Chapter 6

# Conclusions and Future work

## 6.1 Conclusions

In this thesis, we proposed an alternative model called Multidimensional Radial Wavelon Feed-Forward Wavelet Neural Network (MRW-FFWNN), based on wavelet analysis and neural networks, for classification of three classes of EEG signals: Ictal, Interictal and Healthy. In order to find a suitable combination of tools to improve the results reported for this problem, we tested several filters, wavelets and wavelet transformations. The EEG signals used in the experiments reported in this research come from a free-available EEG database, provided by the University of Bonn [BON16]. Two approaches for filtering were tested, IIR and FIR filters. The filtering of the EEG signals was performed in order to remove noise added during recording in the EEG signals. The designed filters and used for this task were an IIR Chebyshev type II filter of order 24, an Elliptic filter of order 9, a FIR filter Equiripple of order 343 and a Least Squares filter of order 350. The decomposition of EEG signals into delta ($\delta$) and alpha ($\alpha$) sub-bands and feature extraction were carried out using the DWT and MODWT by two criteria for the suitable wavelet choice. The criterion 1 selected the wavelet that gave the average highest of the correlations coefficients for each class of the EEG signals. The criterion 2 selected the wavelet that provided the highest number of times that such wavelet obtains the best correlation coefficient obtained for each class of the EEG signals. We selected the Daubechies (Db2, Db4, Db6, Db8 and Db10), Coiflet (Coif1, Coif2, Coif3, Coif4 and Coif5) and Symlet (Sym2, Sym4, Sym6, Sym8 and Sym10) wavelet families to obtain the correlation coefficients with the EEG signals. Each EEG signal was represented by a feature vector of six components, built using the mean, absolute median and variance of both delta ($\delta$) and alpha ($\alpha$) sub-bands. These feature vectors were considered as inputs for the classifiers described in this work, including our proposed classifier MRW-FFWNN.

We obtained results for the classification of three classes of EEG signals with our proposed model MRW-FFWNN as classifier using several structures of binary-tree and VOTE and WV strategies in a OVO decomposition scheme. For comparison proposes, we also analyzed the classification performance of other classifiers: FF- ANN, Elman network, FFWNN, SRWNN and MRW-SRWNN using the same strategies of classification. The best result obtained with our proposed model MRW-FFWNN was of **96.67 %** of accuracy with a binary-tree strategy (see Table 5.9). The same percentage of accuracy was obtained using features calculated by the criteria 1 and 2. The result obtained by the criterion 1 was using features calculated with an Elliptic filter and MODWT for a Ic-In- H structure. For the criterion 2, the best result was obtained using features calculated by an Equiripple-MODWT for a H-In-Ic structure. It should be noticed that our best result is greater than [MAR12] and it is slightly lower than the ones reported in some papers, for example [GHO07], [WAN13], [SHE10], [DUQ14]. We also obtained results for classification of three classes of EEG signals but using only Coiflet 3 and Symlet 8 wavelets, according to criteria 1 and 2, respectively, in the decomposition of EEG signals for all EEG signals. The best result was no better than the previous, we obtained a 93.33 % of accuracy using features calculated by both criteria, 1 and 2.

Some advantages of our proposed approach are that the number of inputs for the classifier is small, due to that only we consider three features for each subband (delta and alpha), with a total of six components of input, therefore our proposed classifier uses less inputs than other classifiers [GHO07], [WAN13], [SHE10], [MAR12] and features inputs are calculated by simples statistical methods. Also, our proposed model reduces the number of adjusting parameters in the net. Finally, we conclude the best result obtained with our proposed approach is similar to other works reported in the state-of-the-art algorithms in the classification to epilepsy-related stages. Therefore, our model can be considered as an alternative for the classification of EEG signals.

The main contributions in this thesis can be summarized as follows.

1. A novel structure was proposed to enhance the classification accuracy of epilepsy on EEG signals by the implementation of a system based on Wavelet-Based Neural Networks. The proposed model is called Multidimensional Radial Wavelon - Feed Forward Wavelet Neural Network (MRW-FFWNN).

2. An optimal selection of mother wavelet was proposed to enhance the classification of several stages identified in EEG signals related to epilepsy.

3. The combination of binary-tree and OVO decomposition strategies with structures WNN were also proposed for classification of EEG signals.

## 6.2 Future work

As future work we will be focused on investigating other possible training algorithms or classifiers and a better feature selection considering other wavelets. The EEG signals can also be analyzed by the Hilbert-Huang Transform (HHT) proposed by Norden E. Huang [HUA08]. The HHT technique for analyzing data consists of two components: a decomposition algorithm called Empirical Mode Decomposition (EMD) and a spectral analysis tool called Hilbert spectral analysis. The HHT can provide a local description of the oscillating components of a signal, whether non-stationary or non-linear [HUA08]. This provides a new approach for analyzing the variability of signals and can be compared with current tools as any of the methods previous in this work.

EMD is a spontaneous multi-resolution method that represents nonlinear and non stationary data as a sum of oscillatory modes inherent in the data, called Intrinsic Mode Functions (IMFs) [MAN13]. Any complicated data set can be decomposed into a finite and small number of IMFs that well-defined Hilbert transforms. The decomposition is based on local characteristics of time and scale of the data. The features of the EEG signals can be extracted from IMFs, time domain or frequency domain, such as: spectral peak magnitude, peak frequency, spectral entropy or spectral energy. These features can be used in the classifiers based on WNN and can improve the classification accuracy.

The learning algorithm can be improved by choosing an appropriate learning rate. Since the learning rate is an essential factor for determining the performance of the classifier trained via gradient descent method, it is important to find the optimal learning rate. Therefore, this algorithm can be improved by using adaptive learning rates method [SUN07] for the training of all weights of MRW-FFWNN. The adaptive learning rates can be derived from discrete Lyapunov stability theorem [SUN07] and these can guarantee the convergence of the MRW-FFWNN.

The positive predictive value (PPV) could be consider as other metric to evaluate the results of these experiments, PPV would give a less biased assessment in the classifier performance. PPV is the proportions of positive results in statistics and diagnostic tests. PPV is defined as the proportion of the number of true positives respect to the number of true positives and the number of false positives. A "true positive" is the event that the test makes a positive prediction, and the subject is correctly identified, and a "false positive" is the event that the test makes a positive prediction, and the subject is incorrectly identified [ALA14].