Signal Processing Algorithms for Analysis of ECG for Classification of Cardiovascular Diseases

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Abstract— **Cardiovascular diseases are becoming a common cause of health concern around the world. The criticality of disease calls for accurate diagnosis and correct and timely treatment. ECG is the most widely used vital signal today which gives accurate information about the cardiovascular functioning. Since recording and interpreting an ECG need skilled physicians. Thus is a need to develop an automatic diagnostic system. This paper presents a systematic overview of diagnosis techniques of cardiovascular diseases using ECG.**

***Keywords—ECG, RR-interval, QRS complex*. Wavelet transform, arrhythmia, ICA**

I. INTRODUCTION

A. *The Electrical Activity of Heart*

The electrical impulse that excite the heart beat starts from the Sino Atrial node (SA) that is located at near to superior vena cava in right Atrium (RA). It is also called the heart's "natural pacemaker". This impulse / signal branches through atria & continues via the Atrio Ventricular node (AV). Simultaneously blood is pumped through the atria into the lower chambers and to the ventricles. Blood circulation in the body will get disrupted if heart beat rate becomes abnormal due to irregularity in the function of this pacem

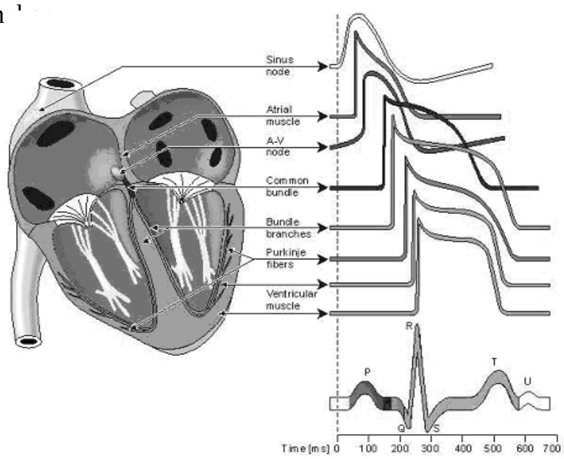

Fig 1:Characteristics waveform of ECG and their corresponding sources in heart.

B. *ECG Characteristics*

Electrical signals described above. These signals are computed by the electrocardiogram or ECG by displaying each individual heart beat as a sequence of electrical waves distinguished by crests and valleys. An ECG gives two major types of information obtained from ECG. First, the nature of electrical activity which can be slow, fast, normal or irregular is determined by time intervals obtained from the ECG signal. Second, pediatric cardiologist can obtain important information about the cardiac functioning such as size and capacity of the heart by measuring the amount of change in the electrical activity of the heart muscle,. The range of frequency of ECG signal is [0.05 – 100] Hz and its dynamic range is [1-10] mV. The ECG signal is characterized together by five peaks and valleys labeled in sequence as P, Q, R, S, T and U as shown in fig.2. Mostly , in ECG U wave are hidden by T wave and upcoming P wave. Only reliable and accurate detection of the QRS complex, as well as the P and T waves determines whether the ECG analyzing system performance is satisfactory or not. Excitation of the atria is represented by P wave. T wave and QRS complex represent the excitation of the. In automatic ECG signal analysis the detection of the QRS complex is critical. As soon as the QRS complex is obtained, a more exhaustive analysis of ECG signal, which including the heart rate & determination of ST segment, etc. can be performed. Figure 1 shows characteristics waveform of ECG and their corresponding sources in heart. Figure 2 shows typical normal ECG signal.

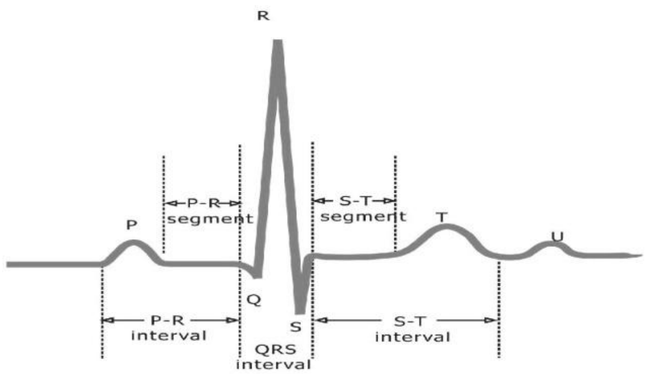

Figure 2: The elaborated ECG signal.

II. LITERATURE REVIEW

[1] Paper presented by P.D.Khandait , N.G. Bawane , S.S.Limaye deals with Wavelet Transform Techniques is used for the feature extraction in ECG signal.

[2] Paper presented by V.S. Chouhan and S.S. Mehta deals with the algorithm reported uses new modified slope feature and it overcomes the limitations and drawbacks of slope based QRS detection algorithms In the presented algorithm, smooth spike-free ECG signal is obtained by moving average filtering, which is suitable for slope feature extraction

[3] Paper presented by Stanislaw Osowski and Tran Hoai Linh studied use of fuzzy hybrid neural network containing of two sub-networks connecting the fuzzy self organizing layer performing the pre-classification task and the Multilayer Perceptron (MLP) working as the final classifier.

For classification of the ECG signals adaptive neuro-fuzzy inference system (ANFIS) can be used. [4, 5, 6, 7, 8, 9, 10, and 11]

A wavelet transform is used for the feature extraction. [12-15].

Q. Xue, Y. H. Hu, and W. J. Tompkins deals with Fast Fourier Transform, Autoregressive Modeling, and Principal Component Analysis are used for features extraction from ECG signal [6]. The features can be classified by using ANN, and two types of statistical classifiers which are minimum distance classifier, Bayes minimum distance classifier.

III. FEATURE EXTRACTION

ECG feature extraction has been studied for long time. The accurate and fast results are proposed by many advanced transformations and techniques.

This section of the paper discusses various techniques and transformations for extracting feature from ECG proposed till now & mentioned in literature.

A. *Wavelet Transform*

The wavelet transform is an efficient tool to analyze non stationary ECG signals. Which is due to time–frequency localization properties. Separation of the related ECG waveform is a morphology description. These descriptions are from the noise, interference, baseline drift, and amplitude variation of the original signal. ECG signal is decomposed using wavelet transform. Several researchers have used the appropriately scaled wavelet transform coefficients as morphological feature vectors instead of original signal time series to achieve good classification performance.[1]

The overview of the proposed system is shown in Figure 3

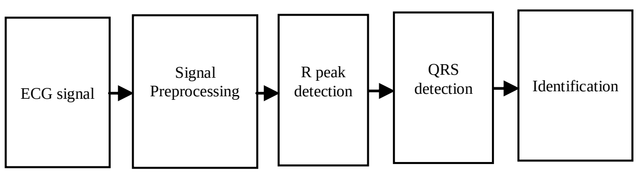

Figure 3:ECG Feature Extraction using wavelet Transform

B. *Independent Component Analysis (ICA)*

A method for finding components from multidimensional statistical data is ICA and has been extensively applied to signal processing problems in areas such as biomedicine, communications etc. It is different from other methods because it looks for factors that are statistically independent and non Gaussian [21-22].

In ICA, the observed data is assume to be a linear combination of independent latent variables such that,

$$v = A\, s \qquad (1)$$

where $v = [v_1, v_2, \ldots, v_N]$ is the vector of observed random variables, $s = [s_1, s_2, \ldots, s_N]$ is the vector of statistically independent variables called the independent components, and A is mixing matrix. If the columns of matrix A are denoted by a_i the model can be written as:

- $$X=\sum_{i=1}^{n} a_i s_i \qquad (2)$$

In this model the only vector known is x and both A and s are estimated.

The Algorithm of ICA

Several ICA algorithms are present, such as Fast-ICA [23]algorithm, also called a fast-fixed point algorithm.

Fast Fixed-Point Algorithm

The 'Fast-ICA' algorithm [24] is a highly well-organized method for obtaining ICA estimates. In this conventional methods for ICA estimation 10-100 times slower than algorithm fixed-point iteration. Fast-ICA algorithm provides a good data analysis method that can be used for both examining fashion and for estimation of independent components (or sources).

IV. ECG CLASSIFIER

A. *Correlation coefficient*

ECG results are classified on basis of the correlation coefficient approach. First, ECG data of five seconds is extracted and using the method of 'So and Chan' the features from ECG data is extracted. The aim is to identify the similarity of waveform while extracting features. The correlation coefficient is used to evaluate the similarity between typical normal beats and the test beat. The total number of computational points is only twenty. If it is similar to the ventricular premature contraction (PVC) beat, system will categorize it as PVC. If it is similar to the normal beat, system will categorize it as normal or atrial premature contraction (APC). Because the waveform of normal and APC are close to each other, further analysis is needed to see if the RR-interval duration is normal or not. If the RR-interval duration is normal, the beat is considered as normal; else it is classified as the atrial premature contraction (APC). After completing the classification of the first five seconds, the algorithm reads the next five seconds ECG data and repeats the same processes.

This system has a number of advantages such as efficiency (99.3%), accuracy (97%.) , and simplicity.

B. *Analysis In Time Domain*

By using a succession of instantaneous heart rates recorded over longer periods i.e. conventionally 24 hours more complicated statistical data can be calculated in the time-domain. They may be separated into two sections (1) NN intervals measurement is the intervals between neighboring QRS complexes which results from the depolarization of sinus node. (2) The differences between NN intervals, those are acquired by analyzing the complete ECG recording. In this work, the NN intervals are the RR interval estimated from beat to beat.

NN intervals : Standard deviation

SDNN is mathematically equal to total power spectrum. Variability in recording period is reflected by SDNN in all cyclic components. In numerous studies, SDNN is taken over a period 24 hours period and covers the higher frequency components which last for a shorter time as well as lowest frequency components within this period. Shorter cycle lengths can be estimated by reducing the monitoring period. SDNN from any arbitrarily selected ECG is not a well defined statistical quantity because it depends on the length of monitoring period. So in practice, for classification, an SDNN measures of identical duration recordings needs to be compared. However, to determine SDNN values (and similarly other HRV measures) durations of the recordings used which should be standardized.

The following parameters can be used as the statistical measures of the recorded data to derive conclusions regarding the diagnosis:

a) Standard deviation of differences between adjacent NN intervals

One of the most common measure is derived from interval differences include the standard deviation of differences between adjacent NN intervals. Standard deviation is calculated and represented by equation 3.

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \qquad (3)$$

Where $\{x_1, x_2, \ldots, x_N\}$ is the sample and $\bar{x}$ is the mean of the sample. The value of the degrees of freedom is specified by the denominator N-1 in the vector $\{x_1 - \bar{x}, \ldots, x_N -$

b) Successive difference of intervals in terms of Root mean square values

This feature can be derived by taking the square root of the squared differences of consecutive NN intervals. Calculation of root mean square is shown in equation 4.

$$x_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_n^2}{n}} \qquad (4)$$

The rms value for a collection $\{x_1, x_2, \ldots, x_N\}$ is shown in equation 4.

C. *Fuzzy Classifier*

The fuzzy method is especially useful because of ease of checking, modification, and addition deletion of every fuzzy variable for a better automated analysis. The parallel reasoning is used in fuzzy method. Beat/rhythm labeling is considered before the final decision is assured by fuzzy method. In case of very high input dimension and a complicated problem, the rule frame consists of large number of fuzzy rules on a higher dimensional support. Interpretation depends more on how well the influence of the input features on the decision process is quantified. The fuzzy Cardiac arrhythmia classifier is comprises of two function blocks, ECG Parameterize and Fuzzy classifier. Work carried out in the ECG Parameterizer involves: detecting ECG features of the database using Daubechies wavelets, using these features to calculate non-linear parameters of ECG signals& classification by using input of these non-linear parameters with Fuzzy classifier. The derived parameters are exported to the latter for the classification.

D. *Adaptive Neuro-Fuzzy Inference System (ANFIS)*

ANFIS was developed as a diagnostic tool which aided physicians to classify the heart diseases. ANFIS is based on the adaptive neuro-fuzzy inference system approach in which network calculation and fuzzy reasoning are used together which helps to achieve good reasoning in quality and quantity. The objective of this approach was to classify the six types of ECG signals. ANFIS is performed using MATLAB in which feature vectors are applied as the input to the ANFIS classifier. The ANFIS network provides 128 fuzzy rules and gives one output.

V. IMPLEMENTATION

For the classification of heart diseases ECG signals are extracted from the MIT-BIH arrhythmia databases which are at frequency interval of 360 Hz.

The block diagram of the classification algorithm is shown in Figure 4. The method involves three steps: (1) preprocessing (2) evaluation of the feature vector (3) classification of ECG signal.

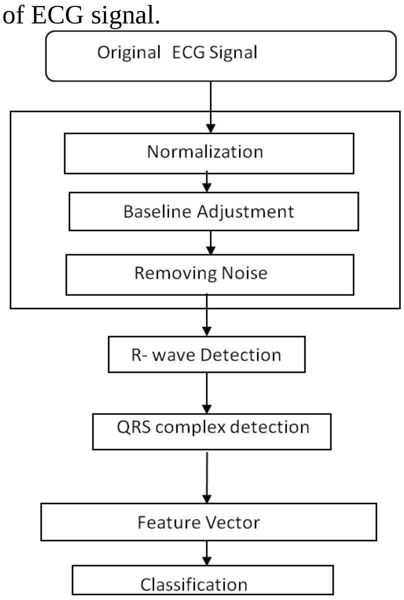

Figure 4: Proposed system for ECG beat Classification.

A. *Pre-processing*

The sample is first processed by using normalization process which helped standardization of all features to the same level. ECG signal baselines can be shifted from zero line due to unexpected conditions like patient movements therefore it can be adjusted at zero line by subtracting the median of the ECG signal. Unwanted contaminants such as noise have to be filtered from the ECG signal to get a proper output. These contaminants were filtered using Low pass filter, High pass filter and Notch filter.

B. *QRS Complex Detection*

Fig. 5 shows the peak/valley detection from the original ECG signal. The peaks and valleys (especially Q, R and S points) become more distinct after this analysis. After extracting the feature of QRS complex detection, we can analyze the feature with others methods. For example, we can perform heart rate variability (HRV) analysis on the R-R interval signal to demonstrate the state of the heart and the nerve system.

For QRS complex detection 4 steps are used:

R peak extraction

S peak extraction

Q peak extraction

QRS complex extraction

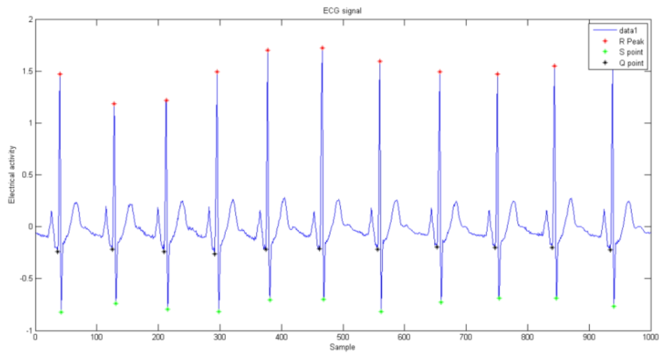

Fig. 5 Typical peak representation of normal ECG Signal

The extraction of characteristics point sis done the following way:

- R peaks are extracted as the highest or maximum peaks in ECG signal which is present in each beat. Using this condition asterisk signs shown in red colour show all the R peaks value.
- S peaks is extracted as the next lowest valley after 'R'.
- For the detection of Q peak values : Q peak are the immediate lowest amplitude value before R peak values.
- Two zero crossing value extracted from
- Before Q peak values
- After S peak values

Then the zero crossing values before Q peak values are subtracted from zero crossing values after S peak values. The subtraction obtained is QRS complex value. By taking average of QRS complex values and dividing it by sample frequency, output will be obtained in seconds.

C. *Heart Rate Calculation*

To calculate the heart rate ECG Signal is analyzed using Wavelet Transforms. The normal value of heart beat lies in the range of 60 to 100 beats/minute. A slower rate than this is called bradycardia (Slow heart) and a higher rate is called tachycardia (Fast heart). If the cycles are not evenly spaced, an arrhythmia may be indicated. If the P-R interval is greater than 0.2 seconds, it may suggest blockage of the AV node. The equation to calculate heart rate is given below:

- $$Heart\ Rate = \frac{1}{(R - R\ interval\ in\ sec.)} * 60$$

VI. ABNORMAL ECG SIGNAL (ARRHYTHMIA)

An arrhythmia is a problem with the rate or rhythm of the heartbeat. While an arrhythmia, the heart can beat too fast, too slow, or with an irregular rhythm. A heartbeat that is too fast is known as tachycardia. A heartbeat that is too slow is known as bradycardia. Most arrhythmia are harmless, but some can be serious or even life threatening. During an arrhythmia, the heart may not be able to pump enough blood to the body. Lack of blood flow can damage the heart, brain, and other organs.

VII. COMPARISON BETWEEN NORMAL AND ABNORMAL ECG SIGNAL

In normal ECG, the time interval between R-R is 0.6-1 second, in case of fast heartbeat the time interval is less 0.6second which is known as sinus tachycardia; in case of slow heartbeat the time interval is less than 0.6 sec that is known as sinus bradycardia. By referring Fig. 10 (a) we can saythat the R-R interval for normal case is between 0.6-1second and from Fig. 10(b) we can say that the R-R interval for abnormal (Arrhythmia signal) case is greater than 1 second that is known as sinus tachycardia abnormalities.

VIII. RESULT

Table I. highlights the difference between R-R interval and Beats per minutes which represent R-R interval, BPM for normal ECG signal and Arrhythmia signal(bradycardia and tachycardia).

TABLE I

	Normal Sinus Rhythm	Bradycardia	Tachycardia
RR interval	0.8980	1.24	0.5560
BPM	66	48.3092	107.9137

IX. CONCLUSION

The results of classifier are at the acceptable stage. It is capable to distinguish between normal and abnormal ECG. This is a important step in cardiac signal analysis. ANFIS was used as classifier to improve the classification rate. It is most suitable. The ANFIS classifier can be a diagnostic tool in the analysis of heart diseases to help the physician. The results show that the method is effective for classification of cardiac arrhythmia. The results conclude that with the help of ANFIS, it is possible to classify the cardiac arrhythmia. The advantage of the ANFIS classifier is ease of implementation And its simplicity.

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