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Brain Abnormality Detection using the Harmonic Wavelet Packet Decomposition and Improved Compositional Pattern-Producing Networks

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Abstract : Epilepsy is one of the chronic neurological disorders which affect the human brain seriously which causes various problems to the human brain. The brain activities are continuously monitored with the help of the Electroencephalogram (EEG) that includes the significant information about the electrical changes about the brain. So, various methods are utilized to analyze the epilepsy disease with the help of the EEG but it has lot of issues as the maximum error rate and minimum accuracy while classifying the EEG features. Thus the paper contributes the Harmonic Wavelet Packet Decomposition and Improved Compositional Pattern-Producing Networks (HWPD-ICPPN) method to recognizing the epilepsy disorder from the brain. Initially the recorded EEG signal has been preprocessed by applying the Multi-linear principal component analysis and that signal is decomposed into various bands such as alpha, beta, gamma, delta with the help of the Harmonic Wavelet Packet Decomposition. From the decomposed signal, various statistical features are extracted and the dimensionality of the features is reduced by ISO-map non-linear dimensionality reduction approach. Finally the selected features are classified by applying the classifiers and the performance of the proposed approach is analyzed in terms of the mean square error, sensitivity, specificity and accuracy.

Keywords : Epilepsy, Electroencephalogram (EEG), Harmonic Wavelet Packet Decomposition and Improved Compositional Pattern-Producing Networks, Multi-linear principal component analysis, ISO-map non-linear dimensionality reduction.

1. INTRODUCTION

Electroencephalography (EEG) is used to monitoring the electrical activity of the brain with the help of the electrophysiological signal because it is non-invasive. The EEG monitors the electrical movements in terms of measuring the voltage fluctuations of the neurons present in the brain [1]. By using this measurement various abnormalities such as sleep disorders, coma, brain death, encephalopathy, stroke, tumors and epilepsy has been detected with efficient manner. Among the various abnormal activities, the epilepsy is the major neurological disease which is characterized by the epileptic seizures. The most common reason of the epilepsy is unknown, even though it created by the various diseases like, birth defects, genetic mutations, brain injury and brain death. So, the dangerous neurological disorder called epilepsy is successfully identified by the EEG. The identified epilepsy seizure has been controlled by the medicines up to 70% but the dangerous seizures are not responded by the medicines it is clearly analyzed from the various surveys. From the survey 22 millions of people affected by the epilepsy which is affected

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nearly 80% in the developing country [2]. So, the several researches have been made to analyze the epilepsy disorder by monitoring the electrical activity of the brain using the EEG measure with effective manner [3].

The EEG is recorded by placing the electrodes on the scalp up to 20-30 minute which is the plus preparation time. From the recorded signal the patient anesthesia level, indirect indicator of cerebral perfusion, amobarbital has been monitored efficiently. By using the recorded signal various authors developing the automatic seizure detection system to improving the recognition rate because the EEG information's are easy to extract. So, the author uses the various methodologies such as Fourier transform, wavelet transform, spectral filtering methodologies to preprocess the signal and those signals are processed by performing the various image processing and machine learning approaches [4]. The approaches create the automatic seizure detection system successfully but it is difficult to deal with the large amount of dataset [5]. The large number of dataset leads to reduce the entire performance of the system. So, the author already proposes the Double Density-Dual Tree DWT based seizure detection system with efficient manner. Even though the method efficiently recognizes the seizure, the effectiveness of the system is further enhanced and the error has been reduced by using the optimization methods.

Thus in this paper, the automatic epilepsy detection system is developed by using the Harmonic Wavelet Packet Decomposition and Improved Compositional Pattern-Producing Networks. The method analyzes the preprocessed EEG signal by decomposing into different bands. From the decomposed band, various statistical features are extracted which are classified using the efficient neural networks. Finally the performance of the system is evaluated in terms of the mean square error, sensitivity, specificity and accuracy. The remaining of the paper is organized as follows; section 2 provides the related works made on the epilepsy detection using the EEG signal. Section 3 discusses that the proposed system methodologies and the related architecture. Section 4 provides the results and discussions. Finally, section 5 concludes the proposed work.

2. RELATED WORKS

This section discusses that the detailed survey about the epilepsy detection methodologies and related reviews. Yatindra Kumar et al., [6] implementing the seizure detection system using the DWT based ApEn and neural network. The author analyzes the recorded EEG signal using the DWT and decomposes the signal into different bands. From the decomposed band the ApEn and approximation value is calculated which is fed into the feed forward artificial neural network for analyzing the various neurological disorders like stroke brain injuries, headache and dementia and so on. Finally the performance of the system is analyzed using the experimental results and discussions which achieve the efficient results. Turkey et al., [7] surveying the various seizure detection methodologies from the EEG to reduces the drawbacks present in the existing seizure detection process. In addition this paper also discusses about the challenges present in the detection and prediction algorithm with efficient manner. The discussed points are used to improve the overall seizure detection rate in the future directions.

Iosif Mporasa et al.,[8] analyzing the seizure detection from the EEG and ECG signal which is used in the various healthcare systems. The author analyzes the physiological signals that are collected from the three subjects and the efficient features are extracted in the short-time analysis. From the extracted features the optimized features are selected by ranking process. The ranked features are fed into the support vector machines which analyze the seizure with efficient manner. Then the author introduces system is improves the accuracy upto 90% when compared to the other methods. In addition the method recognizes the seizure in both offline and online method. Juarez-Guerra et al., [9] implementing the seizure detection system using the neural network with the effective wavelet analysis process. The method analyses the recorded EEG signal using the DWT and the efficient features are extracted using the Maximal overlap discrete wavelet transform (MODWT). The derived features are fed into the feed forward artificial neural network which trains the features according to the efficient training function. The efficiency of the proposed system is analyzed using the University of Bonn bench mark dataset which ensures the accuracy up to 99.26% using the three fold cross validation process.

Nabeel Ahammad et al.,[10]developing the automatic seizure detection system by utilizing the three types of the EEG signal. The recorded EEG signal has been preprocessed and the noise has been removed with efficient manner using the onset using the wavelet features. From the preprocessed EEG, different sub bands are extracted and the various features such as energy, entropy, standard deviation, maximum, minimum and mean value of each feature is computed successfully. The computed features are fed into the linear classifiers which recognize the seizure with effective manner. Finally the performance of the system is analyzed using the CHB-MIT scalp EEG dataset which ensures the 84.2% accuracy when compared to the existing methods. To overcome the drawback present in the previous research works, the author introduces the efficient automatic seizure detection system to reduce the error rate also increase the recognition rate using the HWPD-ICPPN approach. The detailed discussions about the proposed working process are discussed as follows.

3. PROPOSED ABNORMAL DETECTION PROCESS

In the developing world, neurological disorders are most dangerous disease which are continuously monitored and detected with the help of the EEG measurements. Then the automatic seizure detection system has been developed using the CHB-MIT Scalp EEG database with efficient manner. It consists of four different stages such a preprocessing, feature extraction, feature selection and detection or classification which are used to recognize the Epilepsy present in the human brain. The proposed system block diagram is shown in the figure 1.

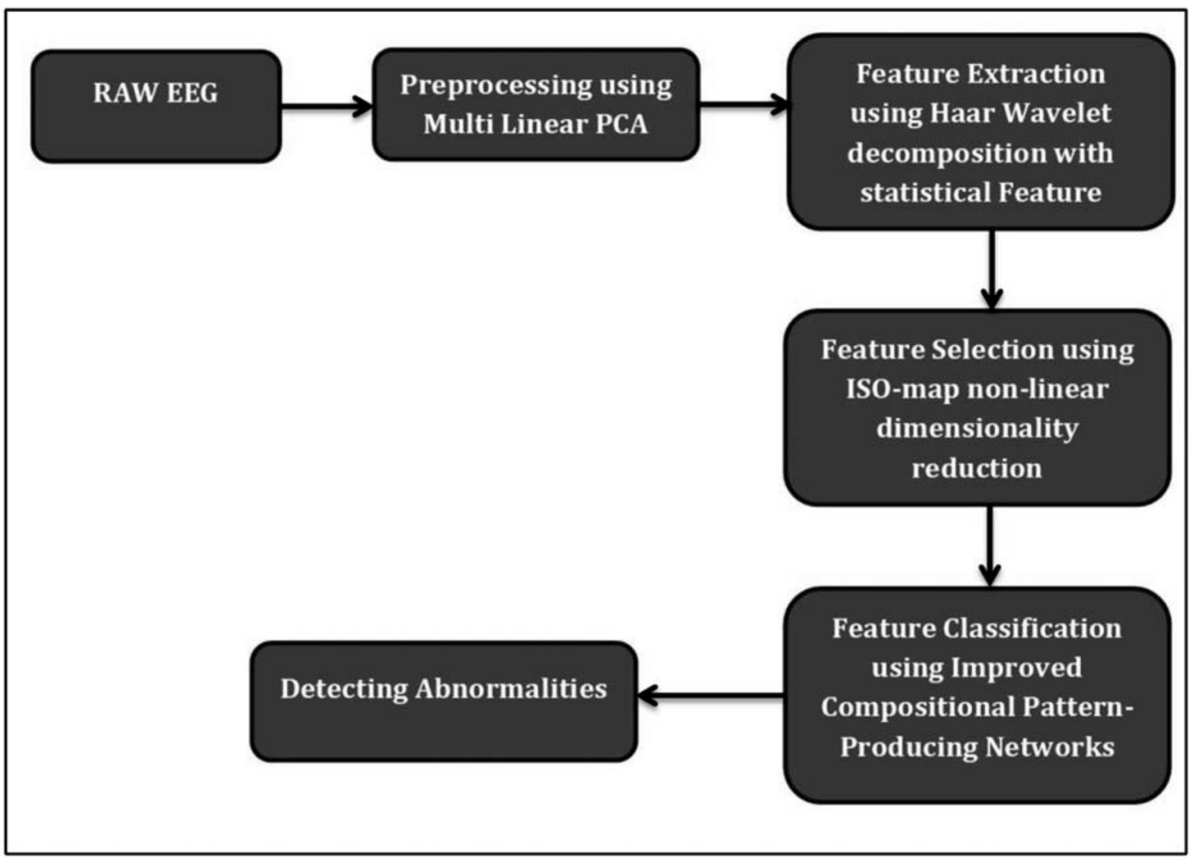

Figure 1: Proposed System Block Diagram

The above figure 1 explains that the automatic seizure detection system by applying the EEG signals. The recorded EEG signal is preprocessed and noises have been removed with the help of the Multi linear PCA method and the noise free signal is decomposed with several bands. From the decomposed band the various features are extracted and the best features are selected with the help of the ISO map non-linear dimensionality reduction method. The selected features are trained and affected abnormal features are classified by utilizing the Improved Compositional Pattern Producing Networks. Based on the matching criteria the abnormality has been identified and the efficiency of the system is analyzed using the experimental results. The rest of the section describes the detailed proposed seizure detection system.

3.1. EEG Preprocessing

The first process of seizure detection process is preprocessing because the recorded EEG signal consists of various noises like patient name, age and other irrelevant details which reduces the entire system performance. So, this paper uses the Multi-linear Principal Component Analysis approach [11] is used to remove the artifacts present in the EEG signal. The Multi-linear PCA analysis the recorded EEG signals in terms of n-way arrays. The analyzed signal is decomposed with the help of the Singular Value Decomposition (SVD) method which completely eliminates the unwanted information from the EEG signal. The SVD has the factorization is the basic operation of mxn matrix and it has another three matrix which follows.,

$$M = U\Sigma V^{*} \tag{1}$$

Where U is the mxm matrix of the left orthogonal matrix that is represented as the $U = [u_1, u_2 \ldots\ldots u_m]$ and ΣV^{*} is the rectangular diagonal matrix and the conjugated transpose the V($V = [v_1, v_2 \ldots\ldots v_n]$ of the *nxn* real matrix of the right orthogonal matrix which is represented as follows,

$$AA^{T} = U\Sigma V^{*} V\Sigma U^{T} = U\Sigma^{2}U^{T} \tag{2}$$

Where AA^T is the eigen vectors of columns of mxm matrices

$$A^{T}A = V\Sigma U^{T} U\Sigma V^{T} = V\Sigma^{2} V^{T} \tag{3}$$

Where A^TA eigen vector of nxn matrix column

Σ is the singular value which is having the non-negative values that is represented

As,

$$\Sigma = \text{diag}(\sigma_1, \sigma_2, \ldots\ldots \sigma_n) \tag{4}$$

Where, σ is the singular value of the A

The diagonal or singular value reflects the amount of variation in the EEG base matrix that is represented as follows,

$$\begin{bmatrix} \sigma_1 & 0 & \ldots & 0 & 0 & \ldots & 0 \\ 0 & \sigma_2 & \ldots & 0 & 0 & \ldots & 0 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ 0 & 0 & \ldots & \sigma_r & ..0. & \ldots & 0 \\ 0 & 0 & \ldots & 0 & .\sigma_{r+1}.. & \ldots & 0 \\ . & . & \ldots & . & . & . & . \\ . & . & \ldots & . & . & . & . \\ 0 & 0 & \ldots & 0 & 0 & 0 & \sigma_n \\ 0 & 0 & \ldots & 0 & 0 & 0 & 0 \end{bmatrix}$$

From the matrix, the first value is according to the direction of the greatest data variants and the remaining value depends on the orthogonal direction of the data variant. Then the SVD performs the rotation operation and align the transformed axis in the maximum data variant direction. Further the dimensionality of the EEG base matrix is reduced by the low rank decomposition process. The data variant which is having the highest rank that will be considered and eliminated for improving the overall efficiency of the system. Finally the recorded EEG signal consists of only low rank information because it consists of lot of useful information which is fed into the next feature extraction stage.

3.2. Feature Extraction

The next stage is feature extraction in which various useful details are retrieved by decomposing the preprocessed EEG signal. Initially the signal has been decomposed into different sub bands such as alpha, beta, gamma, delta and theta with the help of the Harmonic Wavelet Decomposition method [12]. This method analyzes the signal in the form of time frequency representation and decomposes the signal with efficient manner. The wavelet uses the two integers namely *j* and *k*, where *j* represented as the level of the signal and *k* is the translation of the EEG signal. By using this integers the wavelet is represented as follows,

$$\omega(t) = \frac{e^{i4\pi t} - e^{i2\pi t}}{i2\pi t} \tag{5}$$

The represented wavelets are orthogonal and the Fourier transforms are represented in the square window function which is satisfies as follows.

$$\int_{-\infty}^{\infty} \omega^*(2^j t - k).\, \omega(2^{j'} t - k')dt = \frac{1}{2^j}\delta_{j,j'}\, \delta_{k,k'} \tag{6}$$

Where *represented as the complex conjugation and δ is the kronecker's data.

The level of the wavelets increased with less localized time which leads to decompose the signal into different bands. So, the arbitrary function is used to represent as the behaviors of the function with various timescales. In order to combine the negative orders together into a single family of scaling function as follows,

$$\varphi(t) = \frac{e^{i2\pi t} - 1}{i2\pi t} \tag{7}$$

Table 1
List of Features

Features	*Related Formula*
Entropy	$\sum_{i,j=0}^{n-1} - \ln(P_{ij})P_{ij}$
Variance	$\sum_{i=0}^{n-1}\sum_{j=1}^{n-1}(i-\mu)^2.\, p(i,j)$
Mean	$\sum_{i=0}^{2(n-1)} i.\, p_{x+y}(i)$
Standard Deviation	$\sqrt{\left(\sum_{i=0}^{2(n-1)} i.\, p_{x+y}(i)\right)^2}$

The function φ is orthogonal which contains the different *k* value and also the negative function of the wavelet is represented as follows,

$$\int_{-\infty}^{\infty} \varphi^*(t-k).\, \varphi(t-k')dt = \delta_{k.k}{}' \tag{8}$$

By using the orthogonal functions, the harmonic wavelet function is defined in the arbitrary real value $f(t)$ is represented as follows,

$$f(t) = \sum_{j=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} [a_{j,k}\omega(t - K)] + \hat{a}_{j,k}\omega^*(2^j\, t - k)] \tag{9}$$

From the above equations, the signal has been decomposed into different sub bands in the particular frequency like, delta contains the 0-4Hz, Theta contains the 4-7 Hz, Alpha includes the 8-13 Hz, Beta includes the 13-30 Hz and finally Gamma retrieved in the 30-100 Hz with efficient manner. From the decomposed sub bands various features such as mean, variance, standard deviation and entropy features are extracted as follows.

The extracted features are fed into the next feature selection process for reducing the dimensionality of the feature also the method selects the optimal features with efficient manner.

3.3. Feature Selection

The third stage of the seizure detection system is feature selection which is done with the help of the ISO-map non-linear dimensionality reduction approach. ISO-map [13] is one of the isometric mapping methods which compute the quasi-isometric, low dimensional embedding set of the high dimensional data points with effective manner. From the mapped value the geodesic distance has been estimated from the large amount of feature set. Usually the pairwise distance between the data point is calculated with the help of the Euclidean distance measure that completely analysis the neighborhood information. From the neighborhood value the optimized feature set has been identified efficiently by constructing the Dijkstra's graph. From the constructed graph shortest path between the nodes are analyzed from top n nodes using the distance matrix. Then the algorithm of the ISO-map based feature selection process is discussed as follows.

3.3.1. Algorithm for ISO-map Feature Selection Process

Algorithm for ISO-map

Step 1: Analyze and determine the neighbors of each feature point by calculating the radius and Distance of the feature.

Step 2: From the calculated neighboring value, graph need be constructed with the help of the Euclidean distance measure.

Step 3: Compute the shortest path between the two nodes using the Dijkstra's algorithm.

Step 4: Finally compute the lower dimensionality of the feature with efficient manner.

3.4. Feature Classification

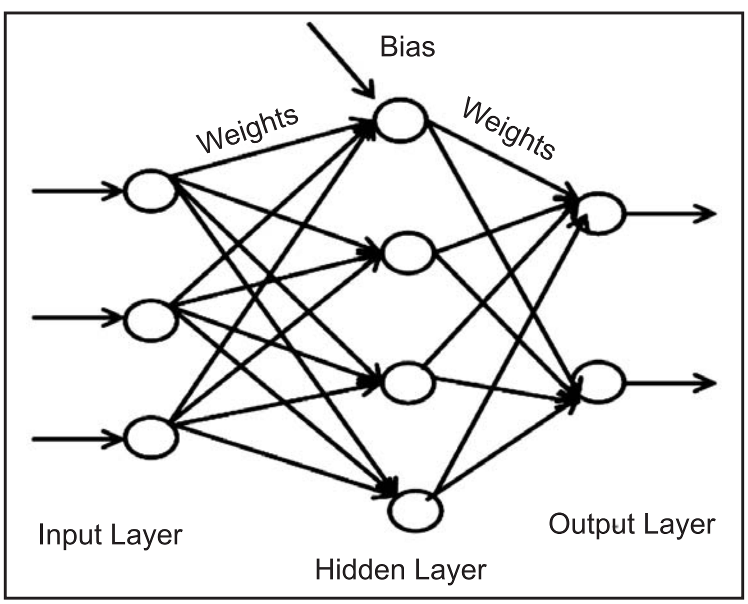

Figure 2: Neural Network Structure

The last stage of the seizure detection system is feature classification which is done with the help of the Improved Compositional Pattern-Producing Networks approach [14]. The neural network is one of the supervised neural networks which are used to classify the selected EEG features. It has different layers namely, input, hidden and output layer which processes the selected features with the weights and bias and every layer has its own weights and bias. The diagrammatic representation of the neural network is shown in the figure 2.

During the output calculation, each layer input is multiplied by corresponding weight value and addition is performed with the bias value. The net output calculation of the neural network is done by with the help of following equation.

$$\text{Net output} = \sum_{i=1}^{N} x_i * w_i + b \tag{10}$$

These weights and bias are used to adjust the error rate in the neural networks. In normal neural network updating of weights and bias increases the mean square error rate which leads to decreases the classification accuracy. So, the intelligent water drop optimization algorithm is utilized to reduce the error rate in the classification process. The weights and bias are optimized by applying the static and dynamic parameter which same as the velocity and soil updating. The updation of weights and bias process is done by applying the following equation (11) in which, each weights are checked against the static and dynamic parameter for optimize those values.

$$\text{velocity}(t+1) = \text{vel}(t) + \left(\frac{q}{b_v + c_v * \text{soil}^{2a}(i, j)} \right) \tag{11}$$

Where, velocity $(t + 1)$ = velocity for next feature, *bv*, *cv*, *q*-Static and dynamic Parameters

After adjusting the weights and bias, the features are trained by using the different type of function such as sigmoid, Gaussian function. The choice of the function is according to the canonical set of the network bias the related feature pattern. Furthermore the CPPN network analyzes the possible inputs from the set of feature to match the testing features with the trained features with efficient manner. Thus the proposed system efficiently determines the seizure related features with minimum error rate and maximum recognition rate.

4. RESULTS AND DISCUSSIONS

In this paper, CHB-MIT scalp EEG dataset [15] has been used to develop the automatic seizure detection system. The EEG is recorded from the 22 subjects such as 5 males age between 3 to 22 and 17 females age from 15-19. The subjects are fed into the laboratory and recording the 23 EEG signals by 256 sampled process. The recorded EEG signal is used to evaluate the efficiency and performance of the proposed automatic system. MATLAB 7.6 has been used to implement the proposed system, training and testing is run on the standard PC with 1GB RAM and 1.66 GHz Intel processor. In Training phase, 80% of seizure and healthy non-seizure signals from the data set has been used to train the classifier, whereas in the testing phase 20 % of seizure and healthy non-seizure signals from the data set has been used to test the classifier. Then the performance of the proposed system is evaluated in terms of the accuracy, sensitivity and specificity.

4.1. Performance Metrics

Sensitivity

Sensitivity [22]is also called as the true positive rate, which is used to measure how the proposed system correctly classify the true positive.

$$\text{Sensitivity} = \frac{\text{True Positive}}{\text{True Positive} + \text{False Negative}} \tag{12}$$

Where True positive is successfully or correctly identified value and the False Negative is successfully rejected value.

Specificity

Specificity [23] is also called as the true negative rate, which is used to measure how the proposed system correctly classifies the false values.

$$\text{Specificity} = \frac{\text{True Positive}}{\text{False Positive} + \text{True Negative}} \quad (13)$$

Where True negative is successfully or correctly rejected value and false positive is successfully rejected value.

Classification

Classification accuracy [24] is the measure which is used to estimate how the proposed system successfully classified the number of heart beats in the correct manner which is determined as follows,

$$\text{Classification Accuracy} = \frac{\text{Number of instances classified correctly}}{\text{Total number of instances}} \quad (14)$$

4.2. Performance Analysis

The performance of the proposed HWPD-ICPPN and ISO-map system is compared with the existing methods such as Principal Component Analysis (PCA), Support Vector Decomposition (SVD), Genetic Algorithm (GA) and proposed feature selection method. The feature selection process improves the efficiency of the seizure detection system which is shown in the following figure 3.

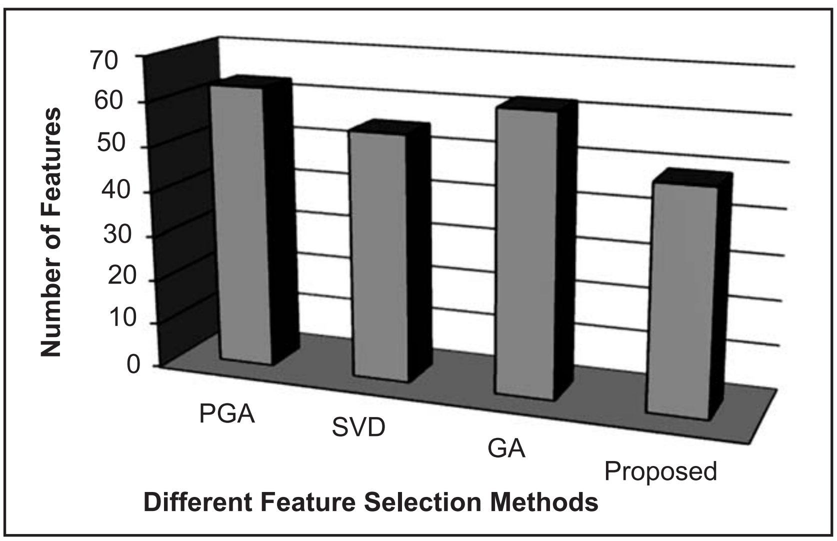

Figure 3: Performance of Various Feature Selection Methods

Figure 3 clearly explains that the proposed ISO-map linear dimensionality reduction method selects the optimized features and minimizes the dimensionality of the feature set than compared to the existing method because the proposed system selects the features according to the connectivity between the features which is analyzed using the graph construction process. The optimized features reduces the error rate which is shown in the figure 4 that helps to identify how the proposed system exactly selects the optimized features from the huge amount of feature set.

The above figure 4 explains that the proposed classifier obtain the minimum mean square error which means it correctly identify the abnormality features from the selected feature set. The minimized error rate leads to increase the sensitivity, specificity of the proposed system which is discussed as follows.

The proposed system ensures the 99.67% sensitivity overall, while the other classification methods such as Support Vector Machine, Multi-layer Perceptron (MLP) and Radial Basis Function Neural Network attains the 93.64%, 95.32% and 96.43% which is shown in the figure 5.

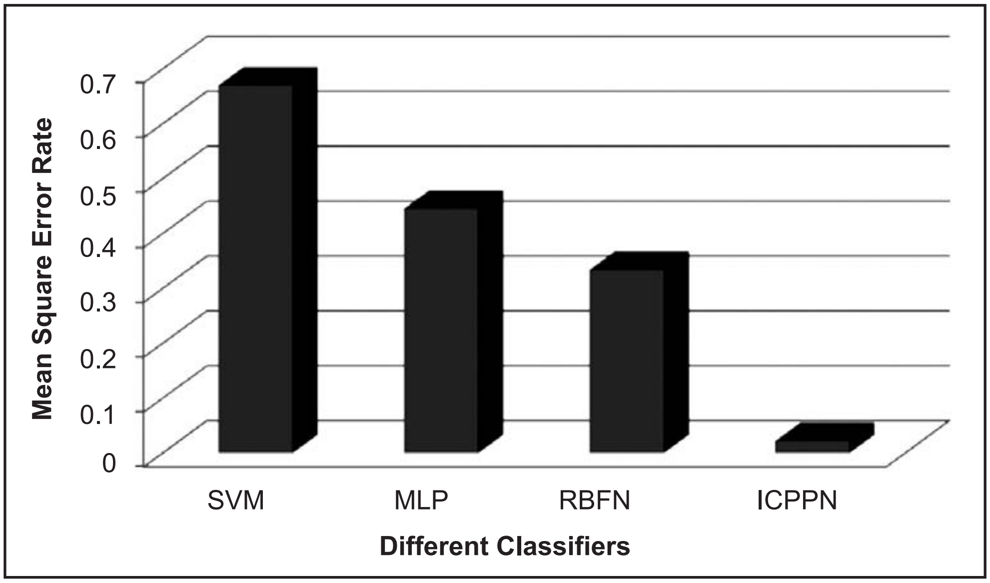

Figure 4: Error Value of the Various Classifiers

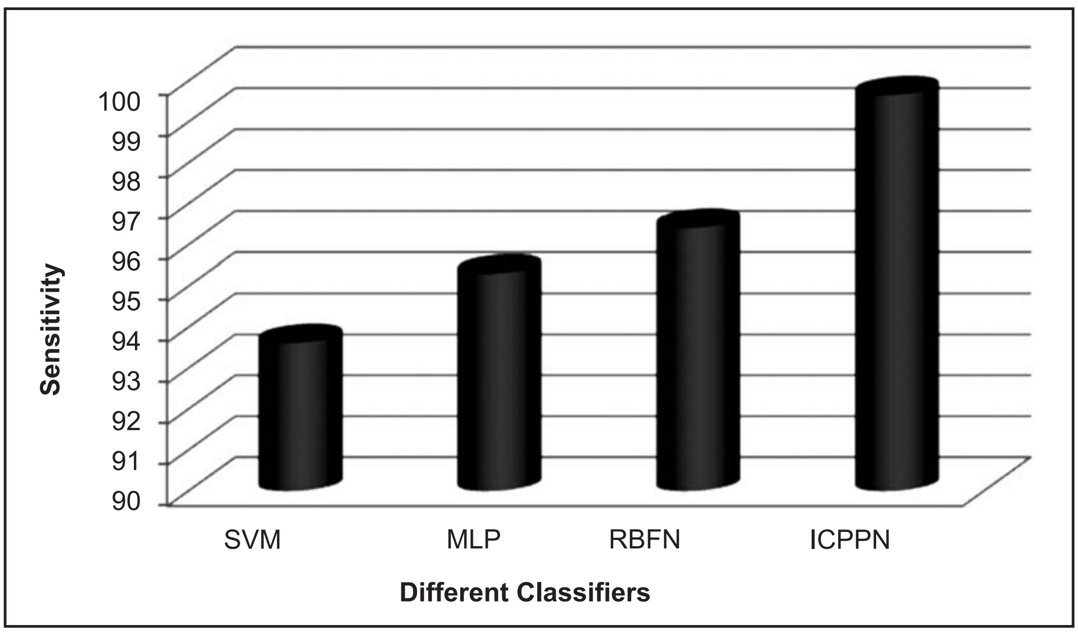

Figure 5: Sensitivity

Figure 6 shows the specificity of different classification techniques the proposed approach PBNN attains 99.93 % specificity overall, while the SVM, MLP and RBFNN attains 93.126%, 94.362 %, 96.126%.

Figure 7 shows the accuracy of different classification techniques, the proposed approach ICPPN attains 99.78 % accuracy overall, while the SVM, MLP; RBFN attains 93.6 %, 95.37% and 96.43%

Thus the proposed system classifies the epilepsy disease in an efficient manner when compared to the existing methods such as Support vector machine, Multilayer Perceptron and Radial Basis Function Networks. In addition, the proposed system overcomes the existing classifiers drawbacks like error rate during the classification and the maximum number of features. The dimensionality of the feature reduced by the optimal feature selection method and the reduced features is trained with the help of the optimized neural network which reduces the mean error rate during the classification. So, the proposed system classifies the seizure diseases with highest accuracy 99.78% with minimum error rate.

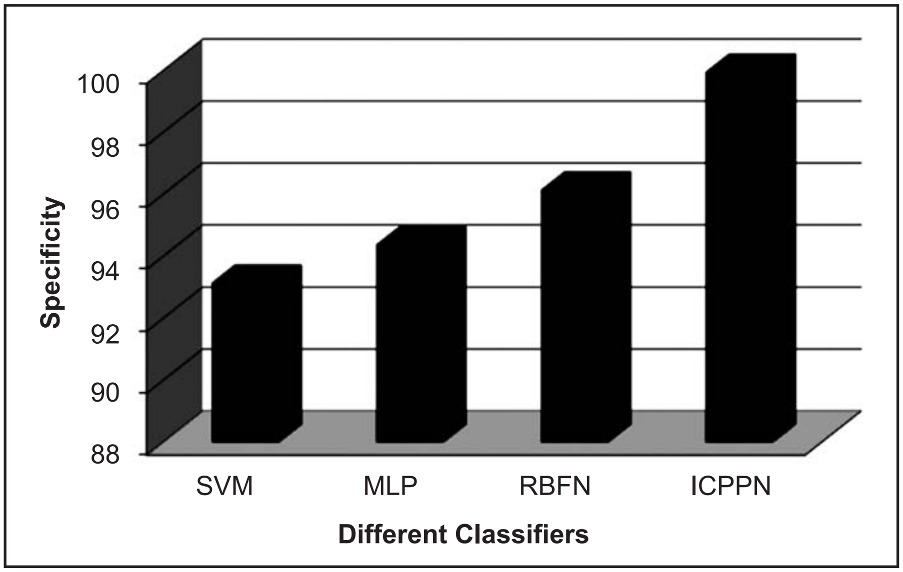

Figure 6: Specificity

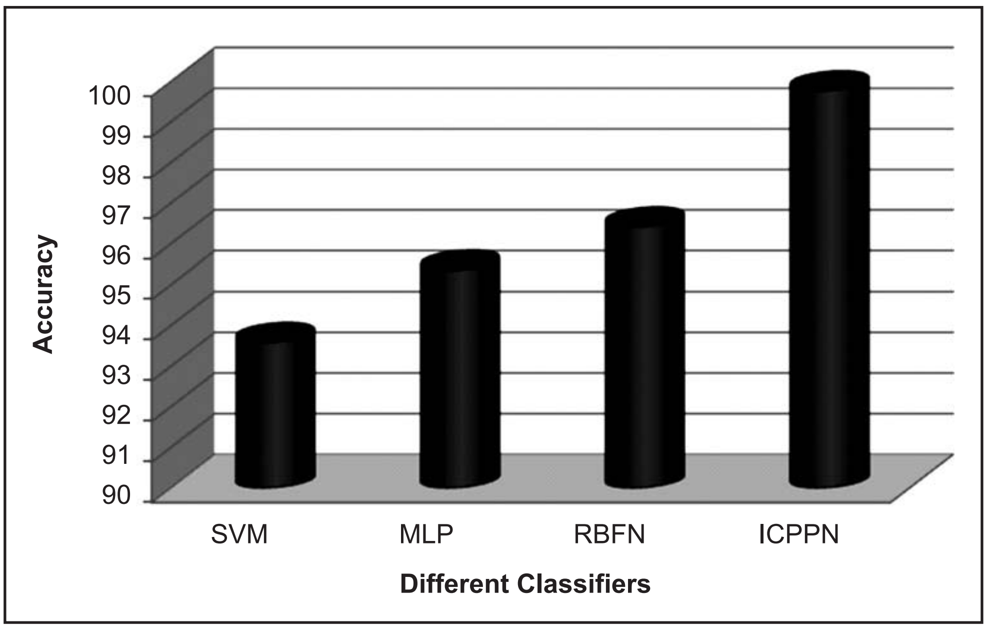

Figure 7: Accuracy

5. CONCLUSION

This paper proposes an effective approach HWPD-ICPPN based automatic seizure detection system from the EEG signal. Initially the EEG signal is preprocessed by using the multi-linear Principal Component Analysis which removes the unwanted information and errors. Then the Harmonic wavelet decomposition method decomposes the EEG signals into different bands such as alpha, beta, gamma, theta and delta. From decomposed bands, various features are extracted and the optimized features have been selected using the ISO-map linear dimensionality reduction method. The method selects the optimized features according to the connectivity and the effective activation function is utilized in the ICPPN method to recognize the seizure with effective manner. Then the performance of the proposed system is evaluated with the help of the experimental results and discussions.

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