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ANN based Prediction of Cardiac Arrhythmia

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Abstract: Cardiac arrhythmia is a serious and life threatening condition of abnormal heart rhythm. Cardiologists mostly rely upon Electrocardiogram (ECG) to diagnose various cardiovascular disorders. Due to various technical limitations in the visual or conventional analysis of ECG, Computer Aided Design (CAD) and analysis of ECG is introduced. Many automatic algorithms were developed for the prediction of cardiac arrhythmia from ECG signal. This paper presents a simple algorithm for the prediction of Cardiac arrhythmia from the ECG signal using Artificial Neural Network (ANN). The input to the classifier is the morphological and temporal features extracted by means of the Pan Tompkins algorithm from different ECG signals obtained from MIT-BIH arrhythmia database and PTB diagnostic ECG database. The results were evaluated in MATLAB and satisfactory results obtained with a classification accuracy of 98.8%.

Keywords: Cardiac arrhythmia, ECG, Artificial Neural Network, Confusion matrix, Classification accuracy

I. INTRODUCTION

The field of control systems has been connected to the biological systems for many decades. Nonetheless, the impact of control systems on devices and applications in the field of biology has only emerged in recent years. The medical applications of control systems technology are different from other areas due to various reasons. The field of biomedical control systems is younger compared to other fields like aerospace, automotive etc...But some noteworthy developments have emerged recently in the areas of cardiovascular systems and endocrinology, like the cardiac assist devices, artificial pancreas etc... Human heart can be structurally divided into right and left parts, each part containing two chambers- atrium and ventricle.
From an engineering point of view, the heart consists of four chamber muscular pump that beats about 72 times per minute in an average adult, circulating blood through every parts of the body. The pump acts as synchronised but functionally isolated two-stage pumps.

The first stage is the atrium which collects blood from the hydraulic system and pumps it into the second stage called the ventricle. In this process, the blood is pumped through the pulmonary circulation to the lungs and through the systematic circulation to the other parts of the body [1].

ECG or EKG is a graphical recording of the variation in voltages produced by the myocardium, with respect to the time, during the cardiac cycle. For the proper functioning of the cardiovascular system, both atria and ventricles must operate in synchronism. As shown in figure1, an ECG signal is characterised by the P wave, the QRS complex and the T wave. In order to facilitate analysis, the horizontal segment of the waveform preceding p wave is designated as the baseline.

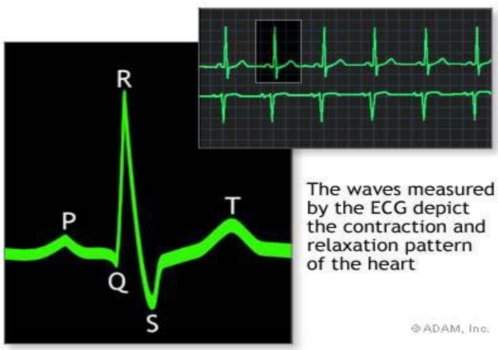

Fig. 1 A Normal ECG waveform

P wave represents the depolarization of the atrial musculature. QRS complex is the combined result of the repolarisation of atria and depolarization of ventricles. T wave represents ventricular repolarisation and U wave is assumed to be the result of after potential in the ventricles.

Usually a 12 lead ECG system is commonly used for ECG recording. Table I gives the physiological nature of a normal ECG waveform.

According to the American Heart Association, any abnormality in the normal heart rhythm is considered to be a condition of Cardiac arrhythmia. In this condition, the heart does not beat properly, which may adversely affect the other organs of the body.

Basically, cardiac arrhythmia is of two types- Brady cardia and Tachycardia. Brady cardia is a condition, when the heart rate is too low, ie. less than 60 beats per minute and Tachycardia occurs when the heart rate is too fast, ie. more than 100 beats per minute.

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TABLE I
PHYSIOLOGICAL NATURE OF NORMAL ECG WAVE

WAVES	SPECIFICATIONS
P wave	Amplitude - 0.25mV Wave interval - 0.11 sec
R wave	Amplitude – 1.6mV
Q wave	Amplitude – 25% of R wave
T wave	Amplitude – 0.1 – 0.5 mV
P-R interval	0.12 t0 0.2 sec
Q-T interval	0.35 to 0.44 sec
S-T interval	0.05 to 0.15 sec
QRS interval	0.09 sec

Ventricular tachycardia and ventricular fibrillation causes sudden cardiac arrest, which is a medical emergency. In this case, the time and mode of death are unexpected. Blood clot in the heart's upper chamber due to atrial fibrillation, may lead to stroke, which affects the blood vessels supplying blood to the brain. It has been reported that the graph of mortality due to cardiac arrhythmia is rising up every year. So advancement in technology for the earlier diagnosis and cure of arrhythmia is required.

ECG is used clinically in diagnosing various disorders associated with the heart. Cardiologists significantly analyse the shape and duration of each wave of the ECG. If the cycles are not evenly spaced, arrhythmia may be indicated. But presently, the visual or conventional analysis of ECG consumes more time and lack accuracy. Hence the necessity of a highly accurate automated system leads to the development of computer aided design and classification of cardiac arrhythmia.

II. LITERATURE REVIEW

Many automatic algorithms were developed for the classification of heart beats for the detection of cardiac arrhythmia from ECG signal. In most of the works, the features extracted from the ECG were considered as the input to the classifier. Various feature extraction techniques including Hilbert transform, Fourier transform, Wavelet transform etc... and various classifiers including ANN, support vector machines, fuzzy nearest K controllers etc...has been utilized in most of the cases.

[3] deals with improved ECG feature extraction using wavelet transform (WT) technique, which may be utilized for the detection of cardiac arrhythmia. Here they made use of the MIT-BIH arrhythmia database and an algorithm for R peak and QRS complex detection were developed. A beat classification accuracy of 98.17% has been achieved. The main advantage they have presented here is lesser time consumption for the analysis of longer duration ECG signal. [4] proposes a neural network based classification algorithm for the classification of paced beat, atrial premature beat as well as normal signal. This algorithm uses the feature extracted by means of discrete wavelet transform (DWT) in order to train the multilayer perceptron neural network (MLPNN) and the classification accuracy is obtained as 96.5%.

In [5] a MLPNN is used as a classifier for the prediction of cardiac arrhythmia. In this case, the heart rate variability (HRV) and R-R interval are obtained from the ECG signal. The linear and non-linear parameters of HRV are used as the input to train the neural network. Here a classification accuracy of about 97% is obtained.

[6] presents a method for the analysis of ECG wave, extract features from it for the classification of heart beats according to different classes of arrhythmia. In this case Fast Fourier Transform (FFT) is used for the noise removal and a feed forward neural network is used for the classification of arrhythmia efficiently. The main advantage presented in this work is that it can identify and predict features even from highly abnormal ECG wave.

In [7] three different NN models are considered for the classification of arrhythmia as normal and abnormal, ie. MLPNN, Generalized feed forward neural network and modular neural network. This is a comparative study and from the analysis result, it is very clear that the MLPNN operate as an excellent classifier for the given arrhythmia classification task with a classification accuracy of 86.65%.

[8] deals with the development of an efficient arrhythmia detection algorithm using ECG signal. Here android is proposed to be the mobile monitoring terminal and the ECG device is wirelessly connected to a smart phone using Bluetooth.

In [9], a four layer feed forward neural network is used for the classification of arrhythmia from the statistical features extracted from the ECG. WT is utilized for the noise removal in this case and a classification accuracy of 90.56% is obtained.

[10] deals with an algorithm to detect and classify the given ECG signal as arrhythmic or normal. In this work, various morphological and temporal features are extracted from each ECG signal obtained from MIT-BIH arrhythmia database and compared with the normal values. The algorithm is tested and detailed results are provided.

[11] presents an efficient software tool based on MATLAB GUI to classify arrhythmia from ECG input. The features are extracted using Discrete Wavelet Transform (DWT). The tool is tested using MIT-BIH arrhythmia database and Creighton University arrhythmia database and an accuracy of 86.61% is obtained.

III. ECG DATA ACQUISITION

A. MIT-BIH Arrhythmia Database

The MIT institute in collaboration with Boston's Beth Israel Hospital (BIH) developed a standard database in 1980 for the detection of cardiac arrhythmia. It is considered to be the first generally available set of standard data for the evaluation of arrhythmia detectors and other related research works.

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In this study, the MIT-BIH arrhythmia database is considered for both training as well as performance evaluation of the proposed system. The arrhythmia database contains 48 records, each containing a two channel ECG signal of 30 minutes duration selected from a 24 hours recording of 47 individuals. These continuous ECG signal is band pass filtered at 0.1 to 100 Hz and then digitized at 360 samples per second per channel with 11 bit resolution over a 10 mV range.

Among these 48 arrhythmia data, 40 data are considered for the training purpose. Usually, about 3/4th of the testing data will be considered from the training set. Here 28 arrhythmia data are included in the test set. Among them 20 data are considered from the training set.

B. PTB Diagnostic ECG Database

Physikalisch – Technische Bundesanstalt (PTB), the national metrology institute of Germany has provided a compilation of digitized ECGs, which can be utilized for research, algorithmic bench–marking or teaching purposes. The ECGs were collected from healthy volunteers and patients with different heart diseases. Among these, 52 healthy controls were considered and a total of 68 normal ECG data were collected.

The ECGs were obtained using a PTB prototype recorder with 16 input channels of input resistance 100 Ω. Each signal is digitized at 1000 samples per second, with 16 bit resolution over a range of ±16.384 mV.

Among the 68 normal ECG data, 40 data are considered for the training purpose. Here 48 normal data are included in the test set. Among these, 20 data are considered from the training set.

IV. EXPERIMENTAL PROTOCOL

Block diagram of the proposed method is shown in the figure 2. The real time ECG signal is initially read by means of certain MATLAB codes. Using Pan Tompkins algorithm, each signal is filtered, processed and required features are extracted. QRS amplitude and R peak index are the outputs of the Pan Tompkins algorithm.

From these, average QRS amplitude and R-R interval are obtained and these are considered as the input to the classifier. Training data and test data are prepared in order to train and test the proposed ANN for the prediction of cardiac arrhythmia.

A. Pan Tompkins Algorithm

Pan Tompkins algorithm is considered to be one of the most effective algorithms for QRS detection. Inputs to the Pan Tompkins function are the raw ECG signal, sampling frequency and flag to plot or not plot. Here the sampling frequency is given as 360 Hz and the flag is set to 1 to have a plot. Figure-3 shows a sample of raw ECG signal given as input.

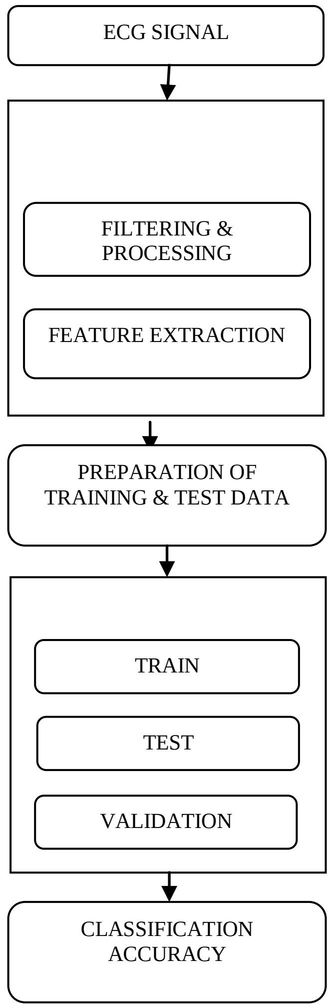

FIG. 2. PROPOSED METHODOLOGY

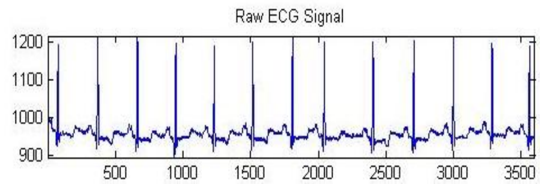

Fig. 3. Raw ECG Signal

The signal is pre-processed and filtered using a combination of low pass and high pass filters to eliminate the baseline wander, muscle noise etc...It is then band passed to cancel the noise of other sampling frequency. The signal is then passed through a derivative filter and the dominant peaks are enhanced by squaring. Figure-4 shows the filtered ECG signal.

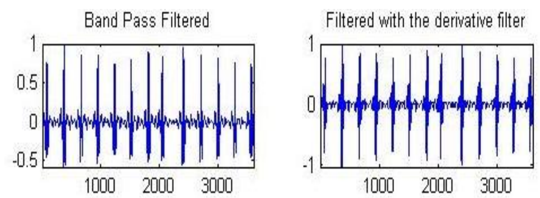

Fig.4. Filtered ECG signal

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Various thresholding techniques are adopted and QRS peak is located in the filtered signal [12]. Figure-6 shows the filtered ECG with QRS peaks detected. QRS amplitudes and R peak index are obtained as the output of the algorithm and consequently the required inputs for the classifier is obtained.

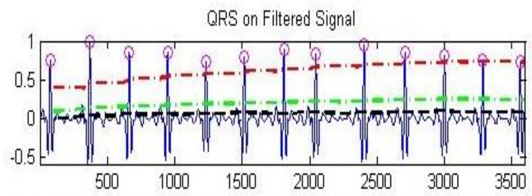

Fig. 5. Filtered ECG with QRS peaks detected

B. Preparation of Training Data and Test Data
Four sets of data have been formulated, which includes the training set, test set and the corresponding target sets. Training set and test set are considered as the input vectors fed to the classifier. Both the input vectors are 2*80 vectors, where 2 features from each of the 80 samples are given as the input to the neural network.

The target vector is supposed to be an n-dimensional unit vector, ie. of the order n*N. Here n which is the number of classes is set as 2, ie. Arrhythmic and normal. The target value for the arrhythmic data is taken as 1 and that for normal data is taken as 0. Hence the target vectors should be of the order 2*80. But the effect of using a target vector of the order 2*80 and 1*80 is observed to be same. So the target vector is finally set to be a 1*80 vector.

C. Artificial Neural Network
ANN may be defined as an information processing model that is inspired by the way biological nervous system, such as brain, process information. The simplest definition for ANN is provided by the inventor of one of the first neuro computers, Dr. Robert Hecht Nielson. He defines a neural network as, " a computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs". This model tries to replicate only the most basic functions of the brain.

The key element of ANN is the novel structure of its information processing system. An ANN is composed of a large number of highly interconnected processing elements called neurons, working in unison to solve specific problems. The major advantages of ANN include adaptive learning, self organisation, real time operation, fault tolerance capability etc...

Consider a set of neurons; say X1 and X2 transmitting signals to another neuron Y. Here, X1 and X2 are the input neurons and Y is the output neuron. Input neurons are connected to the output neuron, over a weighted interconnection links w_1 and w_2. The net input is calculated as,

$$Y_{in} = x_1 w_1 + x_2 w_2 \quad (1)$$

where x_1 and x_2 are the input signals from X1 AND X2. Then the output y can be obtained by,

$$y=f(Y_{in}) \quad (2)$$

ie. Output is a function of the net input calculated. This function to be applied over the net input is called the activation function[2].

Neural networks are typically organized in layers. Layers are made up of a number of interconnected nodes which contain an activation function. Patterns are presented to the network via the input layer, which communicates to one or more hidden layers where the actual processing is done via a system of weighted connections. The hidden layers then link to an output layer, where the output is obtained.

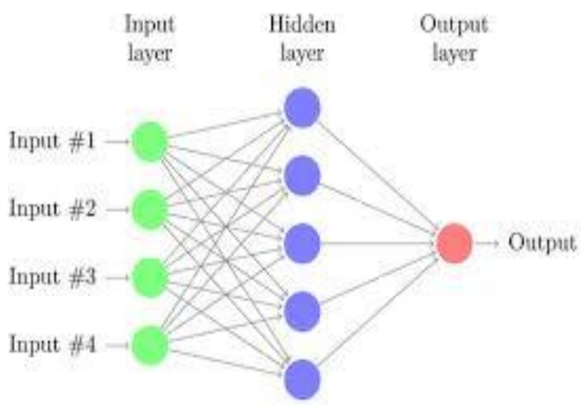

Fig. 6. Feed Forward Neural Network

Most ANNs contain some form of learning rule which modifies the weights of the connections according to the input patterns that it is presented with. The main property of ANN is its capability to learn.
Learning or training is a process by which a neural network adapts itself to a stimulus by making proper parameter adjustments, resulting in the production of desired response. Broadly there are two kinds of learning-parameter and structural learning. Apart from these, learning can be supervised, unsupervised and reinforced learning.

Here a simple feed forward network with a single hidden layer, which learns by means of the backpropogation algorithm is selected to function as the classifier. The neural network is trained by means of the nntool box and a well trained network is obtained for the testing purpose. Mean Square Error (MSE) is considered as the performance measure for training.

Figure-7 shows the regression plot of the trained network which gives better training performance. The newly created trained network is shown in figure 8.

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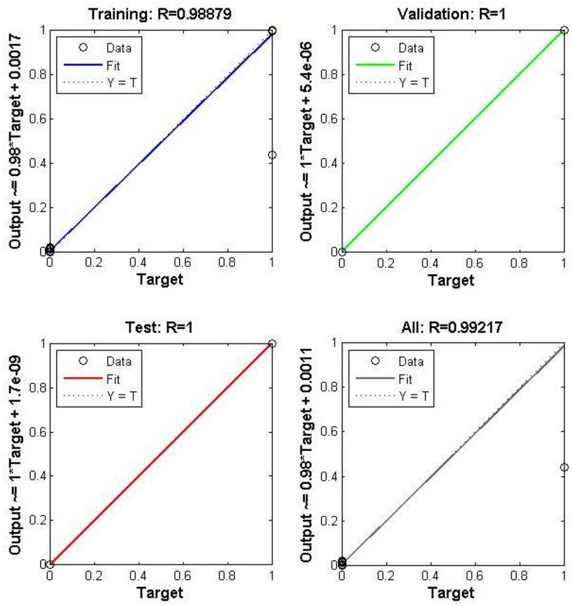

Fig. 7. Regression Plot of Trained Network

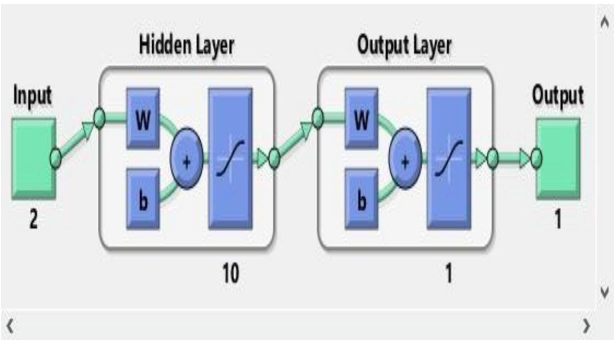

Fig. 8. Newly Created Trained Network

D. ANN Testing and Results

ANN is tested and the performance of the classifier is evaluated by plotting a confusion matrix in order to obtain the classification accuracy. Confusion matrix is also known as the error matrix. It is a specific table layout that allows visualisation of the performance of an algorithm, typically a supervised learning one. Classification accuracy is a measure of how accurate the prediction is.

$$\text{Classification Accuracy} = \frac{TP + TN}{P + N} \quad (3)$$

$$P = TP + FN \quad (4)$$

$$N = TN + FP \quad (5)$$

TP and TN are the number of true positive and true negative. FP AND FN are the number of false positive and false negative.

The classification accuracy of the proposed work is obtained as 98.8% , which is the best accuracy obtained in the prediction of cardiac arrhythmia from the morphological and temporal features of ECG using ANN.

V. CONCLUSION

In this paper, a simple as well as an efficient algorithm for the prediction of cardiac arrhythmia using ANN is proposed. The raw ECG signal obtained from MIT-BIH arrhythmia database and PTB diagnostic ECG database is filtered and the required features are extracted using the Pan Tompkins algorithm. These features are utilized for the ANN training and testing. The classification accuracy obtained is better compared to that of various literatures mentioned. The adaptive and fault tolerant capabilities of ANN make the algorithm more efficient. Obtaining much more reliable features and hence improving the classification accuracy can be considered as the future scope of this work.

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