31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Rules extraction in SVM and Neural Network Classifiers of Atrial Fibrillation Patients with Matched Wavelets as a Feature Generator.

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***Abstract*— Presented paper describes a system of biomedical signal classifiers with preliminary feature extraction stage based on matched wavelets analysis, where two structures of classifier using Neural Networks (NN) and Support Vector Machine (SVM) are applied. As a pilot study the rules extraction algorithm applied for two of mentioned machine learning approaches (NN & SVM) was used. This was made to extract and transform the representation of knowledge gathered in Black Box parameters during classifier learning phase to be better and natural understandable for human user/expert. Proposed system was tested on the set of ECG signals of 20 atrial fibrillation (AF) and 20 control group (CG) patients, divided into learning and verifying subsets, taken from MIT-BiH database. Obtained results showed, that the ability of generalization of created system, expressed as a measure of sensitivity and specificity increased, due to extracting and selectively choosing only the most representative features for analyzed AF detection problem. Classification results achieved by means of constructed matched wavelet, created for given AF detection features were better than indicators obtained for standard wavelet basic functions used in ECG time-frequency decomposition.**

I. Introduction

IT is a challenging task to obtain explicit knowledge from black-box type machine learning systems like e.g. Neural Networks (NN) [12],[13] or Support Vector Machine (SVM) [2] to explain the relationships hidden in classification decisions made by these structures for human users. The difficulty in the interpretation of knowledge gathered in such a systems is one of the main reasons, that although NN or SVM structures are known to be a relatively robust classifiers, their application in medical diagnosis support systems is limited.

A classifier learns from training data and stores learned knowledge into the classifier parameters, such as the weights of a neural network classifier. However, it is difficult to interpret the knowledge in an understandable format by the classifier parameters. Hence, it is desirable to extract IF–THEN rules to represent valuable information in data. Common way used to improve the classifier performance, where the original input signal described in N-element space $x_l \in X \subseteq \Re^N$ is mapped to output classifier vector space with K-class labels $y \in Y = \{y_1, y_2, \ldots y_K\}$ (N>>K) is the reduction of too high input feature vector size in intermediate feature extraction and selection stage. The basic goal of this preliminary stage is to reveal only the most discriminate features for given task and discard remain, reducing also the classifier complexity. Proposed feature extraction tools almost always must depend on the specificity of classification task to be sensitive to features, which will be able to distinguish between health and pathology cases.

The application field of presented multi-domain feature extraction is the trial of detection of atrial fibrillation (AF), which is a supraventricular tachyarrhythmia characterized by uncoordinated atrial activation with consequent deterioration of atrial mechanical function. On the electrocardiogram (ECG), AF is described by the replacement of consistent P waves by rapid oscillations or fibrillatory waves that vary in size, shape, and timing, associated with an irregular, frequently rapid ventricular response when atrio-ventricular conduction is intact. Because of disturbed haemodynamic, atrial fibrillation and atrial flutter are between of the most usual causes of thrombi-embolic events [1].

II. Classifier structure with feature extraction stage based on matched wavelets decomposition

A. *General structure of whole classifier system..*

General structure of described classifier system for screening examination of patients suffered from atrial fibrillation, presented on fig.1 includes feature extraction stage with proposed mixed-domain structure, following by SVM classiffier structure with preliminary original ECG signal preprocessing with important ventricular activation (QRST) cancelation stage.

1) ECG signal preprocessing with cancellation of ventricular activity

On the first preprocessing stage of input ECG signal analysis apart from standard ECG filter implementation the elimination of ventricular activity by QRS complex and T-wave cancellation determining the quality of whole procedure was carried out [6][7]. Literature review of papers connected to AF detection problem shows positive influence of ventricular activation cancelation by removing QRST complex from original signal for further analysis [8]. Traditional methods based on simple QRS cycles averaging and subtraction was not enough in case of significant beat-to-beat changes in real ECG signal, which cannot be treated

Manuscript received April 22, 2009. This work was supported in part by the Polish Ministry of the Science and High Education, under Grant No 1311/B/T02/2007/33.

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as periodical signal. Recent studies report principal component analysis, blind source separation and artificial neural networks [9] as a alternative promising tools for QRST complex cancellation.

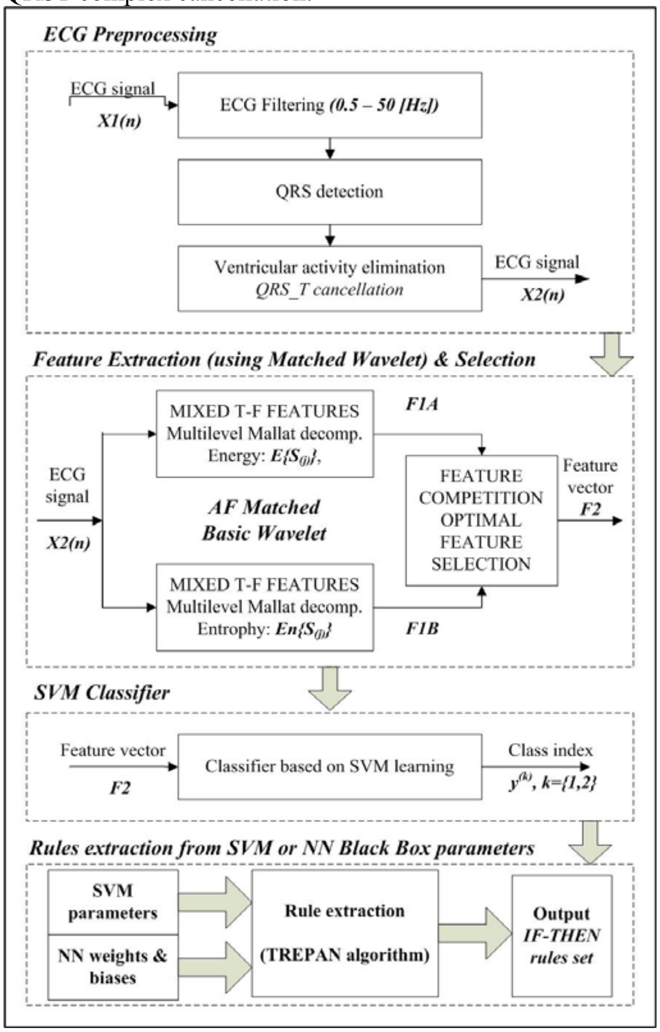

Fig.1. General structure of classifier system with feature extraction stage based on matched wavelet analysis.

In presented approach we proposed to use the advantages of discrete wavelet transform analysis dedicated for non-stationary signals. Reconstructed with threshold detail components ***d4+d5*** of multilevel Mallat decomposition created the base for QRS detection and cancellation by subtraction from remain components.

B. Matched Wavelets as feature extraction tool.

In the context of matched wavelet design a well known brief summary of Wavelet Transform are presented [6],[7]. A mother wavelet $h(x)$ is a finite duration window function, that can generate a family of daughter wavelets: $h_{a,b}(x)$ by varying scale (a) and shift (b) parameters and is given by (1):

$$h_{a,b}(x) = \frac{1}{\sqrt{a}} h\left(\frac{x-b}{a}\right) \qquad (1)$$

The mother wavelet must satisfy the admissibility conditions that it must •be oscillatory •have fast decay to zero and •integrate to zero. A frequency power spectrum compatibility of created matched wavelet with atrial fibrillation ECG complexes was a key do design wavelet basic function dedicated for analyzed classification problem.

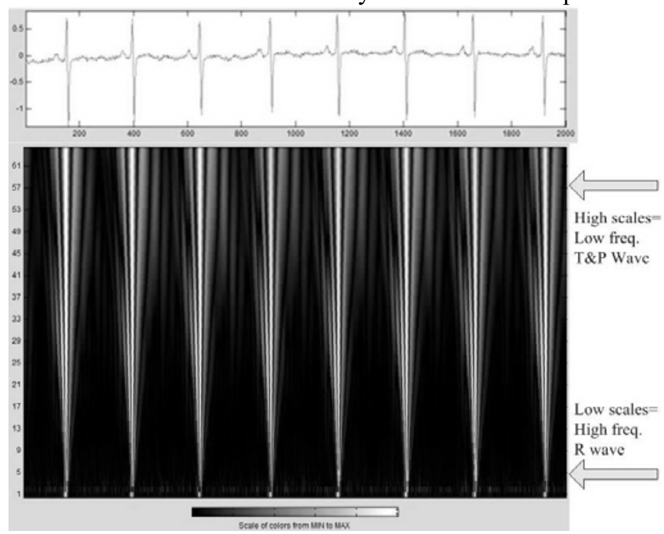

Fig.2. ECG: P, R, T waves activity, which can be seen on different regions of Time-Scale (Frequency) diagram of CWT ECG signal decomposition.

The new vector of extracted features, which should be the most representative set of parameters characteristic for Atrial Fibrillation (AF) detection were composed of parameters resulting the time-frequency signal representation (fig.2) by means of created matched wavelet. This multi-domain feature set covers a wide spectrum of possible AF activity occurrence.

1) Mixed T-F domain:

T-F analysis carried out by fast Mallat wavelet decomposion was used to compute following parameters based on energy and entropy, which correspond to the measure of information included in every frequency sub-band of Mallat j^{th} decomposition (fig.3):

- Energy of wavelet component (2):

$$E_{1,j}\{c_{i,j}\} = (c_{i,j})^2 \Rightarrow E1_{1,j}\{s(n)\} = \sum_i (c_{i,j})^2 \qquad (2)$$

- The (non-normalized) Shannon entropy (3):

$$E_{2,j}\{c_{i,j}\} = -(c_{i,j})^2 \log(c_{i,j})^2 \Rightarrow \\ E_{2,j}\{s(n)\} = -\sum_i \left[(c_{i,j})^2 \log(c_{i,j})^2\right] \qquad (3)$$

Full list of extracted features are included in [10]

C. Support Vector Machine as an extracted features classifier

1) SVM structure. The support vector machine (SVM) is a promising classification technique proposed by Vapnik and his group at AT&T Bell Laboratories [2]. SVM is a good tool for the two classifications. It can separate the classes with a particular hyperplane which maximizes a quantity called the margin. The margin is the distance from a hyperplane separating the classes to the nearest point in the dataset. The advantage of maximum margin criterion is its robust characteristic against noise in data, and making a solution unique for linearly separable problems. In addition, it is important that the SVM with a theoretically strong support is based on the statistical learning theory framework.

2) SVM kernel selection. Matching basic kernel function for specified task is remarkably for SVM classifier performance. Literature described investigations [3] indicate a polynomial kernel as a good solution for prediction problems [4] while radial basis function kernel better suited for classification [5]. Two mentioned types of SVM kernels, expressed by formulas (4) , (5) were used in presented paper:

a) Polynomial Kernel of d - degree

$$k_P = k(x_i, x') = (a + b\langle x_i \cdot x' \rangle)^d \quad (4)$$

with a and b as a constants. A special case for a=0 ; b=d=1 forms a linear kernel.

b) Gaussian Radial Base Function (RBF) Kernel

$$k_G = k(x_i, x') = \exp\left(-\frac{1}{\gamma}\|x_i - x'\|^2\right) \quad (5)$$

with γ width specified a priori.

3) Nonlinear case:

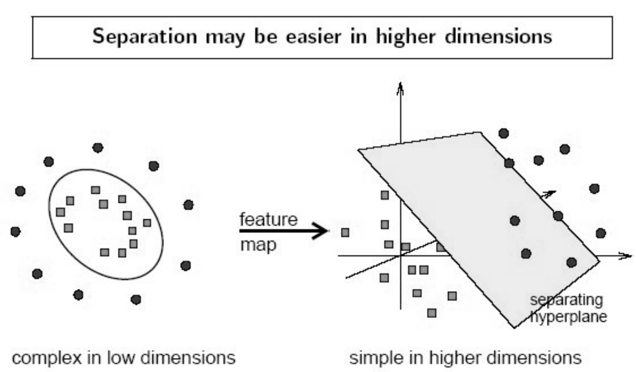

Fig.3. Transformation of features in SVM, from lower to higher dimension space, where the classification can be easier

SVM to effectively handle real-world data, often in non-linear dependences allow to model a non-linear decision surfaces. According to method proposed in [10], the idea is to explicitly map the input data to some higher dimensional space, where the data is linearly separable (fig.2). We can use a mapping (3):

$$\Phi : \Re^N \to \Im \quad (3)$$

where N is the dimension of the input space, and $\Im$ a higher-dimensional space, termed *feature space*. In feature space, the technique described in the above section can be used to find an optimal separating hyperplane. When the hyperplane is found, it can be mapped back down to input space. If a non-linear mapping Φ is used, the resulting hyperplane in input-space will be non-linear.

III. Rules extraction algorithm for SVM and neural network classifier structures

The TREPAN algorithm developed by Craven [13] is a relatively novel rules extraction method converting the knowledge gathered in black-box type structure like e.g. SVM or Neural Networks in IF-THEN rules. On the first stage TREPAN extracts a decision trees from parameters of black-box models using a concept of recursive partitioning similar to induction algorithms. TREPAN forms trees that use M-of-N expressions. An M-of-N expression is satisfied when at least m of its n conditions are satisfied.

IV. Results

A. Feature extraction by means of wavelet decomposition

Selection of appropriate wavelet and the number of decomposition levels is very important in analysis of signals using the wavelet transform. Usually, tests are performed with different types of wavelets and the one which gives maximum efficiency is selected for the particular application. In this work we designed an own wavelet based on best matching algorithm for problem of atrial fibrillation (AF) detection. A created matched wavelet was compared with often used as a reference basic function the Daubechies wavelet of order 2, with the smoothing feature making it more suitable to detect changes of the ECG signals. Therefore, the final wavelet coefficients as a base for new feature vector creation were computed using the matched AF wavelet.

To verify presented method, ECG signals taken from MITBIH database containing AF episodes were tested. Whole data set consisting of 40 cases with long term ECG recordings were divided into learning and verifying set. Optimal number of selected features for classifier effectiveness is presented in fig.4. Performance of presented pattern recognition system was evaluated based on classical measures of classifier Sensitivity and Specificity.

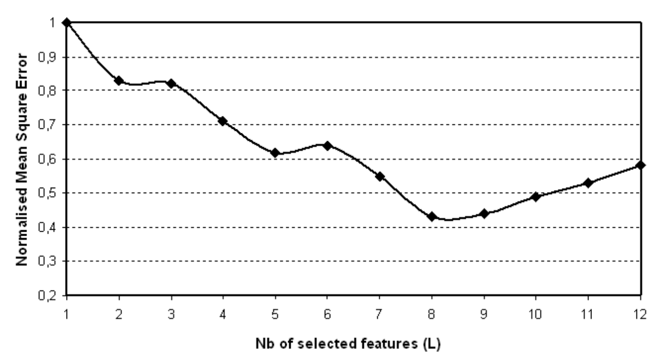

Fig.4. Selection of optimal number of extracted features for classifier error minimalization.

B. SVM Model of black-box classifier

The Matlab implementation of Support Vector Machine theory was used to train the SVM and to adjust its parameters, which was on the next stage put to SVM-TREPAN in order to extract the rules gathered inSVM structure during the learning phase. To select the best set of parameters (γ,C) for the Gaussian kernel, the grid-search and cross-validation approach with $\gamma=[2^8,2^7,2^6,..,2^{-8}]$ and $C=[2^{10},2^9, 2^8,..,2^{-4}]$ was used. Different pairs (γ,C) were tested and the one with the best cross-validation accuracy was selected.

For evaluation of new feature set quality based on matched wavelet decomposition, the performance of different type of classifier structures with chosen type of SVM kernel function with reference systems with no FE stage were compared (TABLE I).

TABLE I
RESULTS OF DIFFERENT FEATURE EXTRACTION APPROACH IN CLASSIFIER STRUCTURES

CLASSIFIER STRUCTURE TYPE	SENSITIVITY	SPECIFICITY
SVM without FE (*Polyn. kernel*)	0.67	0.68
SVM without FE (*Gaussian. kernel*)	0.77	0.75
SVM + FE (*Polyn. kernel*)	0.80	0.82
SVM + FE (*Gaussian. kernel*)	0.90	0.87

The most important feature characterizing classifier performance is its generalization ability. The measure of Sensitivity (SN) and Specicity (SP) was calculated for the chosen in previous subsection structure of whole SVM classifier with feature extraction stage. Apart from classification performance Table I presents also the influence of proposed feature extraction stage for the values of SN and SP obtained for the SVM classifier with no feature extraction stage.

V. CONCLUSIONS

After preliminary data processing including important stage of ventricular activity cancellation a feature extraction from T-F domains based on designed wavelet, matched for atrial fibrillation detection problem was carried out. A SVM based structure was used to classify the new feature characterizing the analysed problem of atrial fibrillation detection. Presented article focuses on improving the SVM classification abilities by preliminary selecting features with maximal weight in classification process. It allowed to find the optimal feature subset selection of from different domain T-F features. Atrial Fibrillation detector tests gave for the optimal structure the value of classifier sensitivity SN=90%, while specificity SP=87% for AF with different degree of organization (atrial flutter, AF1, AF2 and AF3).

A pilot, preliminary study was carried out on the trial of extracting the knowledge from abstract parameters of black-box classifiers (SVM, NN). A set of IF-THEN rules was defined, which meaning is currently interpreted by the authors.

To conclude, obtained results showed, that before pattern classifier can be properly designed and effectively used, it is necessary to consider the feature extraction and data reduction problems. Feature extraction should consists in choosing those features, which are most effective for preserving the class separability. Support Vector Machine structur appeared as an effective tool for biomedical data classifier, improving whole classification process.

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