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An Overview of Ischemia Detection Techniques

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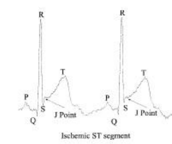
Abstract— In recent years several researchers have put great efforts in biomedical engineering for improving the diagnostic techniques used by the physiologists. A lot of research has been done in biomedical signal processing which includes the signal enhancement, signal compression, artifacts and noise removal like power line interference removal, base line drift removal. For detection of cardiac arrhythmia and ischemia using ECG signal, many emerging techniques and algorithms have been proposed. Ischemia is one of the cardiovascular diseases which are responsible for almost 20% of the deaths around the world. Some of the recently developed algorithms by these researchers have given remarkable results for ischemia. In this paper w

terms of their performance and capabilities with respect to standard databa

Index Terms—algorithms, ECG, Ischemia, ST segment, sensitivity, positive



1 INTRODUCTION

ECG (Electrocardiogram) plays key role in patient monitoring and diagnosis of heart functions. The ECG signal consist of P, QRS complex, T wave has shown in Fig.(1). These waves correspond to the fields induced by specific electric phenomenon on the cardiac surface. Atrial depolarization produces the P wave, ventricular depolarization produces QRS complex and ventricular repolarization produces T wave. The ECG does not look like same in all the leads of the standard 12 lead ECG system. The ECG polarity and the shape of ECG constituents waves may change depending on lead that is used [1]. A number of techniques have been developed to recognize and analyze these waves. Ischemia is one of the most serious and prevalent heart diseases. It is estimated that two to three million people die due to ischemic problem in the world which leads to heart attack. So the researcher's concentration is to find the reliable and timely detection of ischemia from ECG, because ECG is mostly and commonly recorded signal in the patient monitoring and examination process. Detection of ischemia can be achieved by analyzing the ST-T segment as shown in Fig.(1). Ischemia is the cause of decreased blood flow to muscle tissues of the heart. This reduced blood supply may be due to narrowing of the coronary arteries, obstruction by thrombus or may be due to diffusion of small vessels with in the heart. This causes depolarization of resting membrane potential of the ischemic region with respect to the resting membrane potential of the normal region. on account of this potential difference, an injury current flows which is manifested in ECG by elevated or depressed ST segment as shown in fig.(1). Whether the ST segment is elevated or depressed is dependent on the anatomical positions of the heart with respect to the recording electrodes. It may be noted that there are cases in the 12 lead ECG recordings where the ST depression or elevation is not evident even in ischemia beats. On the other hand sometimes ST depression or elevation may be evident in ECG lead III or augmented vector foot (aV

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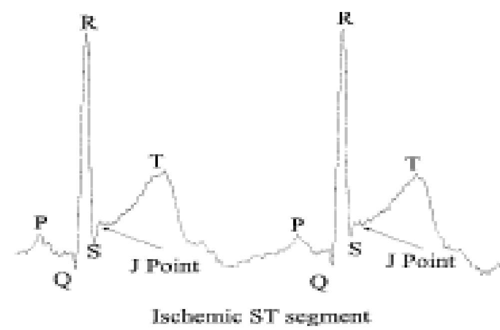

Fig.1 Normal and ischemic ST segment of ECG

Another problem contributing poor detection and classification of ST segment in the ECG includes; slow baseline drift, varying ST-T patterns in ECG of same patient, noise, and power line interference. So besides these problems it may be necessary to detect ischemic episodes when the patient is in CCU or chest pain unit, so for this the long duration electrocardiography like holter recording is the simple and noninvasive method to observe such alterations. A number of methods have been proposed in recent years in the literature for ST-T detection for finding the solution of ischemia based on digital filtering, time analysis of first derivatives, spatiotemporal, wavelet transforms, artificial intelligence based techniques which includes fuzzy, neural network, genetic algorithms, support vector machines, and many more [2] as discussed in detail in methods section. This paper deals with the developed algorithms for the detection of ischemia in terms of their sensitivity and positive predicitivity based criterion and their capabilities with respect to different standard database available worldwide. The paper is organized as follows; the initial stage introduced the ECG & ischemia and middle stage described the various methods for ischemia detection and last stage includes the conclusion and future followed by results and discussion.

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2 Developed Methods for Ischemia Detection

For the accurate detection of ischemia from ECG, it is must to remove the effects of artifacts, noise like power line interference, base line drift as discussed earlier. A lot of research has provided the solution of this problem in ECG by adopting new technologies and algorithms like kalman filtering, wavelets, digital filtering, independent component analysis, various non linear transforms etc. Adopting MMM (multi value, multi organ, multi organ) approach makes the system genesis explicit and it carries possibility of detecting information in multivariate form [2]. After successful removal of the artifacts and noises from the ECG, the accurate detection of QRS complex is needed. The detection of QRS has also been achieved with the detection rate of almost 100% by the researchers.

2.1 By Artificial Neural Networks:

Artificial neural networks (ANN) are made up of interconnecting artificial neurons. Artificial neural networks may either be used to gain an understanding of biological neural networks, or for solving artificial intelligence problems without necessarily creating a model of a real biological system. The real, biological nervous system is highly complex and includes some features that may seem superfluous based on an understanding of artificial networks. Neural network is commonly used for classification purpose in signal processing. By using neural networks one can detect the ischemia efficiently by individual or by combining neural network with another technique like principal component analysis, various transform, and fuzzy logics. Neural network is used for pattern and statistical classifiers and another technique for feature extraction. The ischemia episode detection using adaptive back propagation has been used in [3], [42]. The training is conducted using patterns from ST-T European database. The result shows average sensitivity of 72.22% and positive predicitivity of 67.49%. Other important papers were reported by Jager et.al [4] and laguna et.al [5]. Implementation of adaptive back propagation neural network algorithm. The performance was tested on European ST-T database which achieves the sensitivity of 83.8% and positive predicitivity of 87.1%. Another technique based on principal component analysis by ANN was used in [6]. It employed ST segment feature extraction and radial basis feedback network (RBFN) was subsequently used for classification of ischemic ECG. The method has shown a quite reliable classification rate for normal and ischemic beats of patient of 80% and 90% respectively. Ali Gharviri et.al [7] proposed an adaptive neuro fuzzy system (ANFIS) for automated detection of ischemic episodes only those episodes were chosen from European database which resulted in ST Segment elevation or depression. The algorithm used clustering and ANFIS as classifier that was independent of load used. The sensitivity of 88.62% and specificity of 99.65% was achieved.

2.2 By Hidden Markov Models:

A hidden markov model (HMM) is a statistical model in which the system being modeled is assumed to be a Markov process with unobserved state. An HMM network can be considered as the simplest dynamic Bayesian network. Hidden Markov models are especially known for their application in temporal pattern recognition and bioinformatics like ischemia that can be detected by the use of original markovian approach for online beat detection and segmentation. It provides a precise localization of all the beat waves and particularly of the PQ and ST segment. The markovian approach for ST segment extraction replaces the heuristics rules commonly used for detecting the QRS complexes and beat waveforms by the markov models [8], [9]. Researchers have also used hidden markov models with continuous wavelet transform by finding the time frequency spectra of QRS complexes that were used as input of detection system for finding ischemia [43]. The methods have sensitivity and specificity almost of 90%.

2.3 By Cardiac Imaging

By using imaging technique ischemia can be found in which one can analyze the, changes in 3 D image of the heart in real time efficiently by involving the mathematical equations. The technique has been used by many researchers like Claudio zizzo et.al [10] in which the ECG monitor with automated ST analysis was presented. The advantage of this method is that the time to diagnose dropped from 15 to 9 minute. The ischemia detection function is validated using European ST-T database and it gives sensitivity of 93%. Another paper [11] also uses the concept of imaging sets for quantifying left ventricular wall motion, in which potential wall motion measure was used to detect and evaluate the size of ischemic region. The result shows 3-dominant frequency signature (DFS), 3-discrete wavelet transform (DWT), radial and circumferential strains are good predictors of the ischemic regions. Some researchers proposed that for the ischemic patients having chest pain, the diagnosing techniques should include recoding of ECG followed by their cardiac imaging. The ECG recordings should be made in the different locations of ischemic regions in chest pain like inferior, anterior, septal, lateral, apex were continuously monitored by high resolution 12 lead ECG apparatus [12]. This technique will detect the ischemia caused changes in the depolarization phase of cardiac cycle quantified by high frequency QRS complexes.

2.4 By Self Organizing Map & Support Vector Machine:

Support vector machines (SVMs) are a set of related supervised learning methods used for classification. A support vector machine constructs a hyper plane or set of hyper planes in a high-dimensional space, which can be used for classification, regression. Intuitively, a good separation is achieved by the hyper plane that has the largest distance to the nearest training data points of any class. In general the larger is margin; the lower is the generalization error of the classifier and self-organizing map (SOM). SOM is a type of artificial neural network that is trained using unsupervised learning to produce a low-dimensional, discretized representation of the input space of the training samples, called a map. So by combining these techniques the detection of ischemia is found very efficiently in which the supervising network model is used to exploit the solution for ischemia by utilizing unsupervised learning (SOM) for simple region and supervised learning (SVM) for supervised for difficult region. The sNetSom with radial basis function (RBF) network is used for SOM and SVM are used as supervised expert. The result shows effective results for sensi-

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tivity and positive predicitivity. These methods have highest capability for detection of almost 92% [13], [14].

2.5 By Genetic Algorithm & MCDA:

Genetic Algorithm (GA) is a search technique used in computing to find exact or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics. Genetic algorithms are a particular class of evolutionary algorithms (EA) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover and multi-criteria decision analysis (MCDA), is a discipline aimed at supporting decision makers who are faced with making numerous and conflicting evaluations produced by genetic algorithms. The genetic algorithm and multi criteria decision analysis as combined approach has been employed in four stages viz for preprocessing beat classification, window characterization and episode definition for ischemia detection. The genetic algorithm is used for automatically calculating the optimum values of parameters by its property. The result is validated using European ST-T database and provides better results for ischemia detection with sensitivity and positive prediction of 91% [15] and for more details of genetic algorithm can be referred to [16].

2.6 By Fuzzy Logic:

Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. In contrast with "crisp logic", where binary sets have binary logic, the fuzzy logic variables may have a membership value that is; the degree of truth of a statement can range between 0 and 1 and is not constrained to the two truth values of classic propositional logic. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions. Fuzzy logic is used to make intelligent systems and expert systems for ischemic detection. The fuzzy logic with expert system that implements a multi diagnosis of ischemia has been developed in [17]. The expert system takes in to consideration the diagnostics techniques based on noninvasive stress test to handle the inherent and impression of the diagnosis process. Many researchers have preferred this technology for diagnosis of ischemia patients [18]. The fuzzy c-means algorithm is also used as clustering with three axis sphymography measures pulse pressure waves (PPW) and by analyzing PPW by its harmonics of first three components of Fourier series of PPW, ischemia can be found [29].

2.7 By Direct Measurement of ST Segment Shift:

The direct measurement of shifts occurred in ST segment of ECG signal received from patient in CCU can detect the location, size, position of ischemic region efficiently [19] and by considering the inverse problem of electrocardiography [20]. And by using ST-T segment shift recorded at body surface estimation for transmembrane potential through heart wall was capable to identify the position and size of ischemia [21].

2.8 By QRS slopes:

This method detects the ischemia by the measuring upward, downward, amplitude of QRS slope of ECG. The ECG recordings acquired before and after percutaneous transluminal coronary angioplasty (PTCA) shows that QRS slopes are less steep during artery occlusion [22], [23]. In addition to the changes in slopes of QRS complex it is also observed that in case of induced acidosis by which Na+ and Ca+ conductance, the amplitude of QRS complex changes and ST segment shortened which is further used for ischemia [30].

2.9 By Reducing Lead Sets:

Many researchers have provided solution to detect ischemia based on ECG reduced lead sets in which the subset 12 lead set with all the same limb leads in addition to V1 and V5 chest leads. The result shows that the reduced lead set can achieve similar interpretation accuracy for interior ischemia as those of 12 lead without any retraining & can improve the anterior ischemia and can adapt to ECG morphology changes in derived anterior leads [24]. Another paper presents the enhanced diagnostics performance of American college of cardiology/European society of cardiology (ACC/ESC) ST elevated myocardial ischemia (STEMI) criteria based on 12 lead ECG by using criteria from 3 derived vessel specific leads (VSL's). Study data was consisted of 12 lead ECGs acquired during angioplasty induced ischemic episodes due to balloon inflation and of left axis deviation (LAD), n=35, right coronary artery (RCA), n=47 and left circumflex coronary artery (LCX), n=17 coronary artery. The VSLs were derived from 12 lead ECG by previously developed lead transformations. The result shows VSLs can markedly improve detection of ischemia, especially that caused by LCX artery occlusion [25].

2.10 By Wavelet Transform:

Wavelet Transform is used to have a coherence time proportional to the period of the signal. Wavelet transform are similar to Fourier transform, as Fourier transform is a tool widely used for many scientific purposes, but it is well suited only to the study of stationary signals where all frequencies have an infinite coherence time. But Wavelet transform is used to detect compact patterns for detection of ischemic events by identifying the characteristics points of ECG signal. The characteristic points are then used identify the ischemic episodes. These gives the characteristics points with Fourier transform. This has been used in [9], [26], [27]. The advantage of this method has good sensitivity and nominal positive perdictivity stage with correlation coefficient of unit value. The limitation includes the computation required are higher than other methods.

2.11 By K-L Transform (PCA):

In the theory of stochastic processes, the Karhunen Loève (KL) transform theorem is a representation of a stochastic process as an infinite linear combination of orthogonal functions, analogous to a Fourier series representation of a function on a bounded interval. The distinction is that here, the Fourier coefficients are random variables received from biomedical signals. KL Transform is an optimal transform which provides best statistical characteristics. This transform has also been proposed by [28] to extract the parameters from ST-T complex. In addition, this is sometimes also used for ventricular depolarization and for ischemic episodes detection [5], [42].

3 Results and Discussion

The performance of any method for ischemia detection can be quantified in terms of its sensitivity (Se) and positive perdictivity (+P). As sensitivity = TP/ TP+FN and positive predicitivity = TP/TP+FP. where TP stands true positive, FP for false positive and FN stands for false negative respectively. If an ischemic beat is classified as the ischemic, then it is said to be TP, any normal beat classified as an ischemic beat by mistake then it said to be a FP, similarly if any ischemic beat which is classified as normal beat by mistake it is said to be a FN. For most of the biomedical signal processing techniques, researchers worldwide use standard annotated databases like MIT/BIH, ACC/AHA as common reference, one of database used for ischemia detection is the European ST-T database. This database includes two channels from holter machines corresponding to 90 patients with ischemic heart diseases. It includes numerous ischemic episodes of all types and thus it is very useful in evaluating ischemia detection algorithms. The literature shows that the different researchers have developed new algorithms by adopting different approaches.

As and when there is any development in field of signal processing, the same is applied for biomedical signal this results in continuous enhancement and innovations in diagnostic techniques in general and ischemia detection in particular. This is reflected in the overview of various techniques recently proposed by the researchers for the detection of ischemia. The sensitivity and positive perdictivity of ST segment in ECG is of an average of 87-89% and 90-92% respectively. However there is still the scope for improving the results either by modifying the existing tech. or by application of some new techniques. Apart from the positive perdictivity and sensitivity another parameter used for evaluating the performance of any proposed algorithms is its speed of execution. It is worthwhile mentioning that of all the methods in Table 1, neural network have fastest speed of processing.

TABLE 1
Comparison of Performance of Developed Methods for Ischemia

Method	**Se (%)**	**+P (%)**
RMS method [40]	85	86
Geometric method (Taddei et.al) [41]	84	81
PCA (Jagger et.al) [6]	87	88
Wavelet Transform [9]	92	86
Adaptive Logic Network [38]	72	66
Back propagation Network (Magaveras et.al) [3]	89	78.38
Adaptive Network [38]	88.62	100
Discriminant method [38]	62	66
Fuzzy logic(Vila et.al) [39]	83	75
HMM (Andreao et.al) [37]	89	85
GA and Multi criteria [15]	91	91
Parametric modeling [36]	81	84
PCA and ANN [42]	90	93
Set of Rules [35]	70	63
Rule mining based [34]	87	93
SOM [31]	74.9	73.7
SOM and RBF [31]	79.5	77.6
SOM and SVM [31]	82.8	82.4
HySMID [15]	91	93
Decision Trees [32]	89.89	70.03
Recurrent ANN [33]	77	85
Knowledge learning ANN [33]	71	66

4 Conclusion And Future Prospects

Though some of the techniques like adaptive network may have 100% predictivity, still the sensitivity is only 88%. The 100% sensitivity and 100% predictivity is yet to be achieved. Achieving these numbers is still a challenge for the researchers and requires a lot of future work to be done. It is proposed that combination of two or more techniques may result in building of better classifier for detection of ischemia.

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