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APPLICATION OF NEURAL NETWORKS IN WEATHER FORECASTING

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ABSTRACT: *Weather Forecasting is the task of determining future state of the atmosphere. Accurate weather forecasting is very important because agricultural and industrial sector largely depend on it. Weather forecasting has become an important field of research in the last few decades. In most of the cases the researcher had attempted to establish a linear relationship between the input weather data and the corresponding target data. The Neural Networks package supports different types of training or learning algorithms. In this paper, the application of neural networks to study the design of neural network technique for Kanyakumary District,Tamil Nadu, India. A total of ten years of data collected for training the net work. The network is trained using the Back propagation Algorithm, Radial Basis Function, Regression Neural Network, Optical Neural Network, and Fuzzy ARTMAP Neural Network. The Fuzzy ARTMAP network can give the best overall results in terms of accuracy and training time. It is better correlated compared to the BPN,RBFN,GRNN and ONN networks. The proposed Fuzzy ARTMAP neural network can also overcome several limitations such as a highly non-linear weight update and the slow convergence rate.*

KEYWORDS: Artificial Neural Networks, Forecasting, Weather, Back Propagation, Radial Basis Function, Regression Neural Network, Optical Neural Network, Fuzzy ARTMAP, Neural Network

INTRODUCTION

The weather is a continuous, data-intensive, multidimensional, dynamic and chaotic process, and these properties make weather forecasting a formidable challenge. Weather forecasting is the application of science and technology to predict the state of the atmosphere in future time and give proper location. Human beings has attempted to predict the weather since ancient times [1]. Today, weather forecasts are made by collecting quantitative data about the current state of the atmosphere and using scientific understanding of atmospheric processes to project how the atmosphere will evolve. The chaotic nature of the atmosphere, the massive computational power required to solve the equations that describe the atmosphere and incomplete understanding of atmospheric processes mean that forecasts become less accurate as the range of the forecast increases. The need for accurate weather prediction is apparent when considering the benefits that it has. These predictions may not stop a tornado, hurricane or flood, but they can help us to prepare for one. Great progress has been made in the science of meteorology till now. Meteorologist use different methods for weather prediction. The possibility of numerical weather prediction was proposed by Lewis Fry Richardson in 1922.Practical use of numerical weather prediction began in 1955, spurred by the development of programmable electronic computers. Observation of atmospheric pressure, temperature, wind speed, wind direction, humidity, and precipitation are made near the earth’s surface by trained observers, automatic weather stations.

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The World Meteorological Organization acts to standardize the instrumentation, observing practices and timing of these observations worldwide. There are two methods used in weather forecasting. They are the empirical approach and the dynamical approach. The empirical approach is based on analogues forecasting. This method is useful for predicting local scale and forward simulations of the atmosphere. The process is vitalized by computer modeling. The dynamical approach is useful for modeling large scale weather phenomena and may not predict short term weather vagaries efficiently. Most of the weather forecasting systems combine both empirical and dynamical approaches [2].

Neural network involves numerous meteorological applications including weather forecasting. A neural network is a system composed of many simple processing elements operating in parallel whose function is determined by network structure, connection strength and the processing performed at computing elements or nodes. Artificial neural networks (ANN) are parallel computational models, comprising closely interconnected adaptive processing units. The important characteristic of neural networks is their adaptive nature, where ‘learning by example replaces programming’. This feature makes the ANN techniques very appealing in application domains for solving highly nonlinear phenomena. During last four decades various complex problems like weather prediction, stock market prediction etc has been proved to be areas with ample scope of application of this sophisticated mathematical tool. Weather forecasting is found to be more powerful than any traditional system in the classification of meteorological pattern.

Numerical weather prediction models, Self Organizing Feature Map, SpatioTemporal Neural Network, Quantum Neural Network are used for weather forecasting. Neural network can approximate any smooth, measurable function between input and output vectors by selecting a suitable set of connecting weight and transfer functions[3]. Despite so much of emphasis given to the application of ANN in prediction of different weather events all over the world, Kanyakumari meteorological forecasters did not put much precedence on application of this potent ANN tool in weather prediction. This research work was based on Back Propagation Neural Network, Optical Neural Network, Radial Basis Function Neural Network, Generalized Regression Neural Network and Fuzzy ARTMAP Neural Network are used which trained and tested using past ten years (1991-2011) meteorological data.

There are different classes of neural network and many operations have been done related to the weather prediction system. They are summarized below.

El-Shafie et al. [4] developed feed forward neural network. This model was implemented to predict the rainfall on yearly and monthly basis. The analysis was made on the basis of four parameters viz. Root Mean Square Error, Mean Absolute Error, Correlation Coefficient and Mean Error which suggested that ANN provide better results than the Multiple Linear Regression model.

Chattopadhyay [5] analyzed that Neural Network’s with three nodes in the hidden layer is found to be the predictive model for possibility of predicting average summer-monsoon rainfall over India.

Brian A. Smith et al. [6] focused on developing ANN models with reduced average prediction error by increasing the number of distinct observations used in training and also by adding additional input terms that describe the date of an observation and increasing the

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duration of prior weather data included in each observation, and re-examining the number of hidden nodes used in the network.

Models were created to forecast air temperature at hourly intervals from one to 12 hours ahead. Each ANN model, having network architecture and a set of associated parameters, was evaluated by initializing and training 30 networks.

Fallah-Ghalhary et al. [7] studied the relationship between climate large-scale synoptic patterns and rainfall in Khorasan region. The research attempted to train Fuzzy Inference System based on prediction models. The model predicted outputs were compared with the actual rainfall data. Simulation results reveal that soft computing techniques are promising and efficient.

Wu et al. [8] proposed a hybrid rainfall-forecasting approach which is based on support vector regression, particle swarm optimization and projection pursuit technology.

Wu et al. [9] made an attempt to seek a relatively optimal data driven model for rainfall forecasting from three aspects: model inputs, modeling methods, and data preprocessing techniques. Prediction was performed in two modes in which normal mode and data processing mode. It is considerable whereas those of Moving Average (MA) or Principle Component Analysis (PCA) are light, and analyzed that optimal rainfall forecasting model can be derived from Modular Artificial Neural Network coupled with Singular Spectrum Analysis.

These works are motivated me to study the accuracy of weather forecasting and find out weather prediction system using Back Propagation Neural Network, Optical Neural Network, Radial Basis Function Neural Network, Regression Neural Network and Fuzzy ARTMAP Neural Network.

Objectives and Scope

- The first objective of this study is to develop ANN-based model by using meteorological data of Kanyakumari District located in Tamilnadu, India for one day ahead weather prediction of this area.
- The second objective of this research work is to develop an efficient, reliable and effective weather forecasting system based on Fuzzy ARTMAP. This is a new application in the area of weather prediction.
- The third objective is to identify all important factors that directly influence the change in Weather Forecasting.
- The fourth objective of the research work is to compare the performance of application of Neural Networks such as Back Propagation, Radial Basis Function, Regression Neural Network, Optical Neural Network and Fuzzy ARTMAP.
- The quality and performance of these algorithms are analyzed based on the experimental approach implemented in MATLAB.

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Description of Research Work

Over the last few decades, there has been much research directed at predicting the future of weather behavior and making better decisions. This research has led to many developments in forecasting methods. Most of these methodological advances have been based on statistical techniques. Artificial neural networks (ANN) have been widely touted as solving many forecasting and decision modeling problems. Artificial neural networks have input channels that represent the dendrites, and output channels that mimic the axons. The synapse is modeled by an adjustable weight, located at the juncture between incoming and outgoing channels.

Back Propagation Network (BPN)

Back Propagation algorithm using gradient descent method is the most important algorithm to train a neural network for weather forecasting.Accurate weather forecasting is important in today's world.Agricultural and industrial sectors are largely dependent on the weather conditions[10]. Secondly, it is used to warn about natural disasters. Due to non-linearity in climatic physics, neural networks are suitable to predict these meteorological processes. Back Propagation algorithm using gradient descent method is the most important algorithm to train a neural network for weather forecasting. It provides a computationally efficient method for changing the weights in a feed forward network, with differentiable activation function units, to learn training set of input and output. Being a gradient descent method, it minimizes the total squared error of the output computed by the net. The network is trained by supervised learning method[11].

The training algorithm of back propagation involves four stages.

During the first stage, which is the initialization of weights, some small random values are assigned.

During the second stage, each input unit receives an input signal and transmits the signal to each of the hidden units. Each hidden unit then calculates the activation function and sends its signal to each output unit. The output unit calculates the activation function to form the response of the net for the given input pattern. During the third stage, each output unit compares its computed activation with its target value to determine the associated error for that pattern with that unit.

During the final stage, the weight and biases are updated using the activations.

The Back Propagation algorithm is as follows [12].

step 1. Initialize the weights in the network (often randomly) step 2. Do

step 3. For each e in the training set

a. O= neural-net-output (network, e) ; forward pass

b. T = teacher output for e

step 4. Calculate error (T - O) at the output units step 5. Compute Δw_h for all weights from hidden layer to output layer; backward pass

step 6. Compute Δw_i for all weights from input layer to hidden layer; backward pass continued step 7. Update the weights in the network

step 8. Until all e's classified correctly or stopping criterion satisfied step 9. Return the network

In the proposed technique, back propagation is combined with meteorological experts. Overall accuracy derived from this network was 82.40 %.

Radial Basis Function Network

A Radial Basis Function (RBF) network is a special type of neural network that uses a radial basis function as its activation function. RBF networks are very popular for function approximation, curve fitting, time series prediction, control and classification problems. In RBF networks, determination of the number of neurons in the hidden layer is very important because it affects the network complexity and the generalizing capability of the network. In the hidden layer, each neuron has an activation function. The Gaussian function, which has a spread parameter that controls the behavior of the function. It is the most preferred activation function [13].

The training procedure of RBF networks also includes the optimization of spread parameters of each neuron. Afterwards, the weights between the hidden layer and the output layer must be selected appropriately. Finally, the bias values which are added with each output are determined in the RBF network training procedure. RBF network is a type of feed forward neural network composed of three layers, namely the input layer, the hidden layer and the output layer [14]. A RBF network with m outputs and hidden nodes can be expressed as:

$$= w_{io} + \sum_{j=1}^{n_h} w_{ij} \quad \Phi(\| - \ \|) \; ; i = \quad , , \ldots . . m$$

Considering this argument, the RBF network with additional linear input connections is used. The proposed network allows the network inputs to be connected directly to the output node via weighted connections to form a linear model in parallel with the non-linear standard RBF model. The new RBF network with m outputs, n inputs, hidden nodes and n1 linear input connections can be expressed as:

$$= \quad + \sum_{=1}^{nh} \lambda \, v \qquad t + \sum_{=1}^{nh} w \qquad \varphi(\| - \ \|); \, i = , , \ldots . . m$$

where the λ 's and vl's are the weights and the input vector for the linear connections may consist of past inputs and outputs. The λ's can be estimated using the same algorithm. As the additional linear connections introduce a linear model, no significant computational load is added to the standard RBF network training. Furthermore, the numbers of required linear connections are normally much smaller than the number of hidden nodes in the RBF network. In the present study, given least squares algorithm with additional linear input connection features is used to estimate weight [15].

The Radial Basis Function Neural Network is combined with Back propagation neural network; overall accuracy derived from this network was 88.45 %.Comparing back propagation network it is found that RBF produces good accuracy.

Optical Neural Networks

Optical neural networks interconnect neurons with light beams. As a result no insulation is required between signal paths. The signal path can be made to travel in three dimensions. The density of the transmission path is limited only by the spacing of light sources, the effect of divergence and the spacing of the detectors. As a result, all signal paths operate simultaneously, which results in a true data rate. The strengths of weights are stored in holograms with high density. These weights can be modified during operation to produce a fully adaptive system [16]. The network speed is limited only by the available electro-optical components. The computational time is potentially in the Nanosecond range. The ONN network, multilayer perceptron, trained using modified back propagation is constructed as three layer network with one hidden layer [17].

The steps involved in the process are

1. Transforming the transaction database into a weight matrix
2. Feeding inputs and generating frequent datasets
3. Pruning the weight matrix
4. Generating frequent 2-datasets
5. Generating subsequent frequent datasets

Overall accuracy derived from this network was 83.50 %

Generalized Regression Neural Networks

Generalized regression neural network(GRNN) is a new radial basis function neural network based on mathematical statistics, therefore it is simi1ar in form to the probabilistic neural network. It can be used for weather prediction, modeling, mapping and interpolating or as a controller. GRNN has a universal approximation property for the smooth function, as long as enough data is given, more accurate approximation can be achieved. Even in the case of small number of samples and multi-dimensional, this algorithm is also very effective[18]. GRNN is based on memory, which means all the samples must be stored in the learning network. The demand for storage is large when there are large quantities of samples because each training sample must be stored. GRNN does not require iterative training, so it is simple, stable with fast training speed and good description for the characteristics of dynamic systems. The training of the network depends on data samples, which determines the network can maximally avoid the influence to the results caused by man-made subjective assumptions. Compared with BPN, RBN and ONN,GRNN can find

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an appropriate network faster for few parameters need to be adjusted. The GRNN infrastructure consists of four layers input, hidden, summation and output layer[19]. ***Step 1:*** Input layer — there is one neuron in the input layer for each predictor variable. In the case of categorical variables, N-1 neurons are used where N is the number of categories. The input neurons (or processing before the input layer) standardizes the range of the values by subtracting the median and dividing by the interquartile range. The input neurons then feed the values to each of the neurons in the hidden layer.

Step 2: Hidden layer — this layer has one neuron for each case in the training data set. The neuron stores the values of the predictor variables for the case along with the target value. When presented with the x vector of input values from the input layer, a hidden neuron computes the Euclidean distance of the test case from the neuron's center point and then applies sigma value. The resulting value is passed to the neurons in the pattern layer.

Step3: Pattern layer / Summation layer —For GRNN networks, there are only two neurons in the pattern layer. One neuron is the denominator summation unit the other is the numerator summation unit. The denominator summation unit adds up the weight values coming from each of the hidden neurons. The numerator summation unit adds up the weight values multiplied by the actual target value for each hidden neuron.

Step 4: The decision layer divides the value accumulated in the numerator summation unit by the value in the denominator summation unit and uses the result as the predicted target value.

Overall accuracy derived from the this network was 94.95 %.The results shows that GRNN forecasting model can obtain better performance for weather forecasting compared to BPN,RBN and ONN network model.

Fuzzy ARTMAP Neural Network

Fuzzy ARTMAP is a supervised neural network architecture that is based on "Adaptive Resonance Theory", proposed by Stephen Grossberg in 1976. ART encompasses a wide variety of neural networks based explicitly on human information processing and neurophysiology. ART networks are defined algorithmically in terms of detailed differential equations intended as plausible models of biological neurons. ART networks are implemented using analytical solutions or approximations to these differential equations. ART is capable of developing stable clustering of arbitrary sequences of input patterns by selforganisation. Fuzzy ARTMAP's internal control mechanisms create stable recognition categories of optimal size by maximizing code compression while minimizing predictive error during on-line learning. Fuzzy ARTMAP incorporates fuzzy logic in its ART modules[20] .

Basic architecture of fuzzy ARTMAP

A pair of fuzzy ART modules, ART_a and ART_b, connected by an associative learning network called a map field .The map field makes the association between ART_a and ART_b categories.A mismatch between the actual and predicted value of output causes a memory search in ART_a, a mechanism called match tracking. Vigilance, a parameter (0-1) in ART_a, is raised by the minimum amount necessary to trigger a memory search. This can lead to a selection of a new ART_a category that is a better predictor of output.Fast learning and match tracking enable fuzzy ARTMAP to learn to predict novel events while maximizing code compression and preserving code stability[21].

The Fuzzy ARTMAP learning algorithm

1. Initialize all weights.
2. Present input at ART-a and target output at ART-b. Allow category formation in both modules. The F2 layer nodes in ART-b encode the class information.
3. Get predicted output class information from ART-a by using the map field weights w_{ab}.
4. Compare predicted class with actual class information. If they are the same, go to step 6.
5. Reset current representation in ART-a and search for a better representation.
6. Repeat steps 4 and 5 until a correct match is found.
7. Update all weights in both modules.
8. Go to step 2.

Overall accuracy derived from this network was 97.85 %. The results shows that Fuzzy ARTMAP forecasting model can obtain better performance for weather forecasting compared to BPN,RBN ,ONN and GRNN network model.

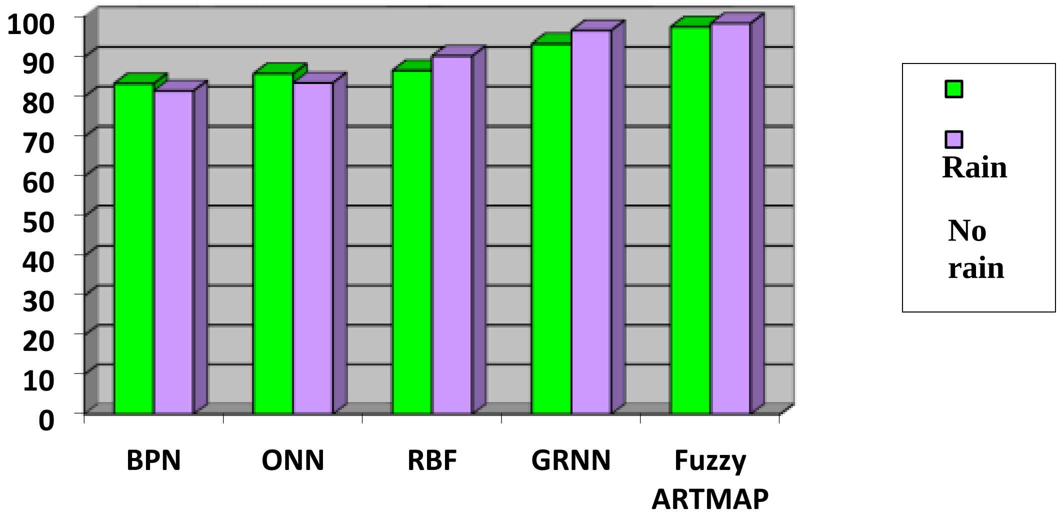
Performance Analysis

To experiment all the Neural Networks discussed at various stages, a sample dataset is taken from metrological department, Kanyakumari District, TamilNadu. These datasets contain real time observations of the weather for the period from January 2001 to December 2011. The datasets contain many attributes. The basic input data for classification needs preprocessing. This procedure helps in the incorporation of temperature, air pressure humidity, cloudiness, precipitation wind direction, wind speed etc. The factors temperature, air pressure, humidity, cloudiness, precipitation, wind direction wind speed, etc. of weather forecasting are consolidated from meteorological experts.

Improvement of classification accuracy in weather forecasting is shown in the following table.

Weather forecasting	BPN	ONN	RBF	GRNN	FUZZY ARTMAP
Rain	83.30	85.80	86.60	93.30	97.50
No rain	81.50	83.50	90.30	96.60	98.40
Overall Accuracy(%)	82.40	84.65	88.45	94.45	97.45

Performance Analysis is shown in the graph.



CONCLUSION

In this research work, a weather forecasting system is implemented using application of neural network technique. From the experimental results, it is observed that the proposed model produces a reasonable accuracy in training which is conducted with 24 parameters (10 years) of the recent temperature, humidity, Air pressure, wind speed etc. and cloudiness with historical data. The model is trained and used to forecast the weather data for next time period, each time forecasting one point ahead.

A total of ten years of data collected for training the net work. The network is trained using the Back propagation (BP) Algorithm, Radial Basis Function, Regression Neural Network, Optical Neural Network, and Fuzzy ARTMAP Neural Network. The Fuzzy ARTMAP network can give the best overall results in terms of accuracy and training time. It is better correlated compared to the BPN,RBFN,GRNN and ONN networks. The proposed Fuzzy ARTMAP neural network can also overcome several limitations such as a highly non-linear weight update and the slow convergence rate. Since Fuzzy ARTMAP has natural supervised learning characteristics and a modular network structure, these properties make it more effective for fast and robust weather forecasting.

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