Evaluation of ECG Signals for Mental Stress Assessment using Fuzzy Technique

G. Ranganathan, R. Rangarajan, V. Bindhu

***Abstract*— This paper presents the evaluation of mental stress assessment using heart rate variability. The activity of the autonomic nervous system (ANS) is studied by means of frequency analysis of the Electrocardiogram (ECG) signal. Spectral decomposition of the Heart Rate Variability before smoking and after smoking was obtained. Mental stress is accompanied by dynamic changes in ANS activity. ECG signal analysis is popular for assessing the activities of autonomic nervous system. The approach consists of 1) Recording the ECG signals, 2) Signal processing using wavelets, 3) Fuzzy evaluation techniques to provide robustness in ECG signal analysis, 4) Monitoring the function of ANS under different stress conditions. Our experiment involves 20 physically fit persons under different conditions. Fuzzy technique has been used to model the experimental data.**

***Index terms*- Adaptive Neuro Fuzzy Inference System (ANFIS), Non-linear System, Electrocardiogram (ECG), Autonomic Nervous System(ANS)**

I. INTRODUCTION

Assessment Of mental stress under different workload conditions is a recurrent issue in many engineering and medicine fields. Although mental stress cannot be measured directly, the physiological response of an operator can be interpreted to assess the level of mental stress. An electrocardiogram (ECG) is a cardiac measure that shows sensitivity towards variations in workload [2]. Heart rate variability (a measure of electrocardiographic activity) has been widely accepted in the literature for the assessment of mental work load.

Electrical activity of heart can be recorded with surface electrodes on chest or limbs. ECG wave shape may be altered by cardiovascular diseases, atrial fibrillation, ventricular fibrillation and conduction problems. ECG signal comprises of P wave, PG segment, QRS complex, ST segment and T wave.

QRS complex wave shape is affected by conduction disorders. Ventricular enlargement could cause a wider than normal QRS complex. The ST segment may be depressed due to myocardial infarction.

Presence of noise is one of the most challenging problems in Signal Processing basically due to the fact that a signal can pick up noise and be distorted such that the information carried by the signal can be misinterpreted. Thus, it is important that the impairments due to noise is reduced or eliminated totally from signals in almost all signal processing and communications tasks.

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Filtering is widely used to remove the noise from the signal. However, in the process, it also removes a part of the signal, which may be an important part of the signal processing application.

The wavelet transform is an emerging signal processing technique that can be used to represent real-life non stationary signals with high efficiency [1]. Indeed, the wavelet transform is gaining momentum to become an alternative tool to traditional time-frequency representation techniques such as the discrete Fourier transform and the discrete cosine transform. By virtue of its multi-resolution representation capability, the wavelet transform has been used effectively in vital applications such as transient signal analysis [2], numerical analysis [3], computer vision [4], and image compression [5], among many other audiovisual applications. Wavelet transform is mostly needed to be embedded in consumer electronics, and thus a single chip hardware implementation is more desirable than a multi-chip parallel system implementation. However, time-varying autoregressive models allow to assess, on a beat to beat basis, the spectral parameters of HRV signal in a fast and efficient way independently on the transitory events found through the whole night recording (provoked by arousals, body movements, changes on sleep stages or apneas).

Noise cancellation is mainly used as interference canceling in ECG, echo elimination on long distance telephone transmission lines and antenna side lobe interference canceling. This paper explains how ANFIS can be used to identify an unknown nonlinear passage dynamics that transforms a noise source into an interference component (noise estimate) in a detected signal. The neural network used in ANFIS is back propagation and the fuzzy model.

Soft computing is a new approach to construct intelligent systems. The complex real world problems require intelligent systems that combine knowledge, techniques and methodologies from various sources. Neural networks recognize patterns and adapt themselves to scope with changing environments. Fuzzy inference systems incorporate human knowledge and perform inferencing and decision making.

A. Related work

In the wavelet based mental stress assessment [6], The heart rate signals are processed first using Fourier transform, and then it is applied to wavelet transform. The activity of the autonomic nervous system is noninvasive studied by means of autoregressive (AR) frequency analysis of the heart-rate variability (HRV) signal.

The goodness of the algorithms is first tested through simulations, and then results obtained on real data during ischemic episodes are presented.

Short term analysis of HRV features has been investigated mostly in ECG data from normal and cardiac patients. Thus, short term HRV features may not have any relevance on the assessment of acute mental stress.An adaptive neuro-fuzzy filtering[4] which is basically a nonlinear system for the noise cancellation of biomedical signals (like ECG, PPG etc) measured by ubiquitous wearable sensor node (USN node). This paper presents non-linear adaptive filter which uses fuzzy neural network (FNN) to treat with the unknown noise and artifacts present in biomedical signals. The presented work based on ANFF (Adaptive Neuro Fuzzy Filter), where adaptation process includes neural network learning ability and fuzzy if-then rules with the optimal weight setting ability.

In fuzzy evaluation[1], stress assessment is done by interpreting the parameters of autonomic nervous system activity using a fuzzy model. The most important contribution of this paper is to quantify the concept of mental stress and to establish a direct functional relationship (independent of individual variations) between ANS activities and mental stress. It seems that the proposed fuzzy evaluation approach, combined with linear (or nonlinear) analysis of physiological parameters, may be helpful in various physiological modeling problems for the handling of uncertainties. The fuzzy evaluation approach, after being applied to mental stress assessment, motivates the start of new interesting research of physical and mental stress separation.

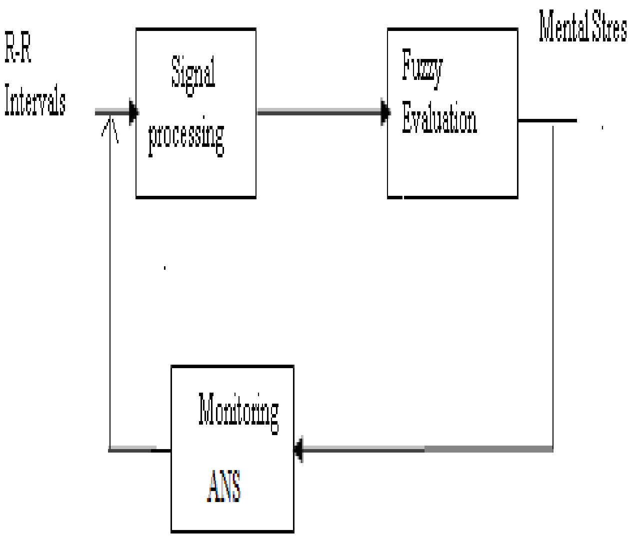

Fig.1 Components of the proposed work

B. Issues

Signal processing techniques suffers due to lack of availability of standard databases, partly due to the relatively low signal-to-noise ratio[9]. The autonomic nervous system (ANS) and especially its sympathetic branch play a significant path physiological role during the early course of hypertension. The study of cardiac variability through spectral analysis of RR interval, blood flow and respiratory activity are based either on FFT or on Autoregressive (AR) modeling and assume stationary of data. However, most physiological signals change in short times and the ANS regulate the cardiovascular function very quickly. Conventional power spectrum density (PSD) estimation methods are not suitable for analyzing heart beat signal whose frequency components change rapidly. On the other hand, time-frequency analysis (TFA) has more desirable characteristics of a time-varying spectrum [6].An emerging body of literature seems to suggest that HRV analysis can be potentially used to measure mental stress. However, a practical problem, which is so far not well addressed in the literature, is to derive some form of quantitative relations between parameters of ANS activity and mental stress[14].

C. Organization

This paper is organized as follows. Chapter 2 illustrates the proposed method with step by step procedure with the associated problems. Chapter 3 explains the signal processing using wavelet transform with various wavelets. Chapter 4 describes the fuzzy processing of the heart rate signal for mental stress assessment. Chapter 5 analyzes the proposed method and compares with wavelet based methods. Chapter 6 discusses the conclusion and future work.

II. PROPOSED METHOD

The autonomic nervous system (ANS), which controls cardiac muscle, is of interest for stress detection. ANS is concerned with the regulation of heart rate, blood pressure, breathing rate, body temperature, and other visceral activities. The ANS activity is divided into two branches: sympathetic and parasympathetic, which influence the sinus node of the heart, thereby modulating heart rate. HRV is a measure of the variability in heart rate. The R-R intervals can be analyzed using some mathematical theories (e.g., fast Fourier transform, wavelet theories, chaos) to assess ANS activities. Disturbed sympathetic and also parasympathetic activity indicates pathological changes of the cardiovascular system[1]. Hereby, heart rate and its variability represent important cardiovascular parameters for the assessment of such regulatory processes. Several studies have shown that low-frequency oscillations (up to 0.15 Hz) predominantly refer to sympathetic activity, while respiration-modulated oscillations (around 0.25 Hz) mainly reflect parasympathetic activity. The components of the proposed work and the experimental setup for recording the ECG signal is shown in Fig.1 and Fig. 2.

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Fig.2 Experimental setup for recording the ECG signal

A. Procedural Steps in the Proposed Method

Problem1: In R-R intervals, estimate the level of mental stress on a scale ranging from 0 to 100 by monitoring the functioning of autonomic nervous system using HRV analysis.

The solution of above problem not only would provide a physiological interpretation of a so-called mental stress but also has the direct applications in engineering fields like adaptive automation and man–machine interface design. The major difficulties in solving Problem 1 are the following.

1) HRV signal is nonstationary, i.e., it is characterized by time variations in its frequency components.

2) The alterations in HRV signal due to a change in the level of mental stress (these alterations would be used to detect the corresponding change) are subjective to individuals.

To resolve the second difficulty, some of the approaches coming from the area of neural network have been used [2] and references therein. However, neural network–based approaches are like a “black box,” since these do not provide a human-understandable insight into relationships between ANS activities and level of mental stress.

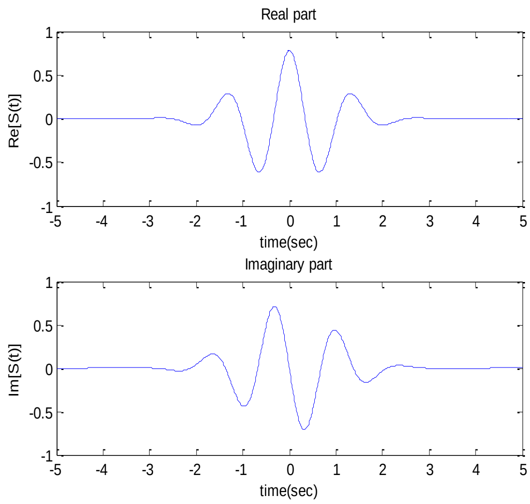
Problem2: While enveloping mental stress monitoring algorithms in real-life ambulatory situations, it is crucial to take human activity (e.g., walking, sitting, standing, and smoking) into account. Cardiovascular variability is highly acted by changes in body posture and physical activity. A major obstacle for ambulatory monitoring is that physiological dyes regulation or emotion effects can be confounded by physical activity. Many physiological parameters, including heart rate, respiratory sinus arrhythmia, and skin conductance level, are strongly acted by both anxiety and exercise. The daily routines involve psycho physiological body activation characteristics.

B. Functional Relationship between HRV and Mental Stress

Heart rate variability (HRV) was compared during rest and under mental stress. The testing procedure consists of the following phases: habituation, arithmetic tasks without and with interference, recovery. Proceeding from the total variance (ms^2), the weighted averaged frequency (Hz) and the variance parts (ms^2) in the frequency bands 'low frequency' (LF-band: 0.04–0.15 Hz) and 'high frequency' (HF-band: 0.15–0.40 Hz) were explored. The variance part modulated by spontaneous breathing within the HF-band was assessed additionally. The variance part in the LF-band under mental stress was significantly increased in the HT group. Activity in the HF-band (without the respiration-dependent part) under mental stress did not differ between both groups, whereas the breathing-modulated part of variance in the HF-band was reduced in the HT subjects. During the recovery period in the HT group, the weighted averaged frequency was still elevated compared to baseline, and the variance part in the LF-band was increased, which may point to delayed recovery behavior. In addition, by using a discriminant analysis 85% of all subjects were reclassified to the original groups, all HT subjects being assigned 'correctly'. Spectral variance parameters enable early discovery of altered cardiovascular regulation. Respiration influences variance in the HF-band in hypertensive subjects and should therefore be paid attention to. The variance part in the LF-band, weighted averaged frequency and the respiration-modulated variance in the HF-band turned out to be the most valid parameters for the differentiation between NT and HT subject.

III. SIGNAL PROCESSING USING WAVELET TRANSFORM

Fourier analysis is a powerful tool for analyzing the components of a stationary signal that are composed of some combination of sine and cosine signals. The Fourier transform is less useful in analyzing non-stationary data, where there is no repetition within the region sampled. Wavelet transforms allow the components of a non-stationary signal to be analyzed. Wavelets also allow filters to be constructed for stationary and non-stationary signals. In signal analysis, the detection of discontinuities is useful for extracting various features. The processing of medical signal like electrocardiograms requires the discontinuities detection.



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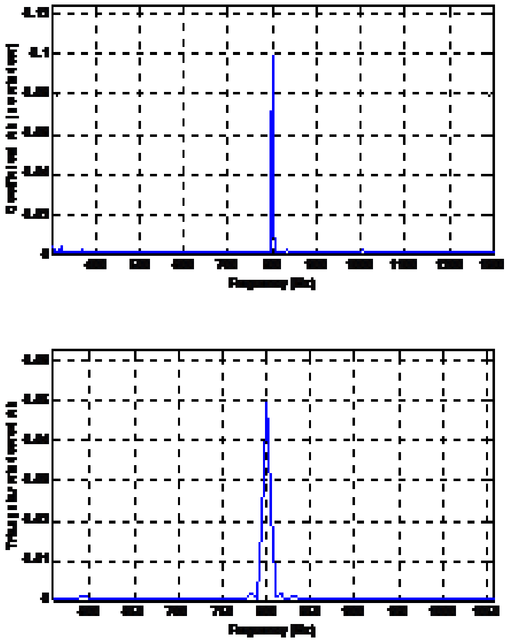

Fig. 5 Frequency response of noisy ECG

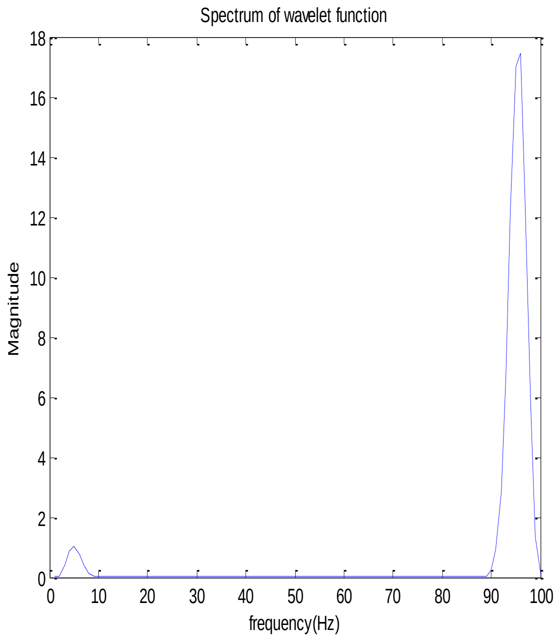

Fig.3 Complex Wavelet function and its frequency response

A wavelet is simply a small wave which has energy concentrated in time to give a tool for the analysis of transient, non stationary or time-varying phenomena such as a wave shown in Fig. 3. The R-R intervals were used to produce an HR signal in beats per minute, i.e., HR (R-R interval). Fig. 3 shows the analysis using the above defined complex wavelet function by plotting frequency response. The frequency response of the original ECG with noise provides less information.

The main idea consists in isolating a block of wavelet coefficients and based upon the information collected about the entire set make a decision about decreasing or even entirely discard the group[10]. This procedure will allow faster manipulation of the information and accelerated convergence rates. The recorded ECG signal is given in Fig. 4 which is corrupted by noise and less informative. Hence the preprocessing of ECG signal is a prerequisite for the mental stress assessment.

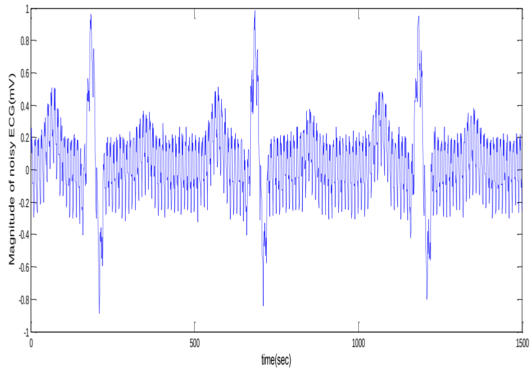

Fig.4 Recorded ECG signal contaminated by noise

The frequency response of the ECG signal without using window function and with the use of triangular window function is shown in Fig.5. It is noticed that both the methods provide less information and not possible to assess the ECG signal. Hence the wavelet transform and fuzzy logic techniques are necessary for the analysis of ECG signals. The ECG signal is denoised using meyer wavelet and applied for mental stress assessment.

IV. ECG SIGNAL PROCESSING USING FUZZY LOGIC

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis to its appropriate membership value. Two well known types are Mamdani-type and Sugeno-type. Both can be implemented in fuzzy logic toolbox. These two types differ in the way output's are determined. Mamdani-type inference expects the output membership functions to be fuzzy sets, and requires defuzzification. A Sugeno fuzzy model has a crisp output, the overall output is obtained via weighted average, thus neglecting the time consuming process of defuzzification required in a Mamdani model[13]. In practice, the weighted average operator is occasionally replaced with the weighted sum operator to reduce computation further mainly in the training of a fuzzy inference system.

The process of identifying a fuzzy model is generally divided into the identification of the premises and that of the consequences. And each of the identifying processes is divided into the identification of the structures and the parameters. The structures of a fuzzy model mean the combination of the input variables and the number of the membership functions in the premises and in the consequences. Sugeno's method finds the best fuzzy model by repeating the followings: (i) the selection of the structures in the premises, (ii) the identification of the parameters in the premises, (iii) the selection of the structures is the consequences, and (iv) the

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identification of the parameters in the consequences. This identifying process is time consuming and the characteristics of a fuzzy model depend heavily on the structures rather than on the parameters of the membership functions. The selection of the structures is first done once in the process. The selection of the structures of types I and II is done only in the premises since the structures of these types in the consequences are automatically determined with those in the premises [13]. After the structures are selected, the fuzzy neural network (FNN) identifies the parameters of fuzzy models automatically.

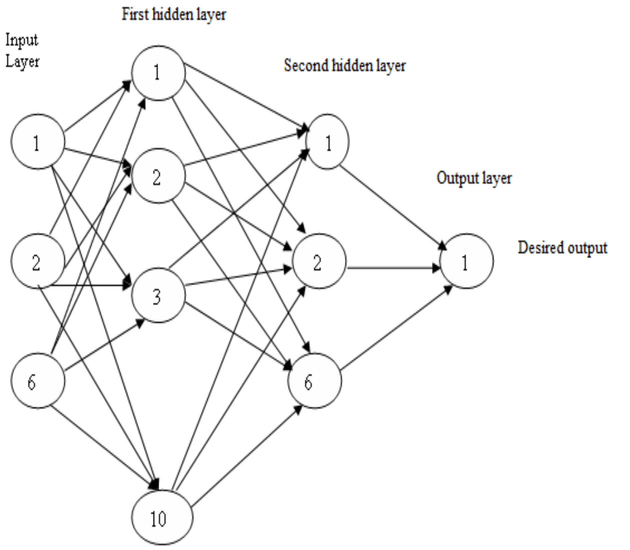

Fig. 6 Neuro fuzzy training network

While implementing the ANN program**,** the network is trained using the back propagation algorithm (BPA). The training process of the network is shown in Fig. 7.

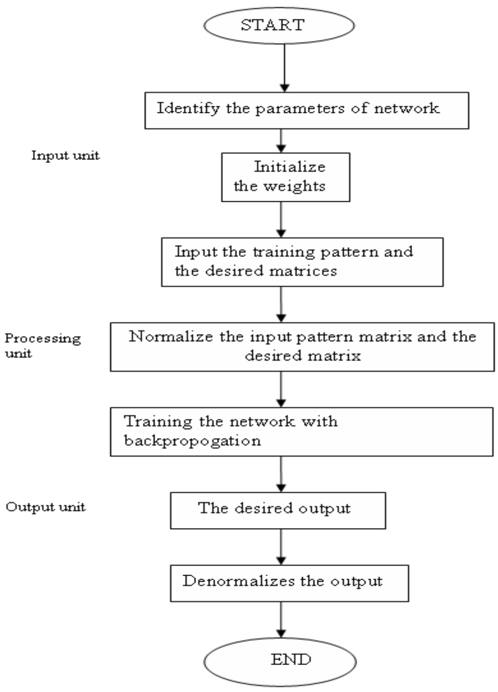

Fig. 7 Flow chart for training algorithm

The input unit includes: identifying the parameters of the network, identifying the weights entering the training patterns and the desired matrices, and normalizing the input and the desired matrices. The processing unit contains the training of the network with the input patterns using the error BPA. The output unit gives the output of the network (the desired value) and demoralizes them. After the training of the network, the unknown patterns will be inserted in the program. The network will recognize the pattern and give the required classification [15].

The only condition a membership function must really satisfy that it must vary between 0 and 1. The function itself can be an arbitrary curve whose shape we can define as a function that suits us from the point of view of simplicity, convenience, speed, and efficiency. A classical set might be expressed as $A = \{x \mid x > 6\}$.

A fuzzy set is an extension of a classical set. If X is the universe of discourse and its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pairs. $A = \{x, \mu_A(x) \mid x \in X\}$

$\mu_A(x)$ is called the membership function (or MF) of x in A. The membership function maps each element of X to a membership value between 0 and 1. The simplest membership functions are formed using straight lines. Of these, the simplest is the triangular membership function. Two membership functions are built on the Gaussian distribution curve: *a* simple Gaussian curve and a two-sided composite of two different Gaussian curves. Although the Gaussian membership functions and bell membership functions achieve smoothness, they are unable to specify asymmetric membership functions, which are important in certain applications

V. PERFORMANCE ANALYSIS

This section provides the results obtained during the processing of ECG signals using wavelets and fuzzy techniques. Wavelet decomposition and reconstruction methods are used to remove the interferences from the ECG signal so that feature extraction can be done without much fuss. The result of decomposition for denoising is provided in Fig.8. The resultant signal is obtained using Meyer wavelet but it may be improved using fuzzy techniques.

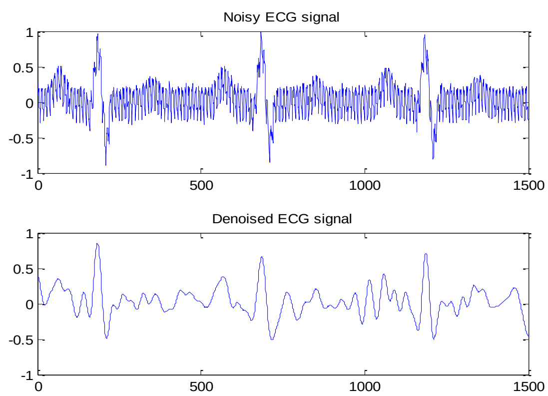

Fig. 8 ECG noise removal using Meyer wavelet

Power spectral density (PSD) refers to the amount of power per unit (density) of frequency as a function of the frequency. The power spectral density, PSD, describes how the power or variance of a time series is distributed with frequency. The power spectral densities of input ECG signal, reference noise signal and measured signal are shown in Fig.9.

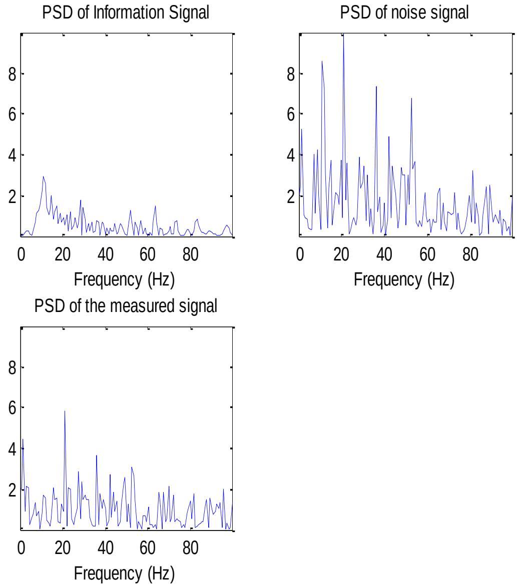

Fig. 9 Power spectral density plots

After extracting desired features from the signal neuro fuzzy training is performed and clustering techniques are used. The popular clustering techniques are fuzzy c-means, subtractive and mountain clustering. The fuzzy c-means clustering using color plot is shown in Fig.10

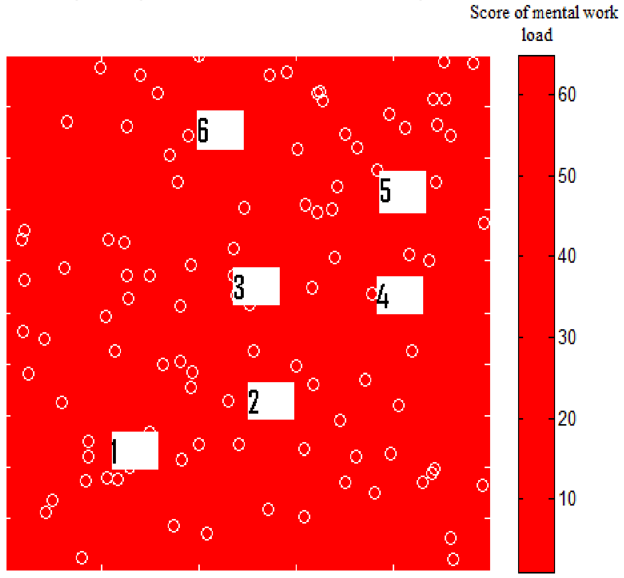

Fig. 11 Fuzzy C-means clustering using color plot

In Fig. 10, While moving along X-axis from cluster 1 to 6, the stress level does not always increases, since stress associated to the 4th cluster is higher than the 6th cluster. Also, moving along Y-axis, there is no significant reduction in the stress level. The reason obviously is that the different individuals behave differently, and an average behavior in Fig. 10 may not represent the real facts. Therefore, we need to handle the uncertainties due to individual variations using a fuzzy inference system. Let us assume that the mental stress is some unknown function of parameters X,Y that needs to be approximated by a fuzzy model using subjective mental workload score (which is an uncertain measure of the mental stress). That is workload sore mental stress uncertainty

VI. CONCLUSION AND FUTURE WORK

This paper has suggested a new approach to stress assessment using ECG signal analysis. The most important contribution of this paper is to establish a direct functional relationship between heart rate variability and mental stress. The wavelet decomposition and reconstruction techniques are used for removing noise and to extract some important features of ECG. The spectral features are identified with the application of fuzzy clustering techniques. The fuzzy evaluation approach, after being applied to mental stress assessment, motivates the start of new interesting research of physical and mental stress separation. The performance may be improved by using Genetic evaluation of ECG signals.

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