finally, the classification and onset determination system (CODS) is developed using a LabVIEW software based on the SOD-BD analysis and ventricular arrhythmia onset detection that has been conducted previously [7, 9]. Figure 1 illustrates the VI front panel of the developed system. From the VI front panel figure, the CODS is divided into six components denoted as A, B, C, D, E and F. A is a file path in which is used to select the desired ECG record that we want to analyze or we can switch to real-time recording by placing the electrodes on the skin. B is a waveform graph used to demonstrate the form of the ECG signals that have been selected from A.

C and D are plotting graphs that indicate and track the amplitude distribution and ratio of the extracted parameters (natural frequency and input parameter), respectively. E shows the graphs of the

changes in rate of ω and υ parameters. C, D and E are used to track any signs of abnormalities by studying the alteration of ECG signals from normal to abnormal rhythm, which are useful in determining the onset of the ventricular arrhythmias. Finally, F highlights the type of ECG signals that is automatically classified by the CODS. If the system detects the ventricular tachycardia episodes, the VT's light emitter diode (LED) turns from green to yellow. If the CODS detects the ventricular fibrillation episodes, the VF's LED turns from green to red colour. Both LEDS remain green when normal sinus rhythm is detected by the system.

In the LabVIEW, the source codes are illustrated in the form of block diagram instead of typical syntax coding such C language or Matlab. Thus it is easy to understand and implement by individuals not familiar and has less knowledge in programming. Figure 2 shows the VI source codes for CODS. As we can see, the VI comprises of six main modules; pre-processing symbolized as 1, segmentation denoted as 2, binary decomposition represented as 3, parameters extraction by second order dynamic algorithm denoted as 4, followed by onset detection that is represented by 5 and finally VT/VF classification module denoted as 6.

In the pre-processing module, the ECG sampling and ECG filtration processes have been conceded in order to ensure the ECG used for analysis are sampled at similar sampling rate and noise free as well. The filtered ECG is then segmented into 4s ECG segment in the segmentation module before decompose into binary signals in the binary decomposition module. Three significant parameters were extracted from these binary signals by second order dynamic algorithm in module 4 and then were analysed for onset determination in module 5. The onset determination module will give us indicator whenever the onset of ventricular arrhythmia is detected by displaying the graphs as seen in the Figure 1 that were denoted by C, D, E and F. Finally, the VT/VF classification module will classify the ECG signals whether it is N, VT or VF by switching the LEDs into its designated colours. The details VI's codes for each module can be referred in the appendix. Figure 3 shows the finalized flow chart of CODS.

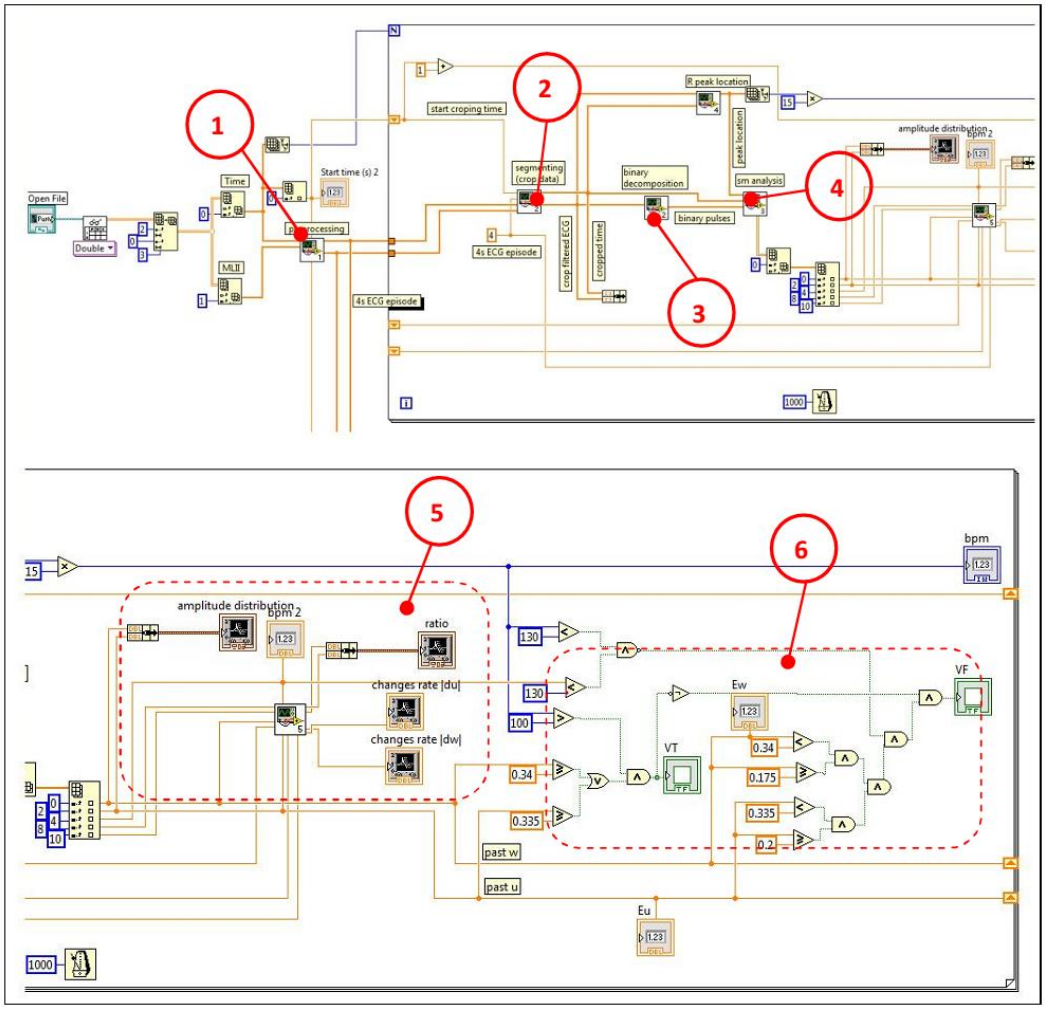


Figure 2 The VI's source code of VT/VF CODS

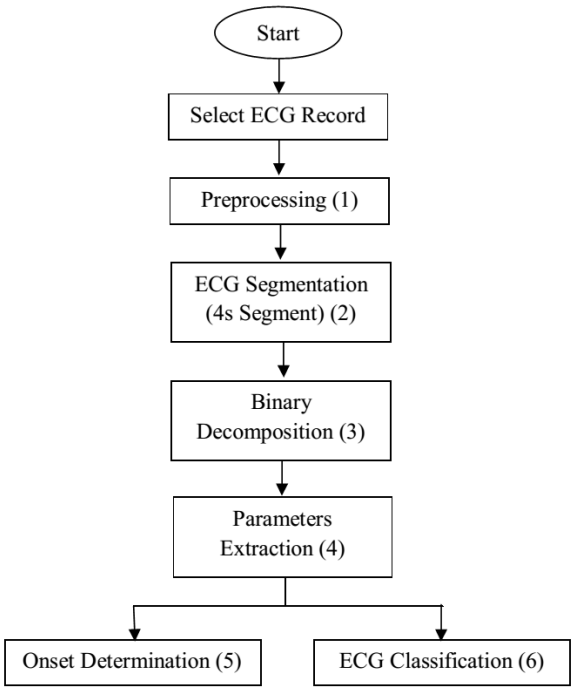


Figure 3 Flow charts of VT/VF CODS

5.0 CONCLUSION

This paper presents a successfully developed ventricular tachycardia and ventricular fibrillation classification and onset determination system (CODS) by combining SOD-BD and ventricular arrhythmias onset determination techniques in one system. This CODS is not only capable of classifying between N, VT and VF accurately, but has the ability to determine the onset of ventricular arrhythmias as well. These abilities are useful for monitoring and tracking patients who having cardiac vascular disease especially for those who suffer from ventricular arrhythmias.

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