Wavelet Decomposition for Detection and Classification of Critical ECG Arrhythmias

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Abstract: - This paper presents an algorithm based on the wavelet decomposition, for feature extraction from the ECG signal and recognition of four types of Ventricular Arrhythmias. A set of Discrete Wavelet Transform (DWT) coefficients, which contain the maximum information about the arrhythmia, was selected from the wavelet decomposition. The algorithm is applied on the ECG registrations from the MIT-BIH arrhythmia and malignant ventricular arrhythmia databases. We applied two different wavelets in our algorithm and the results were compared. The wavelet decomposition enabled us to perform the task with small amount of information.

Key-words: - ECG, Ventricular Arrhythmia, Wavelet Decomposition, Daubechies, Cubic Spline Wavelets

1. Introduction

The cardiac disorders which are life threatening are the ventricular arrhythmias such as Ventricular Tachycardia (VT), Supra Ventricular Tachycardia (SVT), Ventricular Fibrillation (VFIB) and Ventricular Flutter (VFL). The classification of ECG into these different pathological disease categories is a complex task.

Successful classification is achieved by finding the characteristic shapes of the ECG that discriminate effectively between the required diagnostic categories. Conventionally, a typical heart beat is identified from the ECG and the component waves of the QRS, T and P waves are characterized using measurements such as magnitude, duration and area (Fig.1).

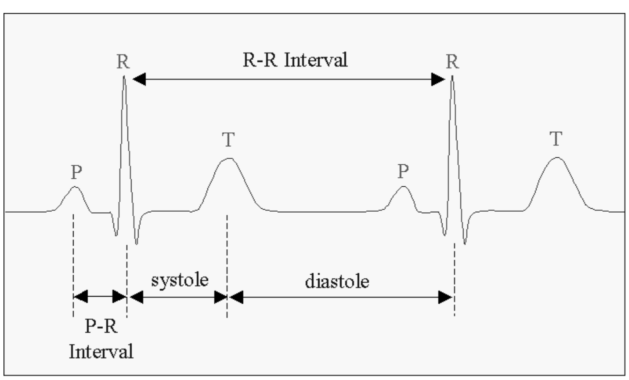

Fig.1. Normal ECG Waveform

In an arrhythmia monitoring system or a defibrillator, it is important that the algorithm for detecting ECG abnormalities should be reliable. The patient will be loosing a chance of treatment if the system is not able to detect the arrhythmia. Also a false positive detection will initiate a defibrillator to give improper therapeutic intervention. Both situations are linked with the patient's life.

Computer based classification algorithms can achieve good reliability, high degree of accuracy and offer the potential of affordable mass screening for cardiac abnormalities.

Among the various algorithms used for this task, Wavelet Transform is quite efficient since the discrete Fourier transform only permits analyzing a discrete time signal using frequency components. The Discrete Wavelet Transform (DWT) has been recently used for analyzing, decomposing and compressing the ECG signals [1].

The wavelet transforms make possible, the decomposition of a signal into a set of different signals of restricted frequency bands. Wavelet processing can be considered as a set of band pass filters [2]. Moreover, the discrete wavelet transform corresponds to a multiresolution analysis [3] which can reduce the redundancy of each filtered signal so that the processing algorithm can be applied effectively to a small data subset of the original signal.

In our study, an algorithm is implemented to detect and classify ventricular tachycardia (VT), Supra Ventricular Tachycardia (SVT), Ventricular Fibrillation (VFIB) and Ventricular Flutter (VFL) using wavelet decomposition.

Compared to the other existing arrhythmia detection and classification algorithms which use DWT, our proposed algorithm uses as small an amount of data as possible, not compromising on the quality of results. Our algorithm uses less than 15% of original data. A total number of 74 ventricular arrhythmia episodes taken from MIT-BIH arrhythmia and malignant ventricular arrhythmia databases were used to test our algorithm.

The analysis is done using Daubechies 4 wavelet and Cubic Spline wavelet.

2. Ventricular Arrhythmia

Arrhythmias are the abnormal rhythms of the heart. They cause the heart to pump the blood less effectively. Most cardiac arrhythmias are temporary and benign. The ventricular arrhythmias are life threatening and need treatment. Such ventricular arrhythmias are Ventricular Tachycardia, Supraventricular Tachycardia, Ventricular Fibrillation and Ventricular Flutter.

Ventricular Tachycardia (VT) is a difficult clinical problem for the physicians. Its evaluation and treatment are complicated because it often occurs in life-threatening situations that dictate rapid diagnosis and treatment. Ventricular tachycardia is defined as three or more beats of ventricular origin in succession at a rate greater than 100 beats/minute. There are no normal-looking QRS complexes. Because ventricular tachycardia originates in the ventricle, the QRS complexes on the electrocardiogram are widened (>0.12 seconds). Ventricular tachycardia has the potential of degrading to the more serious ventricular fibrillation.

A Supraventricular Tachycardia (SVT) is a rapid rhythm of the heart in which the origin of the electrical signal is either the atria or the AV node. Symptoms can come on suddenly and may go away by themselves. They can last a few minutes or as long as 1-2 days. The rapid beating of the heart during SVT can make the heart a less effective pump so that the body organs do not receive enough blood to work normally. The pulse rate will be in the range of 140-250 beats per minute. The QRS complex has normal duration unless bundle branch block is present. When P waves are identifiable, the P wave morphology is often different from sinus P wave morphology, and the P wave may precede, coincide with or follow the QRS complex.

Ventricular fibrillation (VFIB) is a condition in which the heart's electrical activity becomes disordered. During Ventricular fibrillation, the heart's ventricles contract in a rapid and unsynchronized way. It is a medical emergency. If this condition continues for more than a few seconds, blood circulation will cease, as evidenced by lack of pulse, blood pressure and respiration, and death will occur.

Ventricular flutter (VFL) is a tachyarrhythmia characterized by a high ventricular rate with a regular rhythm (Fig. 2). The ECG shows large sine wave-like complexes that oscillate in a regular pattern. There is no visible P wave. QRS complex and T wave are merged in regularly occurring undulatory waves with a frequency between 180 and 250 beats per minute. In severe cardiac or systemic disease states, ventricular tachycardia can progress to ventricular flutter, then to ventricular fibrillation.

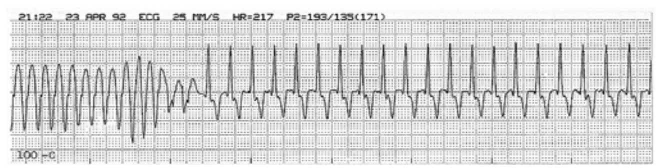

Fig.2. Ventricular Flutter followed by Ventricular Tachycardia

3. Wavelet Decomposition

The discrete wavelet transform (DWT) makes possible, the decomposition of ECG at various scales into its time-frequency components. In DWT two filters, a low pass filter (LPF) and a high pass filter (HPF) are used for the decomposition of ECG at different scales. Each filtered signal is down sampled to reduce the length of the component signals by a factor of two. The output coefficients of LPF are called the Approximation while the output coefficients of HPF are called the Detail. The approximation signal can be sent again to the LPF and HPF of the next level for second level of decomposition; thus we can decompose the signal into its different components at different scale levels.

Fig.3 shows the decomposition process of a signal into many levels. The details of all levels and the approximation of the last level are saved so that the original signal could be reconstructed by the complementary filters. The reconstructed signals at each level are represented by the notations D1, D2, D3 and so on.

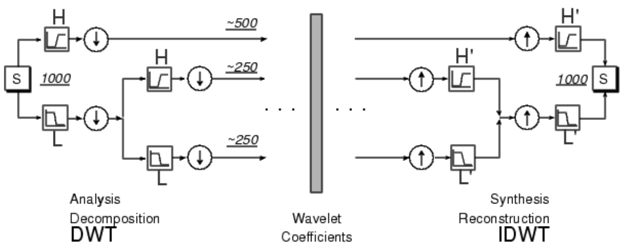

Fig.3. Wavelet Decomposition and Reconstruction

Fig.4 shows the ideal frequency bands for a sampling frequency of 360 samples/second. Depending on the scaling function and the mother wavelet, the actual frequency bands and consequent frequency selectivity of the details are slightly different.

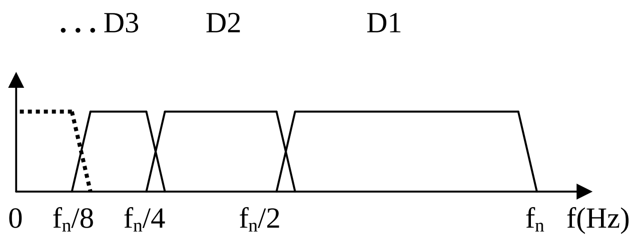

Fig.4. Ideal frequency bands for the various details

4. Algorithm for Detection and Classification

In this section we present the algorithm which efficiently detects and classifies the various ventricular arrhythmias with small amount of information extracted from the original data.

4.1 Description of the Algorithm

Most of the energy of the ECG signal lies between 0.1 Hz to 40 Hz [4]. The detail information of levels 1 and 2 (D1 and D2) are not considered, as the frequencies covered by these levels are higher than the frequency content of the ECG.

Some researchers have used D2, D3 and D4 signal details to detect QRS complexes [5]. But the amount of data in D3 is twice large as in D4 and is a large portion of the total signal data. In order to process as few data as possible, we choose not to analyze the D3 data.

Hence, our algorithm processes only the details at levels 4, 6 and 7, represented by the notations D4, D6 and D7. For the detection and classification of the ventricular arrhythmias, our algorithm follows the steps mentioned below.

- The ventricular fibrillation (VFIB) and ventricular flutter (VFL) have almost similar characteristics. The algorithm first detects ECG episodes that are potentially VFIB and VFL using the details D4 and D6.
- The algorithm then classifies each detected episode either as VFIB or VFL.
- Since the detection of QRS complexes are essential for the detection of ventricular tachycardia (VT) and supra ventricular tachycardia (SVT), our algorithm uses D4 for QRS complex detection.
- After detecting QRS complex, we classified the tachycardia into either VT or SVT by analyzing the details D6 and D7.
- Any portion of ECG signal that has no detected ventricular arrhythmia is considered to be a normal rhythm.

4.2 Methodology

The methodology based on the above mentioned algorithm to detect and classify the life threatening ECG ventricular arrhythmias is explained here.

4.2.1 VFL/VFIL

The ventricular fibrillation and ventricular flutter have frequencies in the range 2 to 5 Hz [6]. Their details can be obtained from D6 (2.875 to 5.75 Hz). The detail D4 has low peak values for VFIB and VT and has high values for VT, SVT and normal rhythm. This is because the frequency spectrum of the signal containing the primary energy of the QRS complex is located in the range 0.5 to 30 Hz [7].

Hence, to find out whether the ECG contains VFIL or VFL, the valley points are detected with our algorithm where the amplitude of D6 is lower than a fixed threshold. The algorithm also checks whether there is a signal above a different fixed threshold level in D4 within a prescribed interval. Based on the energy distributions in the frequency domain, the algorithm differentiate between VFIB and VFL. The energy ratio of D4 to D6 for VF episodes is larger than for VFIL episodes. Therefore comparing the energy ratio of D4 to D6 we could be able to classify the episode as either VFIL or VFL.

4.2.2 QRS Complex
As mentioned in section 4.1, we used only D4 to detect QRS complexes. The positions of R waves are estimated by squaring the D4 signal point-by-point and applying a moving window integrator. An empirically determined fixed amplitude threshold is used to locate local maxima that are considered as QRS complexes.

4.2.3 Ventricular Tachycardia
Ventricular tachycardia (VT) is characterized by very low amplitude S wave and a very fast heart rate. In our algorithm, the amplitude S wave is detected in D6 or D7.

Our algorithm checks whether there is a signal below a predefined threshold in D6 or a different threshold in D7 within certain interval following R wave. The algorithm declares a VT episode based on the interval between adjacent detected VT beats.

4.2.4 Supraventricular Tachycardia
The characteristics of the Supraventricular tachycardia (SVT) are the much higher heart rate than the normal rhythm and the absence of P wave during the R-R interval.

When R-R interval is shorter than that for a normal rhythm, the T and P waves may appear in D6 which also depends on the type of wavelet used. To detect a SVT beat, the algorithm counts the number of peaks within the shortened R-R interval in D6. An SVT episode is decided based upon the interval between the adjacent SVT beats.

4.2.5 Wavelets Used in the Algorithm
We analyzed the problem with two different wavelets, the Daubechies wavelet and the Cubic Spline wavelet.

The Daubechies wavelet is a very popular wavelet for a diversity of applications. The Daubechies wavelet function includes partial properties for all the ECG signal requirements. For arrhythmia classification, the Daubechies wavelet of length four yielded better results.

Spline wavelet is a bi-orthogonal wavelet. They are the first derivatives of smoothing functions and are symmetrical. The higher order of the Spline wavelet results in the sharper frequency response of the equivalent FIR filter. This is always desirable in wavelet transform. But the higher order Spline wavelet is a longer coefficient series, leading to more computational time. Therefore the Cubic Spline wavelet is assumed to have the high enough order for this application.

4.2.6 Data
The MIT-BIH arrhythmia and malignant ventricular arrhythmia databases were used for the analysis [8]. The VT and SVT episodes were taken from the MIT-BIH arrhythmia database and VFIL and VFL episodes were from MIT-BIH malignant ventricular arrhythmia database. The data files from arrhythmia database were sampled at 360 samples/second and that from malignant ventricular arrhythmia database were sampled at 250 samples/second. The sampling rates of these signals were increased to 360 samples/second by zero padding. A total number of 74 ventricular arrhythmia episodes were analyzed with the help of our algorithm.

5. Results and Conclusion
The algorithm has been tested using the ECG registrations from the MIT-BIH arrhythmia and malignant ventricular arrhythmia databases. The ability of each wavelet to detect and classify the various ventricular arrhythmias was checked using the two vital parameters, sensitivity and positive selectivity.

The Daubechies wavelet has the advantage because of its shorter length, since the speed of the operation is proportional to the length of a filter. The sensitivity and positive selectivity of the Daubechies wavelet of length four, for SVT episodes, were 92% and 88% respectively. The results provided by the same wavelet for VFIB episodes were very good.

The Cubic Spline wavelet had the best results for VT episodes as this wavelet has got much better QRS complex detection ratio [9]. The sensitivity and positive selectivity for VT episodes were 93.33% and 96.67% respectively.

In our algorithm, the Daubechies wavelet of length four produced five false negatives. The algorithm failed to detect two SVTs, two VTs and one VFL. In three cases, the algorithm misclassified the normal rhythm as ventricular arrhythmia.

The Cubic Spline wavelet produced seven false negatives. It failed to detect three VFLs, two SVTs and two VTs. In five cases, the algorithm misclassified the normal rhythm as ventricular arrhythmia.

Eventhough the Cubic Spline wavelet produced better results for VT episodes and it has good overall positive selectivity, the Daubechies wavelet of length four gives the best overall sensitivity (Table 1).

Compared to the existing techniques to detect and classify the ventricular arrhythmias, the results obtained in our algorithm were not much impressive. But the advantage is that we used lesser amount of information and were able to get reliable results. When the signal is decomposed into each level, the length of the detail becomes about half for each decomposition. Infact, the length of the detail is a bit larger than half due to convolution operation in the filtering process. The percentage of data what we used in detecting and classifying the ventricular arrhythmias is just 10.3% of the original data.

Conclusively, a reliable method for the detection and classification of ventricular arrhythmias such as VT, SVT, VFIB and VFL using wavelet decomposition is proposed in this paper. With wavelet decomposition we were able to filter out less important frequency components thereby shortening the length of the data to be analyzed.

Ventricular Arrhythmia	Total Episodes	Db 4					Cubic Spline				
		TP	FP	FN	Positive Selectivity (%)	Sensitivity (%)	TP	FP	FN	Positive Selectivity (%)	Sensitivity (%)
VT	30	28	06	02	80	93.3	29	02	01	93.33	96.67
SVT	25	23	03	02	88	92	23	03	02	88	92
VFL	15	14	00	01	100	93.3	12	03	03	80	80
VFIB	04	04	00	00	100	100	03	00	01	100	75
Total	74	69	09	05	87.83	93.24	67	08	07	89.19	90.54

Table 1: Test results showing the sensitivity and positive selectivity of different wavelets

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