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RESEARCH ARTICLE

Application of Soft Computing techniques in weather forecasting: ANN approach

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Abstract

With the rise in the threat of global warming and green house gas effect, it has been a challenging and most important task of the metrological centers worldwide to predict weather in future. Weather forecasting is the application of science and technology to predict the state of the atmosphere for a given location and they are made by collecting quantitative data. Soft computing is an innovative approach to construct computationally intelligent systems that are supposed to possess humanlike expertise within a specific domain, adapt themselves and learn to do better in changing environments, and explain how they make decisions. Soft computing techniques are Fuzzy logic, Neural Network, Evolutionary computing, Genetic Algorithm etc., In this paper we analyze soft computing techniques and apply them to forecast weather.

I. Introduction

Weather is generally referred as the atmospheric conditions that comprise the state of the atmosphere in terms of temperature and wind and clouds and precipitation. It is of great interest to people everywhere, from meteorologists, the scientists, farmers, sailors etc., A weather forecast is simply a scientific estimate of future weather condition. Weather forecasting involves a combination of computer models, observations, and knowledge of trends and patterns.

This paper is dealt with weather forecasting, as it has been one of the most challenging problems around the world because of both of its practical value in meteorology and popular sphere for scientific research. There exist various methods to forecast weather. The most widely used techniques are Numerical and Statistical Methods. The Numerical method is a formulation of a series of mathematical equations and often referred as computer modeling. One Statistical method, the analog method, examines past weather records to predict future events.

The main objective of this paper is to investigate the efficiency of soft computing methods, in particular methodologies based on neural networks, when incorporated into the solution of computationally intensive engineering problems. The trained Artificial Neural Network(ANN) is then used to predict the values of the necessary data.

The most popular soft computing techniques is ANN which performs nonlinear mapping between inputs and outputs, and they also provide alternative approaches to weather forecasting and many researchers have implemented it in their research and concluded that ANN is best suited for forecasting.

II. METHODOLOGY

Soft Computing

Soft Computing provides an attractive opportunity to represent the ambiguity in human thinking with real life uncertainty. Soft computing (SC) is a collection of methodologies, which aims to exploit tolerance for imprecision, uncertainty, and partial truth to achieve robustness, tractability, and low cost. Soft Computing is implemented in engineering and science fields since it can solve problems that have not been able to be solved by traditional analytic methods.

Fuzzy logic (FL), neural networks (NN), and evolutionary computation (EC) are some of the core methodologies of soft computing. Emergent, self-organizing, reflective, and interactive (among human beings, environment, and artificial intelligence) knowledge processing is considered by using soft computing and by borrowing ideas from bio-information processing. Soft computing provides rich knowledge representation (symbol and pattern), flexible knowledge acquisition (by learning from data and by interviews with experts), and knowledge processing (inference by interface between symbolic and pattern knowledge).

Artificial Neural Networks

Artificial Neural network reasoning depends on the extraction of hidden relationships in given datasets. It has the ability to learn from examples, drawing conclusions based on past experiences.

An ANN is composed of collection of interconnected neurons that are often grouped in layers. These neurons are linked with variable weights. A neuron typically consists of three components: (i) a group of weights, (ii) a summation function, and (iii) a non-linear activation function f() which can take many forms, e.g. linear, sigmoid, exponential (Table 1).

$$R = w_1 x_1 + w_2 x_2, \ldots w_n x_n = \sum_{i=1}^{n} w_i x_i$$

Table 1. Artificial neural network activation functions.

Function name	Mathematical expression
Sigmoid	$f(y) = \frac{1.0}{1.0+\exp^{y}}$
Linear	$f(y) = ay + b$
Gaussian	$f(y) = \exp^{-\lvert m+y \rvert^2 \alpha}$
Exponential	$f(y) = \exp(y+m)$
Bipolar sigmoid	$f(y) = \frac{1.0-\exp^{y}}{1.0+\exp^{y}}$

The network "learns" by adjusting the interconnections (called weights or synapses) between layers. When the network is adequately trained, it is able to generalize relevant output for a set of input data. The advantage of neural networks is that a trained neural network is able to provide a correct matching in the form of output data for a set of previously unseen input data.

The sample data is normally represented in the form of an input matrix, X, and the corresponding output vector, Y.

The process of developing an ANN based model consists of the following stages [1][2]:
- Generation of training data.
- Selection of a network type.
- Selection of the input and the output for the network.
- Design of a suitable network configuration.
- Selection of a suitable training strategy.
- Training and validation of the resulting network.

The ANN has capability to extract the relationship between the inputs and outputs of a process, without the physics being explicitly provided .Thus, ANN are well suited to the problem of weather forecasting [3].

Architecture of ANN: The most important thing to discuss after the preparation of the training set is the Architecture. The architecture of any artificial neural network is defined by the layers, numbers of neurons etc. Different forecasting models require different forecasting architecture. The best suited ANN architecture for any forecasting model is the subject of research for a researcher. Following are the key points to be taken in account when developing a forecasting model:

Types of Network: The training and forecasting of any model is dependent upon the types of the network i.e. Multi Layer Perception (MLP), Multi Layer Feed Forward network (MLFFN) etc. The appropriate type of network may converse fast for prediction.

No. Of Hidden Layers: Our forecasting result's accuracy is highly dependent on the numbers of hidden layers. Some problem may converse in single layer ANN or some may converse in multiple layers ANN. Although single layer network is appropriate for solving any problem but it may be so less accurate. For better result multi layer network may be used that may converse slow but produce much better result. One drawback of multi layer network is that it is complex. Multi layer Feed Forward neural Network (MLFFNN) is found the best for forecasting the weather condition.

Algorithms: There are number of training algorithms are available but appropriate selection of training algorithms may leads fast and accurate forecasting results. Back propagation algorithm is found best suited with MLFFNN for forecasting the weather prediction.

Activation function: A number of activation functions are available for training the network but selecting the appropriate activation function may leads to better conversion. We can select any one of following LOGSIG, PURELIN & TANSIG.

Weights/Bias: Apart from all above, another important factor is the initialization of weights and bias. Proper initialization of weights and bias may leads the network to converse fast and in proper direction.

Threshold/Momentum: Threshold value can be set if we want an output by any particular condition, the output is generated only when the threshold value is achieved. Another is the momentum that could be set for smooth conversion of network with the provided momentum factor.

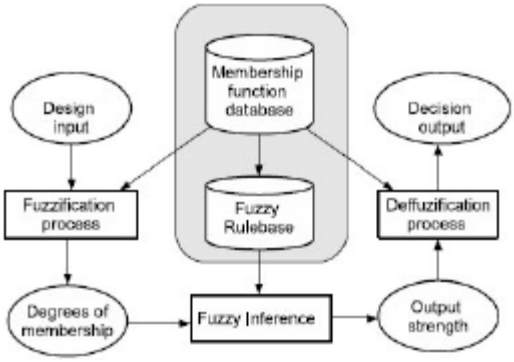
In general it has been observed that out of various forecasting techniques such as statistical and numerical modeling, over the meteorological data, ANN is proved to be an appropriate technique undoubtedly for forecasting various weather phenomenon.

FUZZY LOGIC

Fuzzy logic reasoning is based on human experience and expert knowledge. It has the ability to generate a decision given vague and imprecise information.

Fuzzy Logic(FL), upon which fuzzy models are based, is a generalization of the binary logic. The model comprises four principal components: a fuzziffication process, fuzzy knowledge base, decision-making logic and de-fuzziffication unit.

To develop a FL based model, Crisp data in the form of numerical values are usually the input and output of fuzzy logic based systems. Crisp data set assigns a value of either 1 or 0 to each individual in the universal set, thereby discriminating members and nonmembers of the crisp set under consideration. The membership functions (MF) are those which converts crisp inputs into linguistic terms. The membership functions can take different forms such as Trapezoidal, triangular, sigmoid functions etc., The range of values of membership functions is the unit interval [0, 1].



The membership function of a fuzzy set A is defined by A, A : Universal Set (X) ------> [0, 1].

Table 2. Fuzzy membership functions

Function name	Mathematical expression
Triangular	$f(x,a,b,c) = \max\left\{\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}, 0.0\right)\right\}$
Trapezoidal	$f(x,a,b,c,d) = \max\left\{\min\left(\frac{x-a}{b-a}, 1.0, \frac{d-x}{d-c}, 0.0\right)\right\}$
Bell-shaped	$f(x,a,b,c) = \frac{1.0}{1.0+\left\lvert\frac{x-c}{a}\right\rvert^{2b}}$
Gaussian	$f(x;\alpha,c) = \exp^{\frac{-(x-c)^2}{2\alpha^2}}$
Sigmoid	$f(x,a,b,c) = \frac{1.0}{1.0+\exp^{-a(x-c)}}$

The prediction will consist of the following steps.
1st step: Divide the input & output spaces into fuzzy regions.
2nd step: Data-generated fuzzy rules.
3rd step: Assign a degree to each rule.
4th step: Create a combined fuzzy rule base.
5th step: Determine a mapping based on the combined fuzzy rule base.

Neuro-fuzzy

The neuro-fuzzy model, which involves the integration of ANN and FL techniques are perhaps the most popular hybrid technique. Neuro-fuzzy models are able to take advantage of the fuzzy inference mechanism capabilities in fuzzy logic and the learning ability of neural networks. The ANN technique is usually used as the learning algorithm for the defuzzification process in FL based models. Neuro-fuzzy model should always be interpretable in terms of fuzzy if-then rules, because it is based on the fuzzy system reflecting vague knowledge. The membership functions(Gaussian, triangular etc.,) used in the fuzzy system can be modified during learning.

Back Propagation

Back Propagation is the training or learning algorithm. The network used is generally for Feed Forward Network or occasionally Multi-Layer Perceptrons. Back Propagation networks are ideal for simple Pattern Recognition and Mapping tasks.

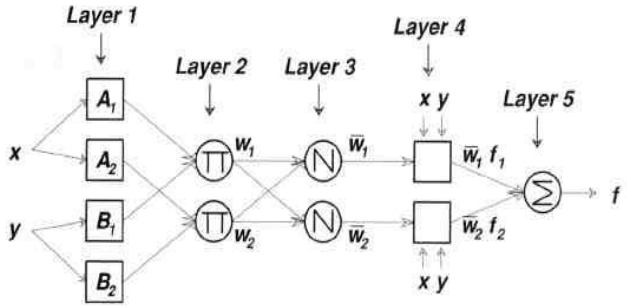
ANN with many layers have been applied successfully to solve miscellaneous problems by training them in a supervised manner with a well accepted algorithm known as error back-propagation algorithm.

The network is first initialized by setting up all its weights to be small random numbers – say between –1 and +1. The network does not have feedback connections but errors are back propagated during training. Errors in the output determine measures of hidden layer output errors, which are used as a basis for adjustment of connection weights between the input and hidden layers. Adjusting the two sets of weights between the pairs of layers and recalculating the outputs is an iterative process that is carried on until the errors fall below a tolerance level. Learning rate parameters scale the adjustments to weights. A momentum parameter can be used in scaling the adjustments from a previous iteration and adding to the adjustments in the current iteration.

BPN is used for doing prediction and tested as the best algorithms for training the ANN. The ANN is trained & tested using real training data set.

ANFIS

ANFIS is basically a synthesis of two intelligent systems: Artificial Neural Networks (ANN) and Fuzzy Inference Systems (FIS). It is a modeling methodology developed by Roger Jang[4]. The ANFIS is based on the architecture of the Takagi-Sugeno-type fuzzy inference system [4]. ANFIS is one of the most popular and well documented neuro-fuzzy systems, which has a good software support [5]. ANN map an input space to an output space through a compilation of layered processing elements called neurons that are interconnected in parallel by synaptic junctions [6]. The amalgamation/integration of ANN and FIS to form ANFIS combines the advantages of the individual intelligent systems to form an advanced technique that may be the best method for weather prediction. ANFIS model preserves the potential of the ANN approach fully, and eases the model building process [7].



ARIMA

ARIMA is an econometric modeling which takes into account historical data and decomposes it into an Autoregressive (AR) process, where there is a memory of past events; an Integrated (I) process, which accounts for stabilizing or making the data stationary and ergodic, making it easier to forecast; and a Moving Average (MA) of the forecast errors, such that the longer the historical data, the more accurate the forecasts will be, as it learns over time. ARIMA models therefore have three model parameters, one for the AR(p) process, one for the I(d) process and one for the MA(q) process, all combined and interacting among each other and recomposed into the ARIMA(p,d,q) model.

The AR (p) model uses the p lags of the time series in the equation.

An AR (p) model has the form: $y_1=a_1y_{t-1}+\ldots..+a_py_{t-p}+e_t$.

The second component is the integration (d) order term. Each integration order corresponds to differencing the time series. I(1) means differencing the data once. I (d) means differencing the data d times. The third component is the moving average (MA) term. The MA (q) model uses the q lags of the forecast errors to improve the forecast.

An MA (q) model has the form:
$y_1=e_1+b_1e_{t-1}+\ldots\ldots+b_qe_{t-q}$.

Finally, an ARIMA (p,q) model has the combined form:
$y_t = a_t y_{t-1} + \ldots + a_p y_{t-p} + e_t + b_1 e_{t-1} + \ldots + b_q e_{t-q}$.

Proposed Methodology

The capacity to learn from examples is one of the main uniqueness of the neural network predictor i.e. BPNN .

The first step of these methods is to obtain normalized data from text files. Patterns are generated and statistical analysis is performed for good correlation among the input variables data. A large part of the data is fed into the training network and the remaining part into the testing network. Finally, it is predicted that the ANFIS model is the best.

The methodology used to design a predictor is summarized as follows:
1. Pre-processing of data.
2. Normalization.
3. Statistical Analysis
4. Neural Network design
5. Training
6. Testing
7. Validation

The prerequisites for any forecasting system using Artificial Neural Network & Back propagation Algorithms are as follows:

Data collection

Publicly available historical weather data of Metrological center, Visakhapatnam, Andhra Pradesh, India is used in this work to predict the weather. The data are divided into several windows where most of these are used for training and the remaining data are used for testing the ANN. All inputs and outputs are normalized before training.

Input variables & selection criteria

The selection of the input variables is most important work in building a forecasting model. There is so systemic approach suggested to select the input variables. The following are certain statistical parameters can be used to determine the relevant inputs.

Table 3: List of Different Input Variables

S.No.	Input Variables	Units
1.	Temperature	Deg.C
2.	Dew Point Temperature	Deg.C
3.	Relative Humidity	%
4.	Wind Direction	10's Deg
5.	Station Pressure	Kpa

Many the variables, the result yielded will be better.

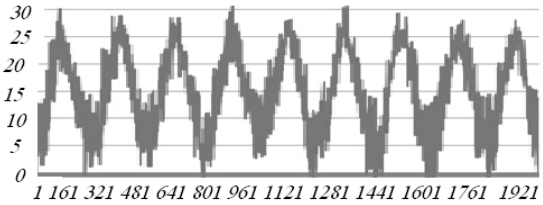
Data Analysis: The variables taken into consideration shall be inter-related & inter-dependent. The inter-relationships of the variables are a big factor in training set preparation & training of ANN. So the normalization should be done certainly & so carefully before making the training set.

Dataset: The data that we acquire for training of our model plays a vital role in forecasting accuracy. This describes how much data we acquire for the training of proposed model. In other terms the time series duration of data as one year, two years, five years so on.

Training set: The training set is one the most considerable entity of our research work. Even it could be said the backbone of the ANN based forecasting system. It contains the input matrix & target matrix which contains the collection of unit input & unit output for the ANN correspondingly. The better the training set, better the result.

Results

For both the models ANFIS and ARIMA, temperature is considered as the input parameter (archive temperature data as temperature curve is provided below). Fuzzy inputs are developed from crisp input set by membership functions on the basis of Gaussian MF for both the models.



From the output obtained from both the models, it is clear that ANFIS predict the result with least percentage error.

Apart from the traditional forecasting systems, ANN based forecasting is much feasible and best suited. Applying soft computing could be one of the best alternatives for weather forecasting.

Conclusion

In this paper, we explain the techniques of Soft computing and their ability to predict natural system's behavior at future time. The techniques were implemented, tested and trained with the existing dataset. The best method suitable to forecast weather is identified.

Soft computing techniques are easy to implement and produces desirable mapping function by training on the given data set. Choosing suitable parameters for the soft computing models is more or less a trial and error approach. Optimal results will depend on the selection of parameters.

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