

A Novel Approach for the Identification of Chronic Alcoholics using ECG Signals

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Abstract—Several medical studies reveal alcohol consumption has pronounced effects on the heart rate variability (HRV) of the consumer. In this article, electrocardiogram (ECG) samples of chronically alcoholic subjects and normative subjects are collected for HRV analysis and feature extraction. Machine learning algorithms then use the features extracted to classify subjects as chronically alcoholic or normative. For this classification problem, a Support Vector Machine (SVM) and an Extreme Learning Machine (ELM) have been trained, and their performance has been compared. While time domain, frequency domain and non-linear features are generally extracted from ECG signals for HRV analysis, in this study a new set of features obtained from Autoregressive Modelling using Exogenous (ARX) Inputs have also been used to improve the accuracy of the algorithms. An accuracy of **80%** and **89%** was achieved by SVM and ELM respectively without the use of ARX coefficients, while an accuracy of **86%** and **95%** was achieved when ARX coefficients were included in the feature set.

Keywords— *Electrocardiogram, Heart Rate Variability, Support Vector Machine, Extreme Learning Machine, Autoregressive Modelling with Exogenous Input*

I. INTRODUCTION

The effects of consumption of alcohol by individuals in large amounts in a short period of time, or gradually for a prolonged period have been studied and documented extensively [1-3]. The Parasympathetic Nervous System (PNS) and Sympathetic Nervous System (SNS) are inputs to the Sino-Atrial (SA) Node of the heart, which initiates heartbeats and in turn controls the inter-beat-interval. The PNS lowers the heart rate, while the SNS increases it [4].

Alcohol consumption acts as a depressant on the brain and nervous tissue, which results in increased SNS activity and decreased PNS activity [5]. This causes an increase in the heart rate and decrease in the Heart Rate Variability (HRV), which is the variation or change in the inter-beat interval of the heart. Studies [6, 7] have detailed the correlation between the amount of alcohol consumed and the extent of change in the HRV, while accounting for factors like the subject's gender, weight, BMI, etc. From the results of these studies, it is possible to draw conclusions that chronic alcoholic and normative subjects can be differentiated based purely on HRV. **In this study, we define**

a chronic alcoholic to be an individual who consumes alcohol frequently and on a regular basis. A teetotaler or very sparse drinker is considered a normative subject. {How do you actually quantify large, regular and frequently?}

Research conducted for the detection of drunk driving [8] utilized HRV analysis to extract time domain features for the classification problem using a support vector machine. Certain other studies [9-11] also used HRV analysis to extract another type of feature (non-linear features) for their classification algorithms. Another form of feature extraction on ECG signals is seen in [12], where spectrum analysis on ECG signals is performed to obtain frequency domain features for the classification of arrhythmia.

Auto Regressive (AR) modelling and AR model coefficients have been used as features for machine learning algorithms for quite a few applications. In [13] identification of individuals using ECG signals was performed by using SVM and K nearest neighbor (KNN) algorithms. One of the features used by the classifiers in that study were the coefficients of the AR model, which had been built to relate the QRS complexes of two successive heartbeats. Another study [14] applied AR modelling on half-second segments of six channel Electroencephalogram (EEG) data to obtain features for a Neural Network which classified the data into one of five cognitive tasks.

As done in the previous studies mentioned above, here also HRV analysis has been used to extract time domain, non-linear and frequency domain features. However, in this study, the features have been used to train the extreme learning machine (ELM) and compare its results with that of the support vector machine (SVM). Along with the above set of features, the use of a new set of features has been proposed in this study to improve the accuracy of the classifiers. An Autoregressive Model with Exogenous Inputs (ARX) has been developed using the ECG signals of alcoholic and normative subjects, and the model coefficients obtained have been used as additional features to the classifiers.

This study ensures that the test subjects were free from heart conditions such as cardiomyopathy, atrial fibrillation or premature ventricular contraction, etc. which can cause arrhythmia. Such a step is crucial to ensure that HRV

measurements from the ECG dataset arise primarily due to the effect of alcohol on the subjects' heartbeat and not due to other pre-existing medical conditions.

II. METHODOLOGY

This section covers the steps followed to filter ECG signals, extract features, train the classifiers and validate their behavior (Fig. 1).

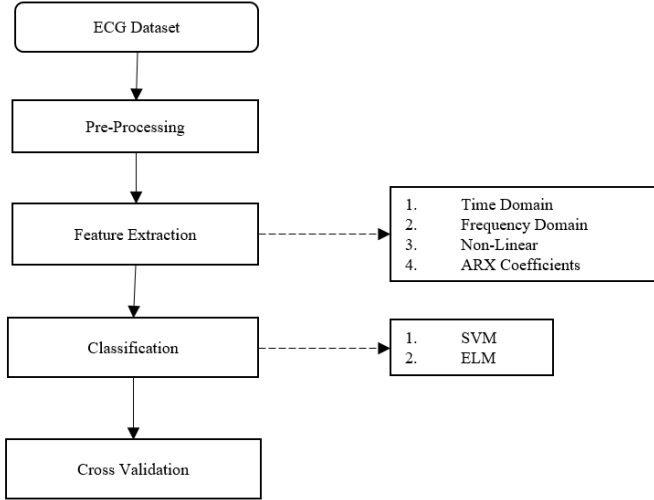


Fig. 1 Methodology

A. Dataset Description

To classify test subjects as chronic alcoholics or normative, the classifier was trained with ECG data recorded at the Autonomic Lab, Department of Neurophysiology, NIMHANS, Bengaluru on ensuring informed consent adhering to the Declaration of Helsinki. The dataset consisted of 56 ECG samples, of which 28 samples were of chronically alcoholic subjects and the other 28 samples were that of normative individuals. The ECG signals were sampled at a frequency of 1kHz and each was recorded for approximately 5 minutes (300 seconds), to capture the activity of the autonomic nervous system (ANS) [15] which is primarily responsible in controlling the heartbeat. **{Patient age, Lead configuration, Instrument used for measurement}**

B. Pre-processing

The ECG dataset had disturbances like baseline wandering and power-line noise, which required removal to obtain clean ECG signals. Wavelet decomposition, a technique to break up a signal into shifted and scaled versions of itself [16], was utilized to remove such sections of the signal.

Here, discrete wavelet transform with Daubechies wavelet was used. The Daubechies wavelet worked well for the ECG dataset because the shape of the QRS complex in the ECG signal and the Daubechies wavelet resembled one another closely [17]. Eight level wavelet decomposition was performed, and removal of the eighth component from the original signal rid the ECG signal of baseline wandering. The power-line noise had a much smaller amplitude than the total swing of the ECG signal, and was left unfiltered.

C. Feature Extraction

Features were extracted from the filtered signal using some of the techniques mentioned in [18, 20]. The four types of features that were extracted have been elaborated in this section.

1) *Time Domain*: Time domain features (Table I) utilize inter-beat intervals (RR interval series) to obtain a measure of the variability in the subject's heart rate. Measurements like the standard deviation of the RR interval series shows how quickly the heart is able to adapt to minor physiological changes in the body and hence, how much HRV is there in the subject. It was seen that HRV decreases in chronic alcoholics [19], and this change was captured by some of the time domain features. Other measurements like the root mean square of the RR interval sequence gave information about the subject's PNS [15] which, as mentioned in previous sections, causes changes in the subject's heart rate.

TABLE I. TIME DOMAIN FEATURES

Time Domain Features	
1	$RR_{mean} = \frac{1}{n} (\sum_{i=0}^n RR_i)$ <p>The mean of the RR interval sequence in milliseconds.</p>
2	$RR_{std} = \sqrt{\frac{1}{n-1} \sum_{i=0}^n (RR_i - RR_{mean})^2}$ <p>The standard deviation of the RR interval sequence in milliseconds.</p>
3	$HR_{mean} = \frac{60 \times 1000}{RR_{mean}}$ <p>The mean heart rate in beats per minute.</p>
4	$HR_{std} = \frac{60 \times 1000}{RR_{std}}$ <p>The standard deviation of the heart rate in beats per minute.</p>
5	$RR_{rms} = \sqrt{\frac{1}{n-1} \sum_{i=0}^{n-1} (RR_{i+1} - RR_i)^2}$ <p>The RMS of the RR interval series in milliseconds.</p>
6	RR_{50} <p>Number of RR intervals that are larger than 50 milliseconds.</p>
7	$RR_{r50} = \frac{RR_{50}}{n-1}$ <p>Normalized number of RR intervals that are larger than 50 milliseconds.</p>

2) *Non-Linear*: Non-linear feature (Table II) extraction methods include the Poincare plot and calculation of the approximate entropy [18]. The Poincare plot is a graphical method to visualize and gauge the HRV of the subject, while the approximate entropy gives a measure of the inter-beat irregularity. Both these techniques help quantify the amount of HRV in an individual.

TABLE II. NON-LINEAR FEATURES

Non-Linear Features	
1	SD_1 – standard deviation of Poincare plot along $x = y$ line.
2	SD_2 – standard deviation of Poincare plot along $x = -y$ line.
3	$ApEn$ – Approximate entropy of RR interval sequence.

3) *Frequency Domain*: Frequency domain features (Table III) take the power spectral density of the RR interval sequence and utilize power contained in different frequency bands as features for the classifiers [18]. These features reflect the activity of the SNS and the PNS [15] which are two portions of the ANS that controls the heartbeat [4].

TABLE III. FREQUENCY DOMAIN FEATURES

Frequency Domain Features	
1	$pk_{freq_{vlf}}, pk_{freq_{lf}}, pk_{freq_{hf}}$
2	Frequency at which the peak of PSD occurs for the very low frequency (VLF), low frequency (LF) and high frequency (HF) bands.
3	
4	
5	$abs_{pow_{vlf}}, abs_{pow_{lf}}, abs_{pow_{hf}}$
6	Absolute power of the VLF, LF and HF frequency bands.
7	pw_{ttl}
8	Total power contained in the signal.
9	$rp_{vlf} = \frac{abs_{pow_{vlf}}}{pw_{ttl}}$
10	
11	
12	$norm_{lf} = \frac{abs_{pow_{lf}}}{pw_{ttl} - abs_{pow_{vlf}}}$
13	Ratio of power in a particular band (VLF, LF or HF) to the power of the signal without considering contribution of power due to VLF band.
	$abs_{ratio} = \frac{abs_{pow_{lf}}}{abs_{pow_{hf}}}$
	Ratio of the absolute power in the LF band to the absolute power of the HF band.

4) *Coefficients of Autoregressive Model with Exogenous Input*: The autoregressive (AR) model establishes a connection between a particular output variable and its previous values [20]. In this study, an expanded version of the AR model called the Auto-regressive exogenous (ARX) input model has been used. The ARX model tries to build a relationship between the input sequence and an expected output sequence provided to it [20] as given by (1).

$$A(q)y(t) = \sum_{t=1}^{n_u} B_t(q)u_t(t - nk_t) + e(t) \quad (1)$$

After the baseline wandering was removed from the ECG signal, it was divided into two halves. One half of the signal was provided as the input to the ARX system and the other half

served as the expected output. These two halves were loaded into the System Identification Toolbox in MATLAB to develop an ARX model. The coefficients of the ARX model were used as additional features to train the classifier.

An overview of the array of features (including those of the five parameter ARX model) are as follows:

$$F = \{ RR_{mean}, RR_{std}, HR_{mean}, HR_{std}, RR_{rms}, RR_{50}, RR_{r50}, SD_1, SD_2, ApEn, pk_{freq_{vlf}}, pk_{freq_{lf}}, pk_{freq_{hf}}, abs_{pow_{vlf}}, abs_{pow_{lf}}, abs_{pow_{hf}}, pw_{ttl}, rp_{vlf}, rp_{lf}, rp_{hf}, norm_{lf}, norm_{hf}, abs_{ratio}, ARX_{coeff1}, ARX_{coeff2}, ARX_{coeff3}, ARX_{coeff4}, ARX_{coeff5} \}$$

D. Classifiers

Two classifier algorithms, each having a different ideology have been trained on the dataset. One of the classifiers is the SVM, which uses the idea of hyperplanes and decision boundaries, while the other is based off neural network concepts and is the ELM.

1) *Support Vector Machine*: An SVM with regularization [21] has been implemented on the dataset of 28 alcoholic and 28 normative samples. An RBF kernel was used in order to better separate the data points in a higher dimension. The SVM makes use of the Simplified Sequential Minimal Optimization (SMO) algorithm [22] to solve the Lagrangian problem and obtain weights for the hyperplane. Finally, the SVM's performance was validated using k-fold ($k = 7$) cross validation (Sub-section E).

2) *Extreme Learning Machine*: The ELM [23, 24] was trained on the same dataset as the SVM and here also, an RBF kernel was applied to the dataset. The accuracy of the ELM varied based on the number of neurons used in the hidden layer. A graphical plot of the accuracy of the algorithm versus the number of hidden neurons showed that the accuracy generally peaked when the number of hidden neurons used were between five and twenty (Fig. 2).

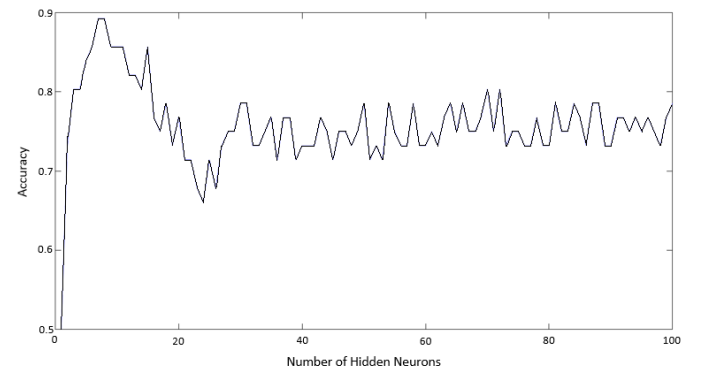


Fig. 2 Accuracy v/s hidden number of neurons

E. Validation

K-fold cross validation with $k = 7$ was used to validate the accuracy of the model that was trained. The dataset was divided

randomly into seven folds with eight samples in each fold. One fold was used as the test set, while the remaining folds were used to train the system. Then, the first fold was returned to the training set and a different fold (2nd fold) was used to test the algorithm's accuracy. Such a process was carried out cyclically to yield 7 accuracies, the average of which resulted in the 7-fold cross validation accuracy.

The sensitivity and specificity of the classifiers was also calculated to ensure the system was not biased and the classification accuracy remained high for the alcoholic and normative classes.

III. RESULTS AND DISCUSSION

Results pertaining to the pre-processing of ECG signals using wavelet decomposition, selection of the ARX model with the most optimal number of parameters, and cross validation accuracies obtained for the SVM and ELM are provided in this section.

The output of applying wavelet decomposition in the pre-processing stage are seen in (Fig. 3). The first subplot shows the original ECG signal with baseline wandering, the second subplot shows the level-8 approximation of the baseline wandering, and the third subplot shows the filtered signal without baseline wandering. All feature extraction mentioned in previous sections was performed for the filtered signal shown in the third subplot.

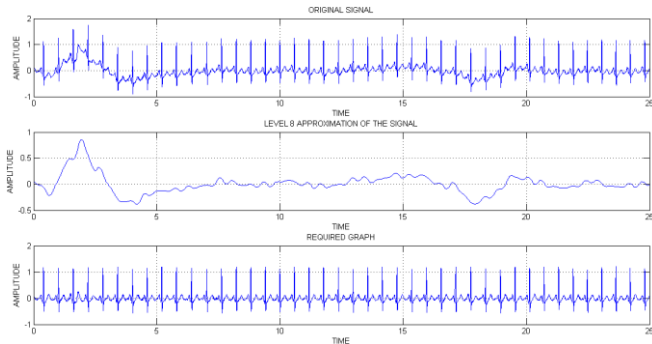


Fig. 3 Wavelet decomposition for baseline wandering removal

ARX models using different number of parameters provided different signal approximation accuracies and misfit percentages. For the ECG dataset used, it was seen that the ARX model's misfit percentage decreased with increase in the total number of parameters used by the model. The misfit observed for a total of five or greater parameters was less than 20%. Increasing the total number of parameters used in the ARX system to a value beyond five, only showed a small and insignificant decrease in misfit (Fig. 4).

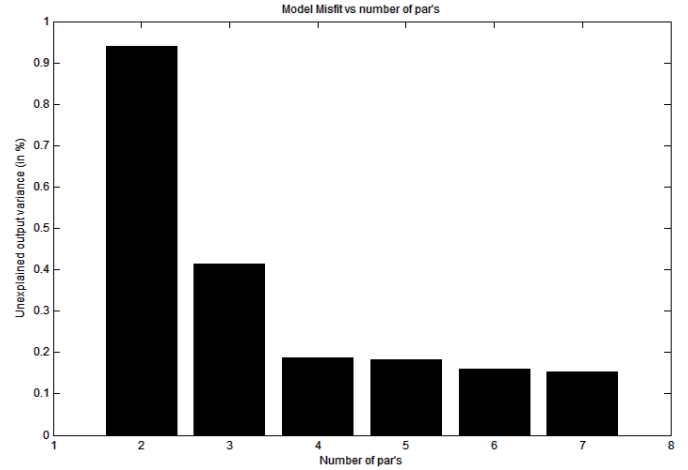


Fig. 4 Misfit versus total number of ARX model parameters

It was also observed that as the number of parameters in ARX model was increased (which resulted in the decrease of the misfit percentage of the ARX model), the accuracy of the SVM and ELM classifiers would increase (Table IV).

What ARX seems to be capturing in its model is the long term changes occurring in the ECG signal. By splitting the signal into two sections and using one as the input and the other as the expected output, an ARX model is built to relate the first half of the signal to its second half. This we believe captures the gradual change that occurs through the span of the initial portion of the ECG signal and its latter portion. While time domain, frequency domain and non-linear features perform HRV analysis using short sections (RR intervals) of the ECG signal, the ARX model utilizes the entire first and second halves. In essence, such a model seems to be another form of capturing variations in the heart rate using longer sections of ECG signal.

As seen from (Table IV), the SVM and ELM algorithms provided 7-fold accuracies of 80% and 89% respectively when only time domain, frequency domain and non-linear features were used to train them. However, the inclusion of the six parameter ARX model coefficients in the feature set increased the 7-fold accuracy of both algorithms to 86% and 95% respectively. In all these cases, the ELM used between eight and twenty six hidden neurons.

TABLE IV. SEVEN FOLD ACCURACIES OF SVM AND ELM

No. of Parameters in ARX Model used for Features	SVM	ELM
Without ARX model coefficients	80%	89%
With 2 parameter ARX model coefficients	80%	91%
With 3 parameter ARX model coefficients	82%	91%

With 4 parameter ARX model coefficients	83%	93%
With 5 parameter ARX model coefficients	84%	95%
With 6 parameter ARX model coefficients	86%	95%
With 7 parameter ARX model coefficients		

IV. CONCLUSION

With the results that have been obtained, it is clear that HRV analysis is a very viable method to extract features from ECG signals for the application of classifying chronic alcoholic and normative subjects. A comparison made between the SVM and ELM classifiers shows that the ELM outperforms the SVM when trained with and without ARX features. The most significant observation was the effect that the ARX features had on the classifiers. The inclusion of ARX coefficients in the feature set worked well with both classifiers and yielded an improvement of 6% in their accuracy.

In the current study, the input weights and number of hidden neurons for the ELM algorithm have been optimized by 'brute force' through multiple trial-error steps. The plan ahead, is to prevent this randomness and utilize a technique called Meta-Cognitive Learning on ELM to make it learn more intelligently and accurately the first time around itself. Another point that can be worked on which might further improve the accuracy of the classifiers, is the use of non-linear ARX (NL-ARX) model coefficients as features. It has been seen thus far that ARX coefficients clearly supplement the classifiers and increase their accuracy. However, in this study, only an intuitive suggestion has been provided about the correlation between the ARX model and the physiological changes occurring in the subject's body on consuming alcohol. Research must be conducted to find the actual association. Finally, an interesting way to broaden the scope of this study would be to convert this binary classification paradigm into one where the algorithm is able to classify subjects into multiple classes based on the level of alcohol intake.

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APPENDIX

Stuff to verify/ask:

1. Sensitivity/Specificity for all orders? No real info being obtained...just shows it was unbiased. Can we just mention in a sentence for one or tow instances?
2. Heading for Table IV ... Contents of first column are too repetitive.
3. Final results of the SVM and Elm mentioned in sentences to be given for which order? The one providing the highest accuracy right?
4. Verify Table, Figure nos, reference numbers
5. Ensure abreviations have been used with full form before hand

Tables preferred at the end of each page

Make new copy and edit...formatting may get messed up