Short-Term And Long-Term Ahead Prediction Of Northern Hemisphere Sunspots Chaotic Time Series Using Dynamic Neural Network Model

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ABSTRACT
Multi –Step ahead prediction of a chaotic time series is a difficult task that has attracted increasing interest in recent years. The interest in this work is the development of nonlinear neural network models for the purpose of building multi-step chaotic time series prediction. In the literature there is a wide range of different approaches but their success depends on the predicting performance of the individual methods. Also the most popular neural models are based on the statistical and traditional feed forward neural networks. But it is seen that this kind of neural model may present some disadvantages when long-term prediction is required. In this paper focused time lagged recurrent neural network (FTLRNN) model with gamma memory is developed not only for short-term but also for long-term prediction which allows obtaining better predictions of northern chaotic time series in future. The authors experimented the performance of this FTLRNN model on predicting the dynamic behavior of typical northern sunspots chaotic time series. Static Multilayer perceptron (MLP) and self organizing feature map (SOFM) model is also attempted and compared against the proposed model on the performance measures like mean squared error (MSE), Normalized mean squared error (NMSE) and Correlation Coefficient (*r*). The obtained results indicate the superior performance of estimated dynamic FTLRNN based model with gamma memory over the static MLP NN in various performance metrics. In addition, the output of proposed FTLRNN neural network model with gamma memory closely follows the desired output for multi- step ahead prediction for all the chaotic time series considered in the study.

Keywords
Sunspots chaotic time series, multi- step prediction, Focused time lagged neural network (FTLRNN), Multilayer perceptron (MLP), Self organizing feature map (SOFM).

1 INTRODUCTION
Predicting the future which has been the goal of many research activities in the last century is an important problem for human, arising from the fear of unknown phenomenon and calamities all around the infinitely large world with its many variables showing highly nonlinear and chaotic behavior. Chaotic time series have many applications in various fields of Science, e.g. astrophysics, fluid mechanics, medicine, stock market, weather, and is also useful in engineering such as speech coding [1], radar detection, of electromagnetic wave propagation and scattering [2]].

Inspired from the structure of the human brain and the way it is supposed to operate, neural networks are parallel computational systems capable of solving number of complex problems in such a diverse areas as pattern recognition, computer vision, robotics, control and medical diagnosis, to name just few [3].Neural networks are an effective tool to perform any nonlinear input output mappings and prediction problem [4].. Predicting a chaotic time series using a neural network is of particular interest [5]. Not only it is an efficient method to reconstruct a dynamical system from an observed time series, but it also has many applications in engineering problems radar like noise cancellation [6] radar detection [7] , demodulation of chaotic secure communication systems [8] and spread spectrum /code division multiple access (CDMA) systems [9,10] .It is already established that, under appropriate conditions, they are able to uniformly approximate any complex continuous function to any desired degree of accuracy [11]. Later, similar results were published independently in [12]. Neural networks are the instruments in broad sense can learn the complex nonlinear mappings from the set of observations [13].The static MLP network has gained an immense popularity from numerous practical application published over the past decade, there seems to be substantial evidence that multilayer perceptron indeed possesses an impressive ability [14]. There have been some theoretical results that try to explain the reasons for the success [15] and [16]. Most applications are based on feed forward neural networks, such as the back propagation (BP)network [17 and Radial basis function(RBF) network [18-19]. It has also been shown that modeling capacity of feed forward neural networks can be improved if the iteration of the network is incorporated into the learning process [20]. From the scrupulous review of the related research work, it is noticed that no simple model is available for long term prediction of sunspots chaotic time series so far and for the individual North hemisphere sunspots chaotic time series. It is necessary to develop a simple model that is able to perform short , medium and long term prediction of such individual northern hemisphere chaotic time series with reasonable accuracy . In view of the remarkable ability of neural network in learning from the instances, it can prove as a potential candidate with a view to design a versatile predictor (forecaster) for the chaotic time series.

The paper is organized as follows. First the optimal static NN based model on MLP is attempted to model the given system. Next on the same parameter the self organizing feature map and best dynamic focused time lagged NN model with built in gamma memory is estimated for prediction for all the short term and long term ahead prediction. Next the comparison between these models are carried out on the basis of the performance measures such as Mean Square Error (MSE), Normalized mean square error (NMSE) and Correlation coefficient (*r*) on testing as well as training data set for multi step head prediction (K=1,6,12,18,24 months ahead). The various parameters like number of hidden layers, number of processing elements, step size, momentum value in hidden layer, in output layer the various transfer functions like tanh, sigmoid, linear-tan-h and linear sigmoid, different error norms L_1,L_2, L_3, L_4 ,L_5 and L_∞, Epochs variations and different combination of training and testing samples are exhaustively experimented for obtaining the proposed robust model for the multi step ahead prediction of the North and South hemisphere sunspots chaotic time series.

2 STATIC NN BASED MODEL

Static NN s typically uses MLP as a backbone. They are layered feed forward networks typically trained with static back propagation. MLP solid based model has a solid foundation [21 - 22]. The main reason for this is its ability to model simple as well as complex functional relationships. This has been proven through number of practical applications [23]. In [11] it is shown that all continuous functions can be approximated to any desired accuracy, in terms of the uniform norm, with a network of one hidden layer of sigmoid or (hyperbolic tangent) hidden units and a layer of linear or tan h output unit to include in the hidden layer. The paper does not explain how many units to include in the hidden layer. This is discussed in [24] and a significant result is derived approximation capabilities of two layer perception networks when the function to be approximated shows certain smoothness. The biggest advantage of using MLP NN for approximation of mapping from input to the output of the system resides in its simplicity and the fact that it is well suited for online implementation. The objective of training is then to determine a mapping from a set of training data to the set of possible weights so that the network will produce predictions y (t), which in some sense are close to the true outputs y (t). The prediction error approach is based on the introduction of measure of closeness in terms of mean square error (MSE) criteria:

$$V_N(\theta,Z^N)=\frac{1}{2N}\sum_{t=1}^{N}\left[y(t)-y(\hat{t}|\theta)\right]^T\left[y(t)-y(\hat{t}|\theta)\right] \quad \text{--- (1)}$$
$$=\frac{1}{2N}\sum_{t=1}^{N}\varepsilon^2(t,\theta)$$

The weights are then found as:

$$\hat{\theta}=\arg\min_{\theta} V_N(\theta,Z^N)$$

by some kind of iterative minimization scheme:

$$\theta^{(i+1)}=\theta^{(i)}+\mu^{(i)}f^{(i)}$$

Where θ **(i)** specifies the current iterate (number "i"), f $^{(i)}$ is the search direction and **μ (i)** the step size.

When NN has been trained, the next step is to evaluate it. This is done by standard method in statistics called independent validation [25]. It is never a good idea to assess the generalization properties of a NN based on training data alone. This method divides the available data sets into two sets namely training data set and testing data set. The training data set are next divided into two partitions: the first partition is used to update the weights in the network and the second partition is used to assess (or cross validate) the training performance. The testing data set are then used to assess how the network has generalized. The learning and generalization ability of the estimated NN based model is assessed on the basis of certain performance measures such as MSE, NMSE and the regression ability of the NN by visual inspection of the regression characteristics for different outputs of system under study.

3 FTLRNN MODEL:

Time lagged recurrent networks (TLRNs) are MLPs extended with short term memory structures. Here, a "static" NN (e.g., MLP) is augmented with dynamic properties [14]. This, in turn, makes the network reactive to the temporal structure of information bearing signals. For a NN to be dynamic, it must be given memory. This memory may be classified into "short-term" and "long-term" memory. Long term memory is built into a NN through supervised learning, whereby the information content of the training data set is stored (in part or in full) in the synaptic weights of the network [26]. However, if the task at hand has a temporal dimension, some form of "short-term" memory is needed to make the network dynamic. One simple way of building short-term memory into the structure of a NN is through the use of time delays, which can be applied at the input layer of the network (focused). A short-term memory structure transforms a sequence of samples into a point in the reconstruction space [27].This memory structure is incorporated inside the learning machine. This means that instead of using a window over the input data, PEs created are dedicated to storing either the history of the input signal or the PE activations.

The gamma memory PE has a multiple pole that can be adaptively moved along the real Z-domain axis, that is the gamma memory can implement only low pass ($0 < \mu < 1$) or high pass ($1 < \mu < 2$) transfer functions. The high pass transfer function creates an extra ability to model fast-moving signals by alternating the signs of the samples in the gamma PE (the impulse response for $1 < \mu < 2$ has alternating signs). The depth in samples parameters (D) is used to compute the number of taps (T) contained within the memory structure(s) of the network.

3.1 Self Organizing Feature Maps (SOFM)

These networks are based on the competitive learning; the output neurons of the network compete among themselves to be activated or fired, with the result that only one output neuron, or one neuron per group, is on at any one time. An output neuron that wins the competition is called a winning neuron. The essential parameters of the algorithm are:

1) A continuous input space of activation patterns that are generated in accordance with a certain probability distribution.

2) A topology of the network in the form of a lattice of neurons, which defines a discrete Out space [3].

The values of weight vectors are updated for the winning node and its neighbors. The weight vectors are calculated as follows:

$$\overline{W}^{l}(t+1) = \overline{W}^{l}(t) + \eta(t)N(c,r)[\overline{X}_{k} - \overline{W}^{l}(t)] \quad (10)$$

Where, Input vector X has K patterns and the number of elements of weight vector is equal to the number of the processing elements in the output layer , t - number of iteration, c - number of cycle, (t)- learning rate ,N(c,r)- neighborhood function ,r - neighborhood radius.

4 SUN SPOT TIME SERIES

A sun spot number is a good measure of solar activity which has a period of 11 years, so called solar cycle. The solar activity has a measure effect on earth, climate, space weather, satellites and space missions, thus is an important value to be predicted. But due to intrinsic complexity of time behavior and the lack of a quantitative theoretical model, the prediction of solar cycle is very difficult. Many prediction techniques have been examined on the yearly sunspots number time series as an indicator of solar activity. However, in more recent studies the international monthly sunspot time series, which has a better time resolution and accuracy, has been used. In particular, a nonlinear dynamics approach has been developed in [28] and prediction results are compared between several prediction techniques from both statistical and physical classes. There has been a lot of work on controversial issue of nonlinear characteristics of the solar activity [28-32]; and a several recent analysis have provided evidence for low dimensional deterministic nonlinear -chaotic behavior of the monthly smoothed sun spot time series [28, 29, 30] and has intense .The data considered the monthly variations from January 1749 to December 2006 .The total samples are 3096 considered. The series is normalized in the range of -1 to +1. The monthly smoothed sunspot number time series is downloaded from the SIDC (World data center for the sun spot Index) [32]. The monthly sunspots time series is a combination of number of sunspots in northern hemisphere and southern hemisphere. In this work, the monthly sunspots of northern hemisphere are considered.

5 EXPERIMENTAL RESULTS:

The choice of the number of hidden layers and the number of hidden units in each hidden layers is critical [33]. It has been established that a MLPNN that has only one hidden layer, with sufficient number of neurons, acts as a universal approximators of nonlinear mappings [34].The tradeoff between accuracy and complexity of the model should be resolved accurately [35-36]. An exhaustive and careful experimentations has been carried to determine the configuration of the static MLP Model and the optimal proposed FTLRNN model for all the step (K=1,6,12,18 ,24) months ahead prediction . It is seen that the performance of this model is optimal on the test dataset for the following No. of taps = 6, Tap Delay = 1. Trajectory Length = 50. All the possible variations for the model such as number of hidden layers, number of processing elements in each hidden layer, different transfer functions like tan h, linear tanh, sigmoid, linear sigmoid in output layer, different supervised learning rules like momentum ,step, conjugant gradient and quick propagation are investigated in simulation. The step size and momentum are gradually varied from 0.1 to 1 for static back propagation rule. After meticulous examination of the performance measures like MSE, NMSE, Correlation Coefficient (*r*), the optimum parameters are found and mentioned in the table 1 for 60% used as training samples, 25 % as testing samples and 15% cross validation samples.

Table 1: Parameters for the Neural network Models

Sr. no.	Parameters	Hidden Layer	Output Layer
1	Processing elements	15	1
2	Transfer function	tanh	Tanh
3	Learning rule	Momentum	Momentum
4	Step Size	1	0.1
5	Momentum	0.8	0.8

It is found that the performance of the selected model is optimal for 15 neurons in the hidden layer with regards to the MSE, NMSE, and the correlation coefficient (*r*) for the testing data sets. When we attempted to increase the number of hidden layer and the number of processing element in the hidden layer, the performance of the model is not to seen to improve significantly .On the contrary it takes too long time for training because of complexity of the model. As there is single input and single output for the given system, the number of input and output processing elements is chosen as one. Now the NN Model is trained three times with different weight initialization with 1000 iterations of the static back propagation algorithm with momentum term for all the three models for all the 1,6 , 12, 18 and 24 months ahead predictions as shown in table 2.

From the table 2, it is observed that FTLRNN model is able to predict the monthly northern sunspots chaotic time series elegantly well as compared to multilayer perceptron (MLP) and self organizing feature map (SOFM) on testing data set with regards to MSE,NMSE and correlation coefficient (*r*). Also the graphs are plotted for desired output and actual output 1,6,12,18 and 24 months ahead prediction for MLP and SOFM neural network as shown in figure 1 to 6 for northern hemisphere. For the proposed FTLRNN model the graphs are plotted for desired output and network output as shown in figure 6 to 12.

Table 2 Performance of Neural Network Models for testing data set (for northern hemisphere sun pots)

K (months)	MLP Neural Network			FTLRNN			SOFM		
	MSE	NMSE	*r*	MSE	NMSE	*r*	MSE	NMSE	*r*
1	0.00252	0.03296	0.9765	0.00207	0.03124	0.98928	0.00211	0.3187	0.9812
6	0.00886	0.12354	0.93954	0.00437	0.06535	0.97497	0.00953	0.14241	0.93298
12	0.02661	0.39485	0.79227	0.01415	0.21006	0.91345	0.02847	0.42241	0.77782
18	0.04681	0.69153	0.4681	0.02173	0.32103	0.86821	0.07968	0.70850	0.58202
24	0.6454	0.95030	0.36815	0.02692	0.39647	0.83186	0.06715	0.98877	0.33654

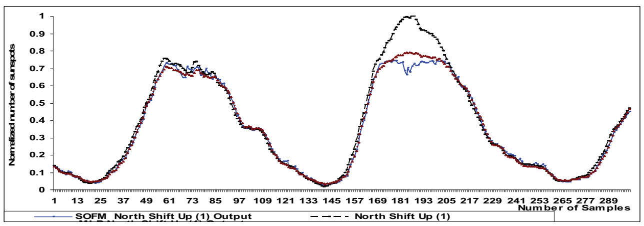

Fig 1 Desired output Vs Actual output for 1 month ahead for north direction Sun Spots MLP and SOFM

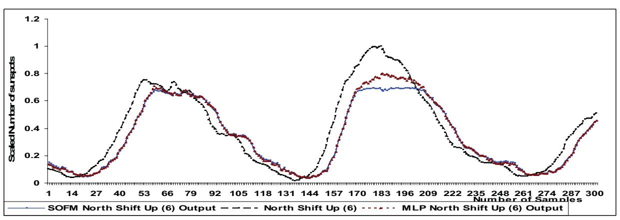

Fig 2Desired output Vs Actual output for 6 months ahead for North direction Sun Spots MLP and SOFM

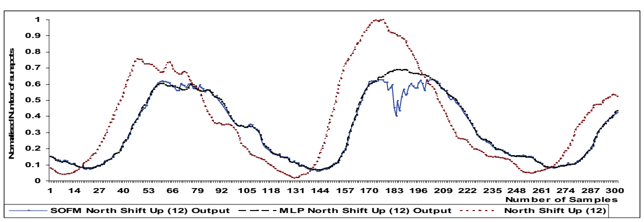

Fig 3 Desired output Vs Actual output for 12 months ahead for North direction Sun Spots for MLP and SOFM model

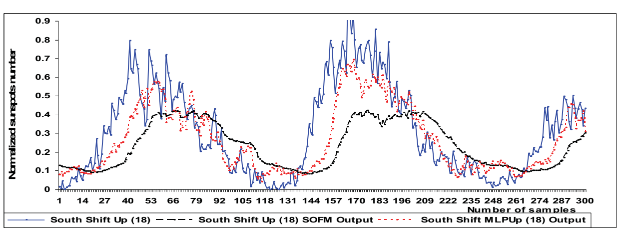

Fig 4 Desired output Vs Actual output for 18 months ahead for North direction Sun Spots for MLP and SOFM Model.

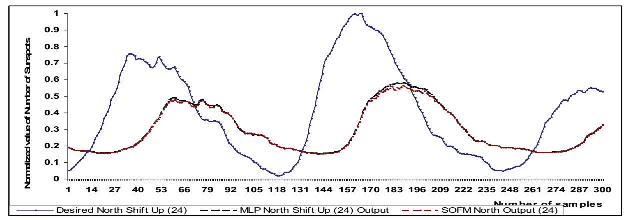

Fig 5 Desired output Vs Actual output for 24- months ahead for north direction Sun Spots for MLP and SOFM model

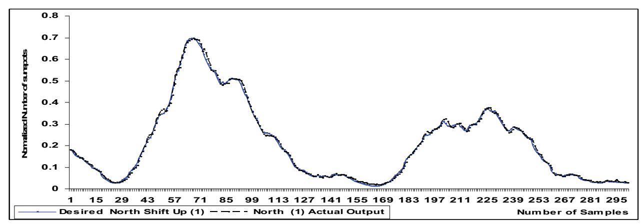

Fig 6 Desired and FTLRNN outputs for North direction Sun Spots for 1 month ahead prediction

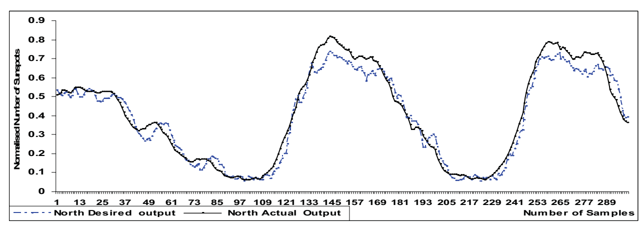

Fig 7 Desired and FTLRNN outputs for North direction Sun Spots for 6 month ahead prediction

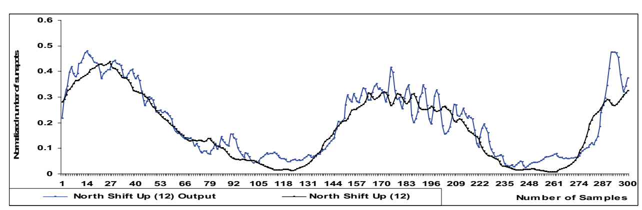

Fig. 8 Desired and FTLRNN outputs for North direction Sun Spots for 12 month ahead prediction

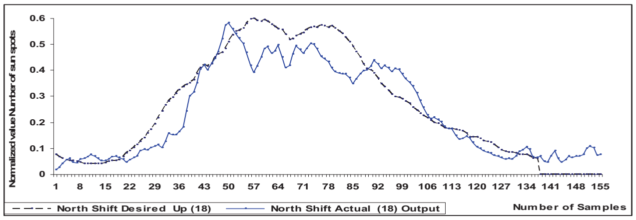

Fig. 9 Desired and FTLRNN outputs for North direction Sun Spots for 18 month ahead prediction

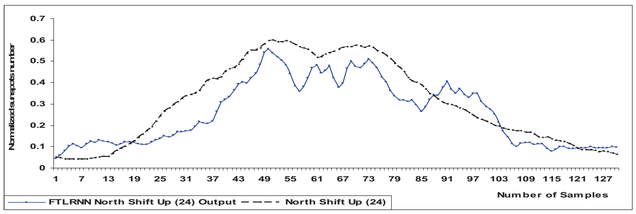

Fig.10 Desired and FTLRNN outputs for North direction Sun Spots for 24 month ahead prediction

6 CONCLUSION

It is seen that focused time lagged recurrent neural network model with gamma memory is able to predict the northern sunspots chaotic time series quite well in comparison with the Multilayer preceptron (MLP) and self organizing feature map (SOFM). Static NN configuration such as MLP NN based model and self organizing feature map (SOFM) network are failed to cope up with the underlying nonlinear dynamics of the sunspots chaotic time series. It is seen that MSE, NMSE of the proposed focused time lagged recurrent neural network (FTLRNN) dynamic model for testing data set as well as for training data set are significant better than those of static MLP NN and SOFMNN model. For the 12, 18 and 24 months ahead prediction the value of MSE and NMSE for the proposed FTLRNN model is significantly improved. Also for the proposed FTLRNN model the output closely follows the desired output for all the months ahead prediction for northern sunspots time series as shown in figure 6 to 10 as compared to the MLP and SOFM. In addition it is also observed that the correlation coefficient of this model for testing and training exemplars are much higher than MLP and self organizing feature map (SOFM) neural network. It is resulted from the experiments that the FTLRNN model learns the dynamics of northern monthly sunspot chaotic time series quite well as compared to Multilayer perceptron and self organizing feature map. On the contrary, it is observed that static MLP NN and self organizing feature map (SOFM) performs poorly bad, because on the one hand it yields much higher MSE and NMSE on testing data sets and on the other hand the correlation coefficient r for testing data set is far less than unity. This is also confirmed from the desired output Vs actual output plots for all the steps for MLP and SOFM model as shown in figure 1 to 6 all the months ahead prediction. Hence the focused time lagged recurrent neural network with gamma memory filter has out performed the static MLP based neural network and SOFM better for all the months' ahead predictions for monthly north hemisphere chaotic time series.

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