MODELING BRAIN WAVE DATA BY USING ARTIFICIAL NEURAL NETWORKS

Cagdas Hakan Aladag[*][†], Erol Egrioglu[‡], Cem Kadilar[*]

Abstract

Artificial neural networks can successfully model time series in real life. Because of their success, they have been widely used in various fields of application. In this paper, artificial neural networks are used to model brain wave data which has been recorded during the Wisconsin Card Sorting Test. The forecasting performances of different artificial neural network models, such as feed forward and recurrent neural networks, using both linear and nonlinear activation functions in the output neuron, are examined. As a result of the analysis, it is found that artificial neural networks model the data successfully and all the models employed produce very accurate forecasts.

Keywords: Activation function, Brain wave data, Elman recurrent neural networks, Feed forward neural networks, Forecasting, Wisconsin card sorting test.

2000 AMS Classification: 62 M 10, 82 C 32, 90 C 59, 62–04.

1. Introduction

Since artificial neural networks can model both the linear and the nonlinear structure of time series, they have attracted more and more attention from both academic researchers and industrial practitioners in recent years [7]. Artificial neural networks have been widely used to model time series in various fields of applications [4], and used as a good alternative method for both linear and non-linear time series forecasting. Zhang *et al.* [11] presented a review of the current status in applications of neural networks for forecasting.

[*]Department of Statistics, Hacettepe University, 06800 Beytepe, Ankara, Turkey.
E-mail: (C. H. Aladag) `aladag@hacettepe.edu.tr` (C. Kadilar) `kadilar@hacettepe.edu.tr`
[†]Corresponding Author.
[‡]Department of Statistics, Ondokuz Mayis University, Samsun 55139, Turkey.
E-mail: `erole@omu.edu.tr`

In addition to its general success in modeling time series in real life, the use of artificial neural networks to model brain wave date is particularly appropriate since their creation was inspired by biological nervous systems. On the other hand, there are different types of artificial neural networks, such as feed forward and recurrent neural networks, and these networks also have a lot of components. Therefore, it is necessary to determine which type of artificial neural network works better on brain wave data. We examine the influence of network type, such as feed forward and Elman recurrent neural networks, and activation functions such as linear and logistic, which are used in the output neurons, on the forecasting performance by analyzing brain wave data which has been recorded during the well known Wisconsin Card Sorting Test. We try to determine the artificial neural network model which gives the best forecasting values. From the results obtained, it is seen that artificial neural networks produce very accurate forecasts for the brain wave data examined.

The paper is organized as follows. Section 2 defines the brain wave data. Section 3 gives an overview of artificial neural networks. Section 4 explains the analysis of the data and gives the performance comparison reports for artificial neural network models used in the forecasting process. Finally, there are some concluding remarks in Section 5.

2. The brain wave data

The Wisconsin Card Sorting Test is a neuropsychological test. Clinically, the test is widely used by psychiatrists, neurologists and neurophysiologists in patients with acquired brain injury, neurodegenerative disease, or mental illness such as schizophrenia. Detailed information about Wisconsin Card Sorting Test can be found in Eling *et al.* [3].

This test was applied to 45 people and two types of signal were recorded per two millisecond. One type of signal was that recorded when the right answers were given, and the second when the wrong answers were given. Then mean values of these signals for the 45 people were calculated for each type of signal. In this way, we have the two series shown in Figure 1 and Figure 2, respectively. Both of these series have 500 data.

Figure 1. The plot of Series 1
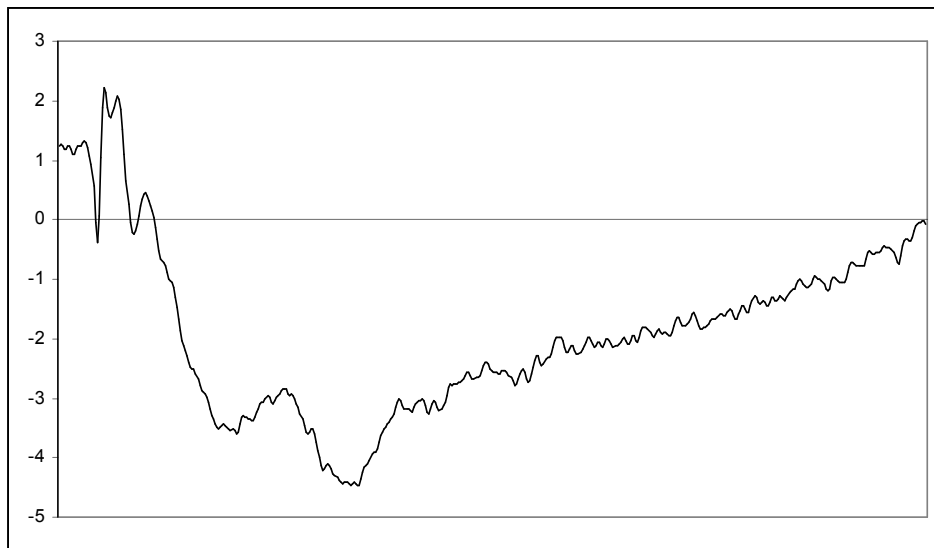
**Figure 2. The plot of Series 2**
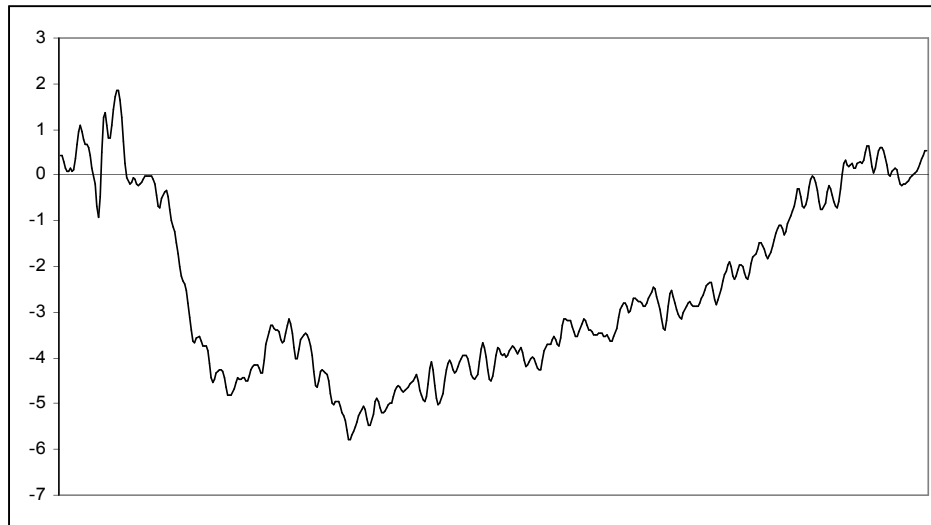
3. Artificial neural networks

"What is an artificial neural network?" is the first question that should be answered. Picton [6] answered this question by separating the question into two parts. The first part is why it is called an artificial neural network. It is called an artificial neural network because it is a network of interconnected elements. These elements were inspired from studies of biological nervous systems. In other words, artificial neural networks are an attempt at creating machines that work in a similar way to the human brain by building these machines using components that behave like biological neurons. The second part is what an artificial neural network does. The function of an artificial neural network is to produce an output pattern when presented with an input pattern.

In forecasting, artificial neural networks are mathematical models that imitate biological neural networks. Researchers have used an artificial neural networks methodology to forecast many nonlinear time series events in the literature [10]. The methodology consists of various elements. Determining the elements of the artificial neural network is an issue that affects the forecasting performance of the network, and should be considered carefully. The elements of an artificial neural networks are generally described as the *network architecture*, *learning algorithm* and *activation function.*

One critical decision is to determine an appropriate architecture, that is, the number of layers, number of nodes in each layer and the number of arcs which interconnect the nodes [12]. However, in the literature, there are no general rules for determining the best architecture. Therefore, many architectures should be tried in order to obtain correct results.

There are two main types of artificial neural network. One of them is called a *feed forward* neural network. The feed forward neural networks have been used successfully in many studies for forecasting. In feed forward neural networks, there are no feedback connections. Figure 3 depicts a broad feed forward neural network architecture that has a single hidden layer and a single output.

Figure 3. A broad feed forward neural network architecture
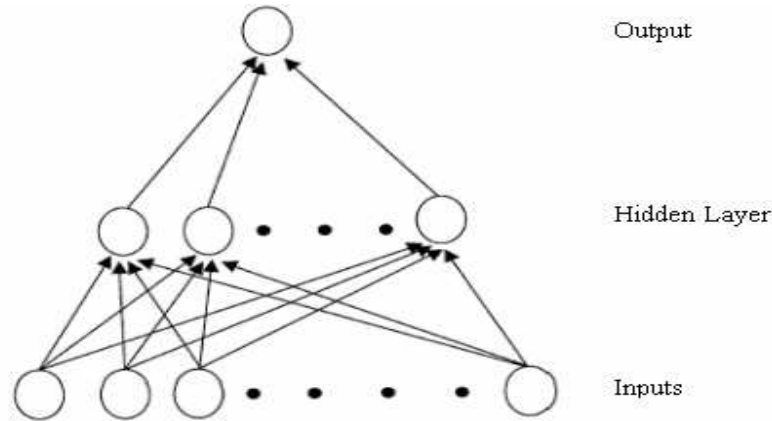
Recurrent neural networks are another main type of artificial neural network. Although the feed forward neural networks have been used in most applications of artificial neural networks, it is also possible to use the recurrent neural networks. One type of recurrent neural network is the *Elman recurrent neural network*, which was introduced by Elman [4]. According to the general principle of the recurrent networks, there is a feedback from the outputs of some neurons in the hidden layer to neurons in the context layer, which is seen as an additional input layer. Compared with other types of multilayered network, the most important advantage of the Elman recurrent neural network is a robust feature extraction ability, which provides feedback connections from the hidden layer to a context layer [9]. The structure of an Elman recurrent neural network is illustrated in Figure 4.

Figure 4. Structure of an Elman recurrent neural network model [5]
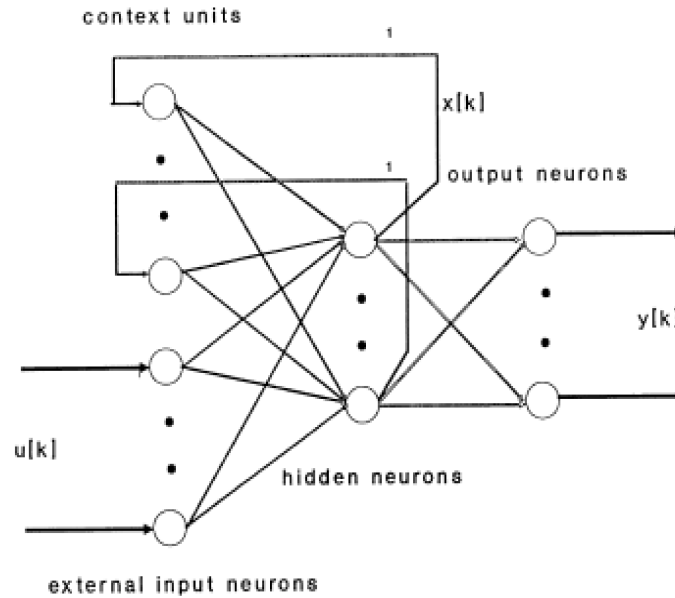
The learning of a specific task by an artificial neural network is equivalent to finding the values of all weights such that the desired output is generated by the corresponding input. Various training algorithms have been used for the determination of the optimal weight values. The most popularly used training method is the *back propagation algorithm* presented by Smith [8]. In the back propagation algorithm, learning of the artificial neural network consists of adjusting all weights by considering the measure of the error between the desired output and actual output [2].

Another element of an artificial neural networks is the *activation function*. This determines the relationship between inputs and outputs of a network. In general, the activation function introduces a degree of the non-linearity that is valuable in most applications of artificial neural networks. The best known activation functions are the *logistic, hyperbolic tangent, sine* (or *cosine*) and the *linear functions*. Among these, the logistic activation function is the most popular [11].

4. Analysis

The brain waves, which have been recorded during the Wisconsin Card Sorting Test, are modeled by using the feed forward neural networks (FNN) and the Elman recurrent neural networks (ERNN). Four artificial neural networks models, whose properties are given in Table 1, are set up to obtain the most accurate results for the two series. In the output node, both linear and nonlinear activation functions are used for each type of these networks. We used the logistic activation function, which is commonly used as a nonlinear activation function in the literature. We would like to note that the linear or logistic activation function given in (4.1) and (4.2), respectively, are used in the output nodes for the different models, while the logistic activation function is used in the nodes of the other layers of all models.

(4.1) $f(x) = x$

(4.2) $f(x) = (1 + \exp(-0.8\,x))^{-1}$

Table 1. The properties of the models

Model Name	Activation Function	Network Type
M1	linear	ERNN
M2	logistic	ERNN
M3	linear	FNN
M4	logistic	FNN

Both series have 500 data. These data are divided into two sections: the training data and the test data. 450 points are used for the training data and 50 points for the test data. In the training process, the Levenberg Marquardt method is used as a training algorithm, since it is an efficient nonlinear optimization method and is used in many optimization packages such as MATLAB. For each model, the best architecture is determined by varying the number of inputs from 1 to 8 and the number of nodes in the hidden layer from 1 to 8. In addition to this, one neuron is used in the output layer of all models. Therefore, for each of the models, 64 architectures are examined, and the architecture which has the smallest value of the *root mean square error* (RMSE) whose formula is given by (4.3), is determined as the best architecture. In the literature, the most preferred performance measure is the RMSE value. In most of the artificial neural networks studies, the RMSE

criterion has been used to determine the best architecture. Therefore, RMSE is employed as performance measure in this implementation.

$$(4.3) \qquad \text{RMSE} = \left(\frac{\sum_{i=1}^{T}(y_i - \hat{y}_i)^2}{T} \right)^{1/2},$$

where y_i is the actual value, $\hat{y}_i$ the predicted value and T the number of data. The values of RMSE are calculated for the test data. In order to make results sound, some other well known criteria such as the *mean absolute percentage error* (MAPE), and the *median absolute prediction error* (MdAPE) are also calculated for the selected architecture.

Four models for each series are used and in this way, the eight best architectures are determined. For these architectures, the calculated RMSE, MAPE, and MdAPE values are summarized in Table 2.

Table 2. Results of the analysis

Series 1	Model	Best Architecture	RMSE	MAPE	MdAPE
	M1	8–5–1	0.0304	0.000100	0.0067
	M2	8–3–1	0.0292	0.000017	0.0039
	M3	4–8–1	0.0299	0.000101	0.0114
	M4	4–7–1	0.0290	0.000011	0.0007
Series 2	Model	Best Architecture	RMSE	MAPE	MdAPE
	M1	6–1–1	0.0501	0.000010	0.0011
	M2	8–3–1	0.0530	0.001500	0.0743
	M3	6–2–1	0.0498	0.000006	0.0003
	M4	8–2–1	0.0526	0.001300	0.0640

According to the values of RMSE in Table 2, it is observed that accurate forecast values are obtained, and that there is no big difference among the results of the artificial neural network models. This shows that the artificial neural networks can model the examined brain waves successfully. For Series 1, the most successful model is M4, with the architecture 4–7–1, that is, a feed forward neural network with 4 input neurons, 7 nodes in the hidden layer and one output node in which the logistic activation function is used.

The other results in Table 2 can be interpreted in a similar way. For Series 2, the best model is M3 with architecture 6-2-1, that is, a feed forward neural network with 6 input neurons, 2 nodes in the hidden layer and one output node in which the linear activation function is used. M3 is the best model for Series 2 in terms of all calculated criteria.

The perfect fit of the actual and the predicted values by the best artificial neural network models mentioned above can be seen visually in Figure 5 and Figure 6. In these figures, the solid line represents the original data and the dotted line represents the forecasted values.

When these plots are examined, it is clearly seen that the determined artificial neural network models produce very accurate forecasts.

Figure 5. Actual data and forecast values produced by the best model for the 50 test data of Series 1

Figure 6. Actual data and forecast values produced by the best model for the 50 test data of Series 2

5. Conclusion

The success of artificial neural networks has been proved in various fields of application. Artificial neural networks consist of artificial neurons which imitate biological neurons. Due to the framework of this method, it could be appropriate to use this

method for modeling waves produced by neurons in the brain. In this paper, the brain wave data, which were recorded during the Wisconsin Card Sorting Test, are analyzed by using artificial neural networks. Both feed forward and Elman recurrent neural networks are employed. In addition, both linear and logistic activation functions are employed in the output neuron. By using combinations of these different components of artificial neural networks, different models are set up to forecast the series. The RMSE values are calculated from the test data, and the best models are determined. For the forecasts obtained, other performance criteria such as MAPE and MdAPE are also calculated to show that the obtained results are reliable. Then the forecasting accuracy of the best models is also examined visually by graphs for the test data. According to the results obtained, it is clearly seen that all of the models produce very accurate forecast values. In another words, artificial neural networks are successful in all the cases examined. Consequently, accurate forecast values are obtained when artificial neural networks are used to analyze the brain waves data examined.

References

[1] Buhamra. S., Smaoui. N. and Gabr. M. *The Box-Jenkins analysis and neural networks: Prediction and time series modeling*, Applied Mathematical Modeling **27**, 805–815, 2003.

[2] Cichocki. A. and Unbehauen. R. *Neural networks for optimization and signal processing* (John Willey & Sons, New York, 1993).

[3] Eling, P., Derckx, K. and Maes, R. *On the historical and conceptual background of the Wisconsin Card Sorting Test*, Brain and Cognition **67**, 247–253, 2008.

[4] Elman, J. L. *Finding structure in time*, Cognitive Science **14**, 179–211, 1990.

[5] Pham, D. T. and Karaboga, D. *Inteligent Optimisation Techniques - Genetic Algorithms. Tabu Search. Simulated Anealing and Neural Networks* (Springer, 2000).

[6] Picton, P.D. *Introduction to Neural Networks* (Macmillan Press Ltd., 1994).

[7] Qi, M. and Zhang, G. *An investigation of model selection criteria for neural network time series forecasting*, European Journal of Operational Research **132**, 666–680, 2001.

[8] Smith, K.A. *Neural networks in business: techniques and applications* (Imprint Info Hershey: Idea Group, 2002).

[9] Şeker, S.. Ayaz, E. and Türkcan, E. *Elman's recurrent neural network applications to condition monitoring in nuclear power plant and rotating machinery*, Engineering Applications of Artificial Intelligence **16**, 647–656, 2003.

[10] Ture, M. and Kurt, I. *Comparison of four different time series methods to forecast hepatitis A virus infection*. Expert Systems with Applications **31**, 41–46, 2006.

[11] Zhang, G.. Patuwo. B.E. and Hu. Y.M. *Forecasting with artificial neural networks: the state of the art*, International Journal of Forecasting **14**, 35–62, 1998.

[12] Zurada, J.M. *Introduction of Artificial Neural Systems* (St. Paul: West Publishing, 1992).