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DETECTION OF CARDIAC ARRHYTHMIA FROM ECG SIGNALS

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ABSTRACT

The first and foremost step in the analysis of ECG for various cardiac disease is the extraction of ECG and classification of ECG based on feature extraction. The prediction of any cardiac disease will come correctly if the feature extraction and classification of ECG are correct. It is very difficult for any expert physicians to predict exactly the cardiac arrhythmia as the volume of data is huge. The monitoring of ECG signals for a long period of time is needed as the changes in ECG may occur at any fraction of time. The computer aided approach helps significantly for monitoring ECG signals for long period of time. Many methods like wavelet transform, Independent Component analysis (ICA), Permanent Component analysis (PCA), Time Domain, Wavelet Transform, Power Spectral Density and Fuzzy logic with Neural network techniques are used either separately or in combination by the Researchers for extracting features from ECG signal. It is found from this survey that among many classifiers, most of the research works uses SVM classifier as it gives high classification accuracy. It is also found from this survey that most of research work uses the ECG data from MIT-BIH database or from Physionet. The parameters which determines the suitable technique for feature extraction and classification are found to be classification accuracy, sensitivity and specificity. This paper presents a survey of various approaches used in the feature extraction and classification of ECG signals.

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KEY WORDS

Feature Extraction; Classification; cardiac arrhythmia; classification accuracy; testing data; training data

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INTRODUCTION

The main tool used in clinical practice to record the electrical activities of heart is ECG. The amplitude and interval features of ECG contains useful information for analysis. The exact identification of the heart disease depends on choosing the correct approach for extracting the features in ECG signals. ECG recording contains volumes of data which is very difficult for manual analysis by the physician. The computer aided analysis of ECG data has drawn the attention of everyone. Many researches are focused in this direction. Hanlin et.al [1] used wavelet transformation for feature extraction from 12 lead ECG signal. They used semi- supervised approach for clustering unlabeled data. Finally the SVM classifier was involved for ECG classification. Ge Dingfei [2] concentrates on the feature extraction of a cardiac abnormal condition called premature ventricular contraction (PVC) and normal sinus rhythm (NSR) and discusses in detail the discrimination between them by conducting data analysis on the data selected from MIT-BIH database. A new method known as Random Projection [7] is used for feature extraction on multi lead ECG signal which mainly concentrates on dimensionality reduction. This method is energy efficient and it is feasible to implement in portable systems for health monitoring. The structure of this paper is as follows: Section 2 discusses the preprocessing methods used to make ECG signal ready for feature extraction along with the techniques for feature extraction by various authors. Section 3 is a discussion on performance of several methods used by the researchers to achieve their goal. Section 4 reflects the research gaps in each of these research works after making a comparon of these techniques with respect to classification accuracy and data size graphically.

RESOURCES AND METHODS

Data preprocessing methods

The ECG data contains unwanted data which is due to muscle contractions, power line interference and baseline drift. The unwanted signal must be removed to get the original ECG data.

THE IIOAB JOURNAL ISSN: 0976-3104

In paper [1], the preprocessing phase comprises of elimination of noise, detection of R peaks and the segmentation of heartbeats. Here Pan Tompkins algorithm is used to find the R peaks. The research work [2] uses the data from MIT-BIH database. The baseline drift and power line interference are removed from ECG signals by a band pass filter with lower frequency pass band of 1Hz and upper frequency pass band of 35 Hz. The ECG data [3] is preprocessed to remove baseline wander and filtered with a band pass filter to remove high and low frequency artifacts. The images for five cardiac conditions namely Normal, Ventricular Flutter, Ventricular Tachycardia, Nodal and Left Bundle Branch Block were collected from physionet database in the work [4]. Totally 100 images were collected from the database. The preprocessing of ECG includes binarization, 1D signal extraction and base line drift removal with median filter. Two kinds of data is used for feature extraction and classification of ECG signals in paper [5]. In this paper the feature points positioning is also done in the preprocessing stage. The data [6] is very large and it is taken from Physiobank archive. Nearly 1200 feature vectors for each class of disease is taken. Here three sets of features are taken for time domain, wavelet transform and for power spectral density. In the preprocessing stage [7] every record consists of 15 simultaneously measured signals. Each of the signals are digitized at 1000 samples / sec and has a 16 bit resolution. The database taken from 60 subjects includes 20 records for normal sinus rhythm, another 20 records for myocardial infarction and 20 cases of cardiomyopathy. Among these 30 subjects are used for training sets and the remaining as testing sets. At any time the selected beat has 700 samples. The analysis in [8] is conducted on ECG signals from MIT-BIH Arrhythmia Database on three kinds of signals namely, the normal ECG, Premature Ventricular Contraction (PVC) and Left Bundle Branch Block (LBBB). The preprocessing phase [9] is applied to whole of the chosen database and the principle characteristics are extracted using Principal Component Analysis (PCA) technique. The tests are conducted on 4 databases randomly generated which comes around 4002 samples. Out of this, 2802 samples of each database is used for training set and the remaining 1200 samples are used as testing set. The raw ECG signal [10] is filtered in frequency domain to remove dc offset. Then fast Fourier transform (FFT) is applied to get low frequency offset removed and baseline drift at zero reference line. Again inverse FFT is applied to get preprocessed signal.

Methods of feature extraction

In paper [1], a most popular time-frequency transformation called discrete wavelet transform technique is used to map the 12 lead ECG segments into the WT space. The new method introduced in this paper called Semi-supervised discriminant analysis distinctly distinguishes the features for various diseases in the ECG segment. A new beat detection algorithm which does not affect beat shape is used in the research work [2]. This algorithm uses two feature sets of data. The first feature set includes energy of wavelet coefficients and RR ratio for the consecutive beats. The second feature set are selected by pre-selection of the coefficients and further by forward selection process. Further a 6-level discrete wavelet transform decomposition is performed on each beat using a 10th order Daubechies. The morphological features are extracted using wavelet transform and independent component analysis together [3]. The dynamic features are obtained from RR interval information. The wavelet analysis is performed with Daubechies wavelet of order 8. FastICA algorithm is used here to extract 18 ICA coefficients for every heartbeat. The dimensionality of feature is reduced to 26 by principal component analysis and this results in 9932% variance. The statistical and morphological feature extraction is done in paper [4] through Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA) techniques.

The technique employed for extracting the features from ECG in the work [5] is Independent Component analysis (ICA). The authors' claim that by taking 10 independent components for each segment of multi lead data more effective results can be obtained. The feature extraction [6] uses the combination of time domain, wavelet domain and power spectral density features. Finally three divergent feature sets consisting of 8 time domain, 32 wavelet transform and 11 power spectral density features are obtained. Another important point here is that all these features are extracted without using QRS detection. The Random Projection [7] technique is used for generating feature vector for all records in the database. This technique reduces the dimensionality of a data set but preserves the geometrical structure. Accordingly Random Projection has reduced the dimensionality of beat from to 50 samples from 700.

In [8] Kernel Principal Component Analysis (KPCA) is used for extracting the non-linearly related structures to the input space through the solution of an eigenvalue problem in a feature space of higher dimension. Two approaches are used here. The first one uses the combination of Principal Component Analysis (PCA) and modified fuzzy one-against-one (MFOAO) for categorizing multiclass signals. The second approach uses PCA, unbalanced clustering (UC) and fuzzy one-against-one (FOAO) algorithms. The UC algorithm is used for discarding the outliers. The feature extraction [9] is done with Principal Component Analysis (PCA) technique and it is combined with unbalanced clustering algorithm (UC) to reduce the complexity in feature extraction. In [10] Sub-band analysis is used to divide the signal into various frequency band components. Every beat in every kind of ECG consists of 250 data points after employing a 6 level decomposition on ECG signal. Three kinds of sub band energy calculations namely normal, mean and Relative mean are performed on the extracted energy coefficients of ECG.

ECG classification methods

In paper [1], the data in the semi supervised discriminant analysis feature space are classifies using support vector machine (SVM). Here the dataset is split into two halves randomly for training and testing. The training set includes 14301 heartbeats and the testing set has 14300 heartbeats. The dataset includes data for six diseases such as Normal, Sinus bradycardia, Left bundle branch beat, Electrical axis left side, Right bundle branch block and Left ventricular hypertrophy.

The ECG classification technique used in paper [2] is Support Vector Machine [SVM]. Here SVM separates all the samples into 2 classes by an optimal hyperplane. The total data in this work are divided into 10 equal size folds. Among these, 9 folds are used for training data. The last fold is trained with 10 classifiers. Finally the ultimate classification performance is determined by averaging the results from all the 10 test sets. The classification tool used in paper [3] is SVM classifier with a Gaussian radial basis function kernel. Based on the training data the SVM classifier is trained. The trained SVM classifier is used to evaluate the data. The implementation of SVM algorithms is through LIBSVM package. The classification of ECG in paper [4] is done using Euclidian and Manhalanobis classifiers. Here 100 segments are taken for training and 50 segments for test samples. These 50 segments are obtained from the extracted 198 segments.

THE IIOAB JOURNAL
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The classification of beats through experiments based on multi-lead data in [5] shows that 11 types of arrhythmia beats can be classified. This work also includes the classification of experimental data from 500 persons. Here the total number of beats collected is 6366 and the abnormal beats in this is 2611. The classification accuracy here is 90.47%, sensitivity is 0.9001 and specificity is 0.9074. The authors indicate that this method can be applied to practical environment. This work also indicates that the training data proportion also affect the result.

The classification algorithms [6] used are decision tree and neural network. In this paper a fivefold cross validation technique is used for the evaluation of the entire ECG database. The experiments also indicate that the classification with decision tree algorithm is better than with neural networks. The classification performance success score, called F- score [6] with entire 51-dimensional features of time domain, wavelet transform and power spectral density feature extractions is 0.947 and it is the highest.

A Neuro-Fuzzy classifier [7] is used for feature classification in ECG signals. This method of classification results in 100% recognition rate for 25 Random Projection coefficient. The method used for classification in [8] is Multi SVM classification on 10 normal signals, 10 Premature Ventricular Contraction (PVC) signals and 14 Left Bundle Branch Block (LBBB) signals. The accuracy of separation of normal beats to abnormal beats is 100% while it is 70% in PVC and 55.71% in LBBB with building of separate SVMs for each pair of classes. In [9] a study is conducted to differentiate five types of heart beat namely normal beat, left bundle branch beat, right bundle branch beat, premature ventricular contraction beat and atrial premature contraction beat. The fuzzy support vector machine (FSVM) is used here for the binary classification of ECG signals. The principal component analysis (PCA), unbalanced clustering (UC) and Fuzzy one-against-one (FOAO) combination is used here for the classification of long term ECG records. The classification of the extracted features [10] is done by using Artificial Neural Network (ANN). The feed forward network uses 1 input layer, 1 hidden layer and 1 output layer. The Multilayer Perceptron (MLP) uses backpropagation algorithm to find the error signal.

RESULTS AND DISCUSSIONS

Discussion on performance

In paper [1], the semi-supervised discriminant analysis performance accuracy rate is 97.64%. When compared with other algorithms. The SVM classifier used for Multi-category classification here uses the cross validation of optimal parameter of SVM for better classification performance. The classification accuracy depends on the features and classifier used. In paper [2] for 770 ECG records, the overall accuracy of first feature set is 88.07% and the overall accuracy for the second feature set is 77.13%. The overall classification accuracy with both feature sets combined is 93.17%. This work shows that ECG features with lower dimensions can be extracted which improves the classification results.

The feature extraction method used in paper [3] separates 15 types of heartbeats depending on ICA features, features in wavelet and RR interval. The average classification accuracy here is 99.66%. The authors in paper [4] claim that the best classifier found for their work is Manhalanobis Distance Classifier which has a sensitivity (Se) of 96% and specificity (Sp) of 92%. In multi-lead ECG classification system based on improved ICA and SVM [5], 10 independent components from each segment are used for extracting ECG features and this is found to give more effective results. The classifier used here is SVM classifier and it classified 11 types of arrhythmia beats. The accuracy of the technique in comparison to other works is 98.18%. The feature sets [6] of time domain, wavelet transform and power spectral density are compared for processing time on a computer with Intel core i7 processor, 2.8 GHZ processor with 4 GB RAM and it is found that time domain features has less processing time with medium classification performance. In ECG analysis the preprocessing step which is critical is QRS detection. The ECG signals are classified successfully without QRS detection.

The computational complexity of Random Projection based feature extraction [7] technique is low. This helps to implement this technique in real time on a wireless wearable sensor platform. The combined accuracy of KPCA and SVM in normal beats [8] is 100% for normal beats while the accuracy is 70% in Premature Ventricular Contraction (PVC) and 85.71% in Left Bundle Branch Block (LBBB). The analysis shows that Kernel Principal Component Analysis (KPCA) with One against all (OAA) is superior to deal with Multi SVM classification.

When used with a large database, the Modified Fuzzy One –Against-One [9] consumes more time but gives good result. In the research work [10] 5 types of arrhythmias are taken for feature extraction and classification. They are normal beat (N), premature ventricular contraction (PVC), paced beat, right bundle branch block (RBBB) and left bundle branch block (LBBB). A total of 25 heartbeats are used for testing which includes 20 samples for each type of arrhythmia. Nearly 100 heartbeats are taken for training. The classification result shows that Normal subband energy (NSE) gives a high classification accuracy of 100% for normal beats, Mean subband energy (MSE) gives the highest classification accuracy of 91.6% for PVC and Relative mean subband energy (RMSE) gives a higher classification accuracy of 95.8% for normal beats, LBBB and RBBB.

THE IIOAB JOURNAL ISSN: 0976-3104

Evaluation of various feature extraction and classification methods

This section of the paper gives an assessment of various methods used for feature abstraction and classification of bio signals. A clear view of several techniques used by various authors for the assessment of bio signals is depicted in **Table– 1.** The data from MIT-BIH database is used most commonly by many researchers.The comparison table also indicates that SVM classifier is popularly used. The review study also shows that the size of the data set has a definite relation with the method used for feature extraction and classification of bio signals.

The metrics used for comparison of works of various researchers are classification accuracy, sensitivity and specificity. In certain [6] works the processing time for feature extraction and classification of bio signals are also considered. The study indicates that as the size of the data set increases, the complexity also increases and the process becomes tedious. Therefore an intelligent combination of different extraction methods and classifiers is the solution in this scenario.

Table: I. Comparison of various feature extraction and classification methods

Author and year	ECG data collection	Feature extraction method	Classification method	Efficient features	Performance metrics
Hanlin Zhang, 2013	12 lead ECG data	Wavelet transform	SVM classifier	High classification accuracy, good generalization ability	Total classification accuracy = 97.64%
Ge Dingfei, 2012	MIT-BIH database	Wavelet transform	SVM classifier	possible and feasible to extract ECG features with lower dimensions from wavelet coefficients improvement in the classification results	193 ECG records considered and heartbeat classification accuracy is 88.07%
Can Ye, 2010	MIT-BIH Arrhythmias database	Wavelet Transform (WT) Independent Component Analysis (ICA)	SVM classifier	Single-lead performance is superior than any other previous works carried so far	Heartbeat classification accuracy is 99.91% with 84630 records out of 84707 ECG records correctly classified, 15 classes of heartbeats are classified final arrhythmias detection accuracy is 99.93%
Rizwan R. Sheikh, 2009	Physionet	PCA LDA	Two classifiers namely, Euclidean and Manhalanobis used	Classification of cardiac segments based on statistical and morphological features extracted from ECG	Best classifier found is Manhalanobis Distance Classifier with sensitivity Se=96% and specificity Sp=92%
Mi Shen, 2010	MIT-BIH Arrhythmia Database and 2500 practical data gathered from 500 persons	An improved Independent Component Analysis (ICA)	SVM classifier used for multi classification	Classification accuracy compared to other works is 98.18%	For multi classification average accuracy of testing data is 98.18% and the average Sensitivity is 98.68% For practical data 2-classification Experiment accuracy of testing data is 90.47% and the Sensitivity is 90.01%
Serkan Gunal, 2013	Physiobank archive	Time domain (TD), Wavelet transform (WT) and power spectral density (PSD)	Decision tree, Neural network	High classification performance if TD, WT and PSD combined in a large database Less processing time for TD with medium classification performance	For combined TD+WT+PSD features F-score = 94.7% for decision tree F-score = 90.7% for Neural network

Iva Bogdanova, 2012	Physikalisch-Technische Bundesanstalt (PTB) Diagnostic ECG database	Random Projection	Neuro-Fuzzy classifier	Feasible and energy efficient Can be implemented wireless sensor platforms due to its low complexity	30 subjects ECG data constitutes training set and 30 subjects ECG data constitutes testing set Jaccard index is 90% for 20 coefficients
Maya Kallas, 2012	MIT-BIH Arrhythmia Database	Kernel Principal Component Analysis (KPCA)	Two multi-SVM classification schemes used are 1.One-Against-One (OAO) 2. One-Against-All (OAA)	Higher average classification accuracy	Very high average classification accuracy of 97.39% for OAA with KPCA
Mohamed cherif Nait-Hamoud, 2010	Real database from MIT-BIH arrhythmia database of ECG arrhythmias	Principal Component Analysis (PCA)	Fuzzy Support Vector Machine (FSVM)	The complexity of classification is reduced with Unbalanced Clustering algorithm	The average classification accuracy when PCA+UC+FOAO algorithms used and R=2 is 97.895%
Pratiksha Sarma, 2014	MIT-BIH arrhythmia database	Wavelet subband energy based	Multilayer Perceptron Neural network	Performance optimization of classifier by using statistical properties of subband energy features	Normal subband energy classification accuracy = 90.78% Mean subband energy classification accuracy = 84.12% Relative mean subband energy classification accuracy = 91.62%

The relation between the size of the dataset in terms of heartbeats and the classification accuracy is shown separately in **Table– 2**. This table indicates that as the total number of samples increases, the complexity increases for feature extraction and classification. A suitable method has to be carefully selected in this case. The comparison also shows that wavelet transform for feature extraction and SVM classifier for classification gives better results.

Table: 2. Relation between data size and classification accuracy

Ref. No.	Size of dataset	Classification accuracy
[1]	Training set data size – 14301 Testing set data size – 14300	97.54%
[2]	770 classes	88.07%
[3]	85300 beats	99.25%
[4]	Training – 100 segments Testing – 50 segments	Se=96% and specificity Sp=92%
[5]	Training data – 7016 heartbeats Testing data – 91.509 heartbeats	90.74% Se=90.019%, Sp=90.74%
[6]	1200 features per class	F-score = 94.7% for decision tree F-score = 90.7% for Neural network
[7]	Training data – 30 real subjects ECG Testing data – 30 real subjects ECG	Jaccard index is 90% for 20 coefficients
[9]	Training data – 2802 samples Testing data – 1200 samples	97.895%
[10]	Training data – 25 heartbeats Testing data – 100 heartbeats	Average classification accuracy = 88.84%

THE IIOAB JOURNAL ISSN: 0976-3104

DISCUSSION

The graph in **figure– 1** gives an idea of which technique to use when the data size is small and big. It is found that good results can be obtained by choosing Independent Component Analysis technique for feature extraction from ECG signals and SVM classifier method for classification of ECG signals.

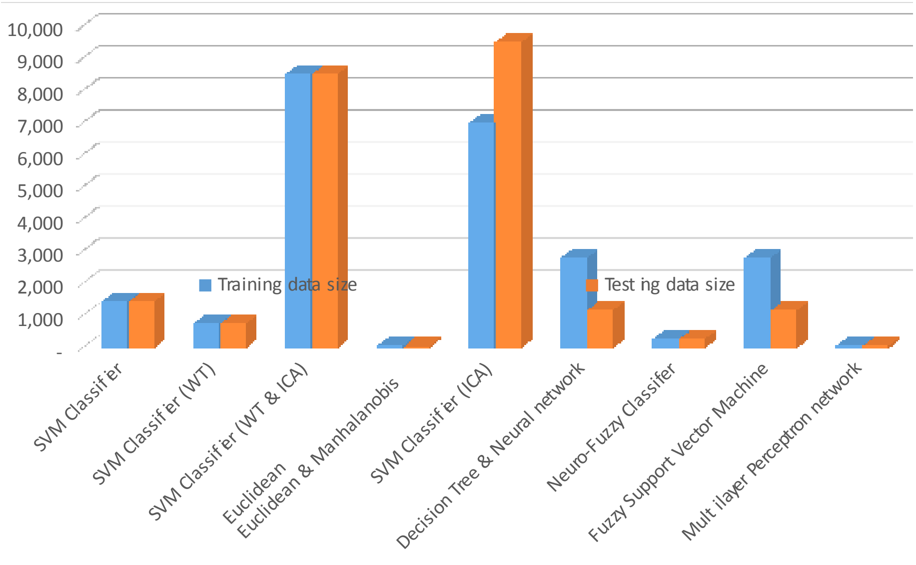

Fig: 1. Dependency between data size and techniques used

The success of the selected method for classification of ECG signals depends on the classification accuracy. This is depicted graphically in **figure–2**. It is found that among many classifiers, SVM classifier in combination with Fuzzy network gives good results.

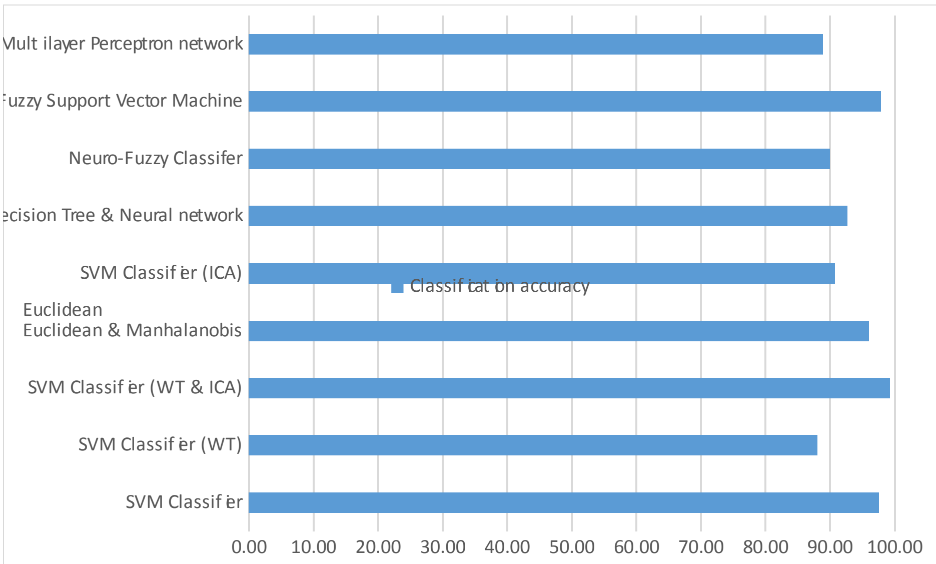

Fig: 2. Classification techniques and Classification accuracy

Research gaps

The technique of semi supervised learning ability [1] gives good result only for small training set and when the labeled data is insufficient. Experiment and analysis have shown that better classification results can be obtained for lower dimension features that that of features with higher dimensions. The study on feature extraction [2] includes only wavelet coefficients with reduced dimension of 34 only. The work in paper [4] is useful only for off-line ECG signal analysis. The authors indicate that their work is helpful for medical students for learning ECG off-line analysis. The research gap in this work is that this is not suitable for online ECG analysis on real time bio signals. The results in [5] shows that the structure of the training data should be in proportion to the overall data to get better results. When the amount of data increases, the computational complexity also increases. Efficient methods of feature selection is mandatory here to get effective results. Focus on fusion of classifiers is necessary as there exists a relationship between the classifiers and the diseases they classify. The evaluation of feature sets [6] and classification is done on four types of heart conditions namely, normal, congestive heart failure, ventricular tachyarrhythmia and atrial fibrillation. No mention is made about the application of this method to other kinds of heart diseases. Also, this technique is applicable for off-line ECG analysis only. For a bigger data set [7] it is necessary to examine the average recognition rate for several executions of the proposed hypothesis. Here it is concluded that due to low computational complexity the Random projection concept is applicable for wireless sensor platforms. But how exactly this technique can be implemented is not highlighted. The research experiments [8] are conducted on MIT-BIH arrhythmia database on only three kinds of cardiac diseases. There is no mention about the application of this technique in real time ECG signal analysis. The results [10] shows that for a particular kind of cardiac disease only a particular type of wavelet subband method must be applied to get high classification accuracy. The decision on which type of wavelet subband energy method is applicable for what kind of cardiac disease comes out after conducting many experiments on trial and error basis.

CONCLUSION

This paper gives a brief review on various methods applicable for feature extraction and classification of bio signals used by different researchers. The research works of various researchers are studied and compared on the basis of techniques used for feature extraction and classification and the resulting accuracy. It is noted that many research works uses wavelet transform for feature extraction and SVM classifier for classification of bio signals. Another interesting feature noted is that the selection of data size has a great impact on the selection of technique to be used for feature extraction and classification of bio signals. Further the study indicates that many research works are being carried out in this area as a feasible solution suitable for clinical application is not achieved so far.

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CONFLICT OF INTERESTS
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