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Development of Temperature-based Weather Forecasting Models Using Neural Networks and Fuzzy Logic

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Abstract

In critical fields such as flight, agriculture, tourism, etc, forecasting is an important issue due to its effectiveness in human life to know what will happen for unpredictable situations and events. Weather forecasts provide critical information about future weather conditions. Actually, weather forecasting plays an important role in our daily life by predicting what the weather will be tomorrow and it is reflected in a wide area of applications in our life so, we can prevent huge damages by forecasting the coming of storms or typhoons or get benefits from the forecasting activities. The temperature warnings are important forecasts because they are used to protect life and property and to improve the efficiency of operations. We propose computer-based models for weather forecasting based on temperature to predict the daily temperature using two techniques, artificial neural networks and fuzzy logic. The main purpose from this study is to develop different weather forecasting models based on the two techniques over different regions. The developed models show that the objectives of the study were achieved successfully. Finally, the models have been tested and the results confirm that the proposed models are capable to forecast the daily temperatures.

Keywords: *forecasting models, weather, neural networks, fuzzy logic*

1. Introduction

Although there is always a hope for the future of what will happen for unpredictable situations and events, no anybody knows what will be in the future, for example, the weather forecasts for the next day, the stock market forecasts for tomorrow, or the enrollments forecast for the next year, such of these forecasts are called "time series forecasting". Humans are always interested in oncoming events; they are important due to its effectiveness in human life. Hence we can forecast tomorrow's events by using some prediction techniques [1].

Forecasting methods may be classified into three types: judgmental forecasts, univariate methods, and multivariate methods. Judgmental Forecasts based on subjective judgment, intuition, and any other related information. In univariate methods, the forecasts depend only on present and past values of the single series being forecasted. In Multivariate methods, the forecasts of a given variable depend, at least partly, on values of one or more additional time series variables.

There are two types of time series data:

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1. Continuous time series: an observation is recorded at every instant of time, denoted using observation x at time *t*, x (*t*).
2. Discrete time series: an observation is recorded at regularly intervals, denoted using observation x*t*.

A variable is a value or a number that changes in increased or decreased pattern over time. There are two mainly categories of variables, independent variable and dependent variable. The independent variable and dependent variable are differing in an experiment. The independent variable is a variable that is varied or manipulated in the experiments by researchers; it refers to what is the influence during the experiment. The dependent variable is the variable that is simply measured by the researchers; it is the response that is measured. The dependent variable responds to the independent variable. It is called dependent because it depends on the independent variable. We cannot have a dependent variable without an independent variable.

For example on such types of variables; we are interested in how temperature affects on tourism rate. The independent variable would be the temperature and the dependent variable would be the tourism rate. We can directly manipulate temperature levels and measure how those temperature levels affect tourism rate.

It is possible to forecast various kinds of data, anyway time series shows the changing of a value in time. The value can be impacted by also other factors rather only time. Time series represents discrete historical values and from a continuous function it can be obtained using sampling.

There are four main components of any time series; trend, seasonal, cyclical, and irregular. They are listed and explained in the followings:

1. Trend move up or down in a predictable form, they tells whether a particular related data set have increased or decreased over a period of time. Trend is a long term movement in a time series and a rate of change in a time series. It can be shown as an upward or downward tendency. A simple way in trend detection is taking averages over a certain period of time.
2. Seasonal often named to as seasonality, it repeats over a certain period such as a day, week, month, year, season, *etc.*, and they are defined as the repetitive and predictable movement around the trend line.
3. Cyclical describes upward or downward movements around a given trend in a time series (any regular fluctuations). Cyclic variations are not regular as seasonal variation. There are different types of cycles of varying in length and size.
4. Irregular do not fall under any of the above three components, because it doesn't predictable. It is caused by unlooked-for circumstances.

2. Research Problem

Weather term refers to the conditions of the air on the earth surface at a given place and time. Forecasting is the guessing in unknown situations and computing future forecasts from present and past values. Prediction is fairly similar, but more general term than forecasting. Both can refer for guessing of time series [2]. We will use forecasting term specifically in this study because we talk about a specific topic which is the weather. Weather forecasting is the process of forecasting changes of the atmosphere, such as atmospheric pressure, precipitation, temperature, wind speed and direction, humidity, etc.

In this study, also we are talking in particular about the temperature then we can say that "it is the application of science and technology to predict the state of the temperatures for a

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future time and a given location" [3, 4]. Weather Forecasting is a typical problem in pattern recognition field [5].

Weather forecasts provide important information about future weather conditions [6]. The gathering of information is always the first step needed in weather forecasting. Actually weather forecasting plays an important role in our daily life by predicting what the weather will be tomorrow, also weather forecasting is reflected in a wide area of applications in our life such as economy, tourism, agriculture, etc .So, we can prevent huge damages to occur by forecasting the coming of storms or typhoons or get benefits from the forecasting operations [7]. On the other hand the temperature warnings are important forecasts, because they are used to save the whole life and properties, improve the efficiency of operations and by humans to plan a wide range of daily activities [3, 8]. Therefore many of studies were carried upon this field because of its importance.

The goodness of a weather forecast [9], consistency, quality and value. Consistency, basically respect to the meteorologist. Quality respects to the match between forecasts and observations. Value, is determined by economic benefits, it is interest to users. All these types are related to each other. For instance, when an economic decision is based on weather forecasts, the relation between quality and value is determined by the user and absolutely depends on the type of problem [10].

The weather is a continuous, data-intensive, multidimensional, dynamic and chaotic process, these properties addition to its challenges are enough to make the weather forecasting to be considered a complex process [11-13].

Meteorological parameters such as temperature are important for agricultural, economic, tourism systems, etc. Forecasting on future conditions is most often needed in these systems. Weather forecasts then become a great importance.

There are two mainly problems in the weather forecasting system, the first problem is the weather forecasts may be an uncertain [14, 15]. The uncertainty of weather forecasts have a direct impact on the uncertainty of the system states [16], as result there is a need in minimizing the uncertainties by using techniques, approaches, methods or models that may be available to these systems.

The second problem in which it is considered the main disadvantage of traditional forecasting approaches is that they cannot deal with forecasting problems in which the historical data are represented by linguistic values (*e.g.,* hot, normal, cold). Some of systems need large data sets, using a limited number of data set in such endeavors in such of these systems will be reflected in a certainty. The need for accurate weather forecasting and from other hand it can be deal with linguistic variables is evident when we looking at the benefits that it has [4]. The accuracy of weather forecasting is important in many sectors are largely dependent on the weather conditions [13]. Because of all the previously mentioned problems and challenges, the weather forecasting takes attention from the researchers.

In this study we propose a computer-based solution for weather forecasting based on temperature to predict the next day temperature using artificial neural networks and fuzzy logic techniques. Hence, we can summarized the main purpose is to develop four weather forecasting models based in two techniques artificial neural networks(ANNs) and Fuzzy logic (FL). These two models were developed into two different regions, Amman airport and Taipei city / China.

The dangerous weather events caused thousands of deaths and loss of billions of U.S. dollars each year all around the world. Any change in the climate may affect on many social, economic and tourism activities, ranging from agriculture to transportation to water resource management [17]. Because of weather’s importance and effects the decision makers have grown to accredit on weather forecasts provided by the meteorological stations.

Forecasting of weather conditions is the main service provided by the meteorological community. Many governments and private agencies are working on its behavior but, it considered a challenged and incomplete process [18]. So, weather forecasting has been one of the most challenging problems on the worldwide, Not only because of its practical value in meteorology, but it is also a typical “unbiased” time series forecasting problem in scientific research fields [19, 20].

3. Literature Review

3.1. Neural Networks Techniques

There are many studies were done for weather forecasting based on artificial neural networks. Neural networks are appropriate technique for forecasting time series because it can be learned only from examples, without any need to add additional information that can bring more confusion than forecasting effects. Neural networks are able to generalize and are resistant to noise. On the other hand, it is generally not possible to specify exactly what a neural network learned and it is also hard to estimate possible forecasting error.

Forecasting of time series using neural network consists of teaching the network with historical data in a selected limited time and applying the taught information to the future. Data from past are provided to the inputs of neural network and as shown in Figure 1. We then expect the future data from the produced data that generated by the network.

Several Kinds of neural networks can be used for forecasting, such as Feed-Forward, Back-Propagation, Radial Basis network and others. In the rest of this text we will focus on the studies that were done on weather forecasting.

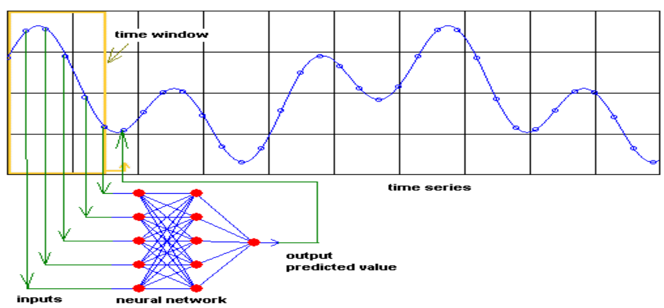

Figure 1. Teaching of Time Series Without Interventional Variables

A neural network-based algorithm for predicting the temperature has been presented using Back Propagation Neural Network (BPN) technique [3]. This type of algorithms minimizes convergence and damps the oscillations. Back propagation neural network technique for temperature forecasting can give a good results and it can be considered as a replacement to traditional meteorological methods, because of the used package supports different types of training or learning algorithms and it can equitably approximate several functions, also the ability to determine the nonlinear relationship that exists between the historical data (temperature, wind speed, humidity, *etc.*,) supplied to the system during the training stage and on that basis, make a forecasting of what the temperature would be in future.

Artificial neural network (ANN) models have been proposed by [21] in forecasting the minimum temperature using the back propagation algorithm. The presented work was carried out using a limited number of data. The proposed method has a number of restrictions: heavy computational requirements, absence of ANN design approaches to define the values of the learning coefficient n, and the momentum coefficient a and Lack of its availability in all sites So, this requires additional neural network models to be build for different sites.

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A radial basis functions network (RBFN) was proposed which includes one year's data consisting of daily maximum and minimum temperature, and wind-speed for Vancouver, British Columbia, Canada [6]. This works was done as a comparison between the performance of three neural network models; radial basis function networks, multi-layered perceptron (MLP) neural network and Elman recurrent neural network (ERNN). ERNN takes more training time depending on the training data-sets size and the number of Parameters. The conclusion, ERN could be an accuracy model, if good data selection strategies, training paradigms, and network input and output representations are defined properly. RBFN yields the best results, comparing with these models it more accuracy, requires less training time and more reliable for the weather forecasting problem considered. Also the proposed RBFN network can overcome numerous restrictions of the MLP and ERNN networks such as highly nonlinear weight-update and slow-convergence ratio. Since the RBFN has natural unsupervised learning properties and modular network structure, making it a more effective alternative for weather forecasting.

Neural-networks-based ensemble models were developed and applied for hourly weather forecasting of southern Saskatchewan, Canada [11]. This work was done as a comparison between the proposed ensemble model performance with multi-layered perceptron network (MLPN), Elman recurrent neural network (ERNN), radial basis function network (RBFN), Hopfield model (HFM) predictive models and regression techniques. The parameters of temperature, wind speed and relative humidity are used to train and test these models. With each model makes forecasts for the next day for the winter, spring, summer and fall seasons. The performance and reliability of the models are evaluated by a number of statistical measures. The empirical results show that HFM relatively has less accuracy and RBFN is relatively has more efficiency for the weather forecasting problem. In comparison, the RBFN model performed better than MLPN and ERNN, while the HFM model has the lowest accuracy. In the conclusion, the ensemble of neural networks produced the most accurate forecasts results.

A new architecture of neural network models has been proposed using the functional graph. The weather forecasting models were carried out using ENN, Functional Graph based ENN, Opto-electronic neural network and Functional graph based opto-electronic neural network [22]. Electronic Neural network (ENN) is a set of processing elements (neurons) with a high degree of interconnections (weights) between them. The results are compared with two meteorological experts, they show that: (i) the performance of Functional Graph based ENN is better than the performance of ENN. (ii) The performance of Functional graph based opto-electronic neural network, is better than the performance of Opto-electronic neural network. The functional graph based neural network models are capable to solve X-OR problem.

In Cairo city as a study area, a comparison has been undertaken between three neural networks architectures with different training techniques, the popular multilayer perceptron (MLP), and the radial basis function network (RBF) and feed forward neural networks which were trained by differential evolution algorithm [12]. These techniques were evaluated to forecast temperature and daily data- sets (*i.e.*, maximum, minimum and average temperature) of Cairo city were used as training set. The obtained results show that the popular feed forward neural network which trained by DE (Differential Evolution algorithm) is most accurate model to use as a temperature predicator especially in the uniform temperature distribution (minimum or maximum temperature) which can be considered more effective technique for temperature forecasting.

An application of neural networks for short-term temperature forecasting (STTF) Systems for Kermanshah city, west of Iran was developed [4]. Multi-Layer Perceptron (MLP) architecture of neural networks was applied to model the system. This system was trained and

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tested using ten years (1996-2006) meteorological data to forecast one day ahead. The results show that MLP network has the minimum forecasting error and can be considered a suitable method to model the STTF systems.

An integrated back propagation based genetic algorithm technique to train artificial neural networks was proposed [13]. The proposed technique is a combination of two techniques together Back Propagation algorithm and genetic algorithm techniques. Three main weather variables were chosen for forecasting (mean air temperature (ºC), relative humidity (%) and daily rainfall (mm)) in the Ludhiana city of Punjab (India) for the month of January /2009.This combined technique can learn efficiently by combining the strengths of genetic algorithm with back propagation. The empirical results show that the combined BP/GA technique is more effective and suitable candidate for weather forecasting than the traditional gradient based back propagation algorithm because the presented BP/GA technique is more near to the target than the back propagation algorithm.

A proposed methodology was carried out using rainfall and temperature weather parameters over the east coast of China [20], it is based on some necessary data preprocessing technique and the dynamic weighted time-delay neural networks (DWTDNN), which is a type of dynamic neural networks, and it is a simplified version of the focused gamma network and an extension of TDNN. The results show that neural networks with a few of hidden layers and an arbitrary bounded and non-constant activation function can effectively forecast the weather.

The application of Artificial Neural Network (ANN) for weather forecasting using a Photovoltaic system was implemented to forecast daily weather conditions based on numerous parameters; rain, cloudy, dry day and storm [23]. Multiple Multilayer Perceptron (MMLP) was used and trained using Levenberg Marquardt (LM) algorithm as a comparison between the performance of MMLP and single MLP network. Experimental results demonstrate that the MMLP more efficient in term of performance than the traditional ANN concept of selection an MLP with least number of hidden neurons.

Recurrent Fuzzy Neural Network (RFNN) is one of the most effective methods belonging to machine learning [8]. The authors used this method for weather forecasting. Three weather parameters included; maximum temperature, minimum temperature, and rainfall spanning from 1981 to 1990 in Melbourne, Australia. This work has two scenarios. The first scenario is that the predicted value (predictand) depends on its values in the past, *i.e.,* predictors are maximum temperature at time points (t-1), (t-2), (t-n). The second scenario is that the predictand depends on the values of parallel time series, *i.e.,* predictors are maximum temperature, minimum temperature, and rainfall at time point (t-1). Empirical results after a comparison with two scenarios show that scenario 2 always more efficiency than scenario 1.

A solution to the weather forecast problem based on artificial neural networks has been proposed [24]. Prediction system is built based on multilayer perceptron network trained with back propagation algorithm; training samples consist of date information combined with meteorological data from the last three days gathered at the meteorological station in Miami, USA. The results demonstrate that the average error is 5.72%, and the correlation ratio between predicted and real changes is equal to 0.7136.

A model of support vector machine for temperature forecasting was proposed [25]. As a comparison results in term of the performance of SVM with MLP for different orders, it have shown that SVM better than MLP which trained with back propagation algorithm for all orders. This model can be alternative approach to replace some of the neural network based models for weather forecasting when the selection of the parameters is done properly.

Mean absolute error (MAE) is a measure for the performance. The authors in [26] focused on developing ANN models with objective of reducing the mean absolute error (MAE). The

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developed models to forecast temperature at intervals from one to 12 hours ahead, for each ANN model there is a network architecture and set of associated parameters, and each of these models was simulated by training 30 networks and calculating the mean absolute error (MAE).

3.2. Fuzzy Logic Techniques

A Temperature Prediction model has been proposed Using Fuzzy Time Series. The new fuzzy time series model called the two-factor time-variant fuzzy time series model for temperature forecasting [7]. Two algorithms for temperature prediction then proposed. Both algorithms have the advantage of obtaining good forecasting results. The empirical results show that the results of Algorithm-B* are better than the results of Algorithm-A and Algorithm-B. These algorithms have advantages, both they can give good results. The time complexities of the proposed algorithms are O (cwm), respectively, where c is the number of partitioned groups in the historical data, w is the window basis, and m is the number of elements in the universe of discourse.

A novel method was developed to forecast temperature and the Taiwan Futures Exchange (TAIFEX), based on the two-factor high-order fuzzy time series [27]. For each value in a real-valued time series is represented by a fuzzy set, after that, it is represented by fuzzy sets form a fuzzy time series. Therefore, the real-valued time series is transformed into a fuzzy time series. The proposed method is an efficient in term of it has higher forecasting accuracy rate and it has a smaller mean square error than the other methods.

3.3. Hybrid Techniques

A rough set based fuzzy neural network algorithm has been proposed to solve weather forecasting problems [28]. The experimental data are from World Meteorological Organization. The least square algorithm (LSA) was used in the learning stage of fuzzy neural network to obtain global convergence and the rough sets method was introduced to determine the numbers of rules and original weights. Five attributes or parameters are considered, and these attributes are FRS, dew temperature, wind speed, temperature and visibility. The authors have been selected the data from some city (Date: Jan 1, 2000—Jan 31, 2000) in China. The result of forecasting by the proposed algorithm is that visibility is 10.4202 on Jan 7-2002. Actual visibility is 10.624 on Jan 7-2002. The error rate is (10.624-10.4202)/10.624=1.918%.

A Weather Forecasting System was presented using concept of Soft Computing i.e. a neuro-fuzzy system was used to predict meteorological position on the basis of measurements by a weather system [18]. The authors considered atmospheric pressure a primary key parameter and atmospheric temperature and relative humidity secondary type. They examined temperature as forecasts of weather conditions in some cases to observe the effect of temperature.

A new method was developed for temperature prediction and the TAIFEX forecasting based on mixed techniques, fuzzy logical relationships and genetic algorithms [29]. The method builds two-factors high-order fuzzy logical relationships based on the historical data and uses genetic algorithms to control the length of each interval in the universe of discourse. The experiments indicated that this method gets higher forecasting accuracy rates than the methods presented in [7] for temperature forecasting. It also gets a higher forecasting accuracy rate than the methods presented in [30] and [19] for forecasting the TAIFEX.

In another work, a combined method of two techniques was proposed for forecasting the daily average temperature and the TAIFEX based on the automatic clustering techniques and two-factor high-order fuzzy time series [1]. An automatic clustering algorithm was used to generate clustering-based intervals to make each interval in the universe of discourse have a different length. From the empirical results, the proposed method gave higher forecasting accuracy rates than the existing methods in [7, 27, 30-32].

4. Research Methodology

In this section, the methodology of the research would be discussed. The steps of the methodology are: the awareness of the problem, suggestion, development, evaluation and conclusion. Research methodology is more than just collections of method to perform a research; it is a systematic way to solve the research problem [33]. The research methods refer to the methods and techniques used by the researcher in performing the research, for example data collection technique, data processing techniques and instruments.

To develop this model, a methodology based on a general methodology in research design is used, because it has the logical phases that are used to develop this model [34, 35].

According to [36], the design research methodology contains the following major steps: awareness of the problem, suggestion, development, evaluation and conclusion. Awareness of problem gives a picture of the problem and some ideas of the problem solving. The problem may come from multiple sources and reading in a connected discipline may also provide the chance to obtain the new findings. The output of this phase is a proposal for a new research effort.

The suggestion phase follows after the awareness of problem phase and is closely connected with it. When the problem is properly recognized and understood, we may have several candidate solutions. The output of the suggestion phase is tentative design. The development phase is the implementation of the tentative design. The implementation techniques will be different depending on the artifact to be created. The software development and a high level package or tools are required to make an assumption in this phase.

In the evaluation phase, the artifact is evaluated following to some of measurements, which will be clearly discussed in the experimental results section. The results from evaluation is indicated the consideration of future work and used as feedback to another round of the Suggestion phase. The Conclusion phase is the last part of the design research methodology. The results and knowledge gained in the effort have been learned and can be repeatedly applied to the further research.

4.1. Steps of the used Methodology

4.1.1 Awareness of the Problem Phase: The weather forecasting faced major problems; weather forecasts are subject to uncertainties. The uncertainties of weather forecasts have a direct effect on the uncertainty of the system states. The traditional approaches cannot deal with forecasting problems in which the historical data are represented by linguistic values (*e.g.,* hot, normal, cold). In this work we will overcome on this problem.

4.1.2. Suggestion Phase: Firstly, we gathered the data sets from Jordan metrological department for two years 2004/2005 include temperatures, precipitation, and humidity as a parameters for weather forecasting system for the Amman airport models. For the Taipei city/china models we gathered the data sets from [7], which include temperatures for June, July, August, and September 1995/1996. The study suggests models for weather forecasting to solve the above recognized problems. The output of this phase is a tentative design / model. The design includes selecting and formulation of suitable architecture, selecting suitable learning algorithms, and selecting the other suitable settings of the neural networks

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models to achieve the desired results. We treated with the fuzzy logic models with the same approach by choosing the appropriate settings.

4.1.3 Development Phase: After designing the model, the research proceeds with the development of the system prototype. The completed design will then be translated to a program code using some of software. In our weather forecasting models we don't have a graphical user interface but, we wrote the codes of the models using MatLab software, there is no need for a graphical user interface to get the results. MatLab considered an excellent environment for forecasting using artificial neural networks and fuzzy logic.

4.1.4 Evaluation and Conclusion Phase: The main purpose of conducting testing is to minimize as little as possible the weather forecasting models from bugs and errors. In the evaluation phase, the models were evaluated following to some of measurements, which will be clearly discussed in the experimental results section. The results from evaluation is indicated the consideration of future work and used as a feedback. The conclusion phase is the last part of the design research methodology. The results and knowledge gained in the effort have been learned and can be repeatedly applied to the further research.

5. System Modeling

5.1. System Modelling

To forecast the temperature for the next 24 hours, or to predict the population of China for one year ahead, *etc.*, we need to construct an abstract model that reflects the reality and actuality of the real system. System modeling can be viewed as a conceptual framework to describe a system and can be viewed as an abstraction.

The abstracted model may be logical or mathematical. A mathematical model is a mathematical that describes the behavior of a system. A mathematical modeling is the use of mathematics to translate the system into the language of mathematics, this implies that a mathematical modeling attempts to describe and explain real-world phenomena. The real-world term also implies that mathematical models are used in various fields including the natural sciences, engineering disciplines, social sciences, *etc.*,

The development of a mathematical model depends on the system's elements. Thus, through model development, there is a need to optimize two things: simplicity of the model and accuracy of the model. Actually the accuracy is complementary to the simplicity. A mathematical model usually describes system variables regardless of their types; real or integer numbers, Boolean, strings, *etc.*, System's variables reflect some characteristics of the system such as timing data, counters, and event occurrence.

Mathematical modeling problems are often classified into white-box or black-box models according to how much a priori information is available. In a black-box model there is no prior information available, and a white-box model, all necessary information is available. To make the model more accurate, we need to use more a priori information as possible. Artificial neural networks (ANNs) models are good for complex systems especially when input– output patterns are in quantitative form, when the input and output information are not in quantitative form, but in qualitative or fuzzy form, fuzzy models are good in these situations. ANNs are considered an approach for black-box models, which need the input and output data sets.

The system modeling is used to mimic the behavior of systems under different operating conditions. This can be performed via experiments. But, sometimes it is difficult to do experiments on real systems due to the reasons; the experiments may be costly, time consuming, and a risk may be exist.

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Modeling has essential benefits in which we need them in certain situations; when a system does not exist on the real world and we wants to develop a new system. Thus the modeling process is helpful in knowing, prior to the development of the system on how the system will work for different conditions and inputs. Modeling make us think deeply about the structure of model before creating a physical model. Modeling gives us a well known idea about a system through interaction with what we develop. Modeling improves system performance by changing the system structure including inputs and environment conditions to improve its performance. To have candidate solutions, modeling also allows us to find many alternate solutions to improve system performance.

5.2. Modelling Approaches for Complex System

A complex system is a system that comprises a large number of interacted components. The entire activity of complex system is nonlinear (the activity of the entire activity does not obtained from the summations of individual components) and typically exhibits hierarchical self-organization under selective pressures. Mathematical models are accurate and precise systems, but the system complexity can be accessible only up to certain limit. When system's complexity increases, mathematical model development becomes more difficult and time consuming to simulate complex system models.

Modeling using ANN approach is better in comparison to mathematical models. From related literatures that demonstrate it is necessary to have accurate and sufficient training data set in order to have a good ANN model. Actually this is difficult in most real-world problem. The real-world problems have qualitative or quantitative form; qualitative form is difficult to translate into quantitative form. Thus, there is only one approach for such situation which is fuzzy modeling.

Mathematical modeling techniques have more accuracy and are appropriate when a problem is less complex. Using ANN modeling is recommended to be employed in the medium complex systems. Fuzzy modeling approach is used in highly complex systems.

5.3. Models Classifications

Models and modeling languages can be classified in different ways in order to address different aspects of a system. Hence, different models can serve several purposes. The classification of models can be useful for choosing the right type of model for the interested purpose and intended scope. System models may be classified:

5.3.1 Physical vs. Abstract Models: The system modeling does not mean the model must be represented physically to understand how it works, such as airplane model, car model, *etc.*, Such of these models are called physical models. Physical models are most easily understood. An abstract model is a model in which represented via symbols, rather than physical representation. The abstract model is more common but less understood and recognized. We can write a language or take a conceptual thought to constitute the abstract model, this is called the symbolism.

5.3.2 Mathematical vs. Descriptive Models: The mathematical model is represented via the language of mathematical symbols and concepts. Hence, the mathematical model is a special type of the abstract models. The simplest example of the mathematical model is the distance = acceleration × time.

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5.3.3. Static vs. Dynamic Models: The distinct difference between static and dynamic model of a system is that a dynamic model refers to runtime model of the system. Dynamic modeling is used to represent a system over a time. Static modeling is used to represent a system in which time simply plays no role.

5.3.4 Steady State vs. Transient Models: A steady state is representation of the state of a system with time and in which the behavior is stable, the state in one time period is of the same pattern as any other period. Transient behavior is a "one-time" phenomena, it is the behavior of the system whereby the system response to changes during time.

5.3.5. Deterministic vs. Stochastic Models: The systems may contain probabilistic (*i.e.*, random) components or not. A system model is called deterministic if it does not contain any probabilistic components. In deterministic model, the output is "determined" in advance when the set of input quantities and relationships in the model have been specified. Most of systems have at least some random input components; and these lead to stochastic simulation models (*i.e.*, queuing and inventory systems). In stochastic simulation, the produced output is by itself random, and it's only an estimation of the actual characteristics of the model.

5.3.6. Continuous vs. Discrete Models: Discrete model is a model in which the state variables change only at a countable number of points in time (finite number of states). In these points the events occur and lead changes in a system state. Continuous model is a model in which the state variables change in a continuous pattern, and not in abrupt pattern from one state to another (infinite number of states).

6. Introduction to Fuzzy Logic

The fuzzy concept means the vague and lacking the exact and clarity, which means the values or boundaries can vary according to context or conditions, instead of being fixed once and for all. Actually the fuzzy has different semantics, but these can become clearer only through further specification, including a closer definition of the context in which they are operationalized.

The reasoning of fuzzy logic looks like human reasoning, instead of the entire data to be relying on crisp line and to have only two values which may incomplete or ambiguous, Fuzzy logic able to process this situation and to provide approximate solution.

A conditional fuzzy proposition or rule has the form: IF w is Z THEN x is Y, This rule should be interpreted: x is a member of Y to the degree that w is a member of Z, for example; IF experience is high THEN salary is high. The membership value of salary in the fuzzy set high is specified by the membership value of experience in the set high. Rules are usually expressed in the form: IF variable is 'property' THEN 'action'. For example:

- IF temperature is very cold THEN turn on the heater.
- IF temperature is cold THEN slow down the heater.
- IF temperature is normal THEN keep the level of the heater.

Practically, the fuzzy inference system can be described in the five steps:

1) **Fuzzifying Input:** Initially, once inputs are available, the degrees of the inputs to which they belong to each of the appropriate fuzzy sets are determined via membership functions.
2) **Applying Fuzzy Operators:** If the rule consists of multiple parts (antecedent), there are need to apply logical operators to evaluate the degree of the strength for the rule.

3) **Applying the Implication Process**: The implication is a process whereby the output membership functions on the basis of the strength of the rule are shaped. The output is a fuzzy set of the consequence, whereas the input for the implication process is a single number given by the antecedent.
4) **Aggregating All Outputs:** Aggregation is unifying the outputs of each rule. The aggregation is performed only once for each output variable. The output of the aggregation process is a single fuzzy set which is the combination of a list of truncated output fuzzy sets returned by the implication process for each rule.
5) **Defuzzifying:** Finally, the output of the defuzzification process is a crisp value whereas; the input is the aggregated output fuzzy sets. Recently, many of various methods in defuzzification process have been proposed by investigators including, the maximum, the means of maxima, height, and modified height method, and the centroid.

7. Experimental Results

This section discussed the implemented weather forecasting models using two techniques, the artificial neural networks and fuzzy logic. The followings are two sections show results from the empirical. MATLAB software was used for the development of models; it considered an efficient environment for such kind of forecasting. The models were implemented using neural networks technique in two regions, Amman airport and Taipei / China, and also the models were implemented using fuzzy logic technique also in two regions. The followings demonstrate these models with their results in details.

The VAF (Variance Accounted For) is a measure, which is used to evaluate the quality of the model, by comparing the actual output with the output of the model. VAF represents the percentage of the converge between the actual output and the output of the model. When y1 and y2 are matrices and the two matrices are equal then the VAF is 100%. The VAF is computed as follows.

$$VAF = \left(1 - \frac{var(y1-y2)}{var(y1)}\right) \times 100\ \% \qquad (1)$$

Error calculation is another measure; it can be used as a measure of error made by the neural network and fuzzy logic models. MSE is one of the most commonly used functions which are the summation of absolute difference between the estimated values and the true values divided by the number of samples n.

$$MAE = \frac{\sum_{i=1}^{n} |Estimated\ value\ i - Actual\ value\ i|}{n} \quad (2)$$

7.1Amman Airport Models

This section demonstrates the two implemented models that are established using data sets of Amman airport (Figure 2) which is a region in the campus of Jordanian meteorological department. The data sets that were used in these models are in the period of Jan-2004 to Dec-2005. The entire data sets (2004, 2005) were divided into two parts, the first part (Jan-Dec/ 2004) for training, and the second part (Jan-Dec/ 2005) for testing. The models were developed using two techniques, artificial neural networks (ANNs), and fuzzy logic (FL).

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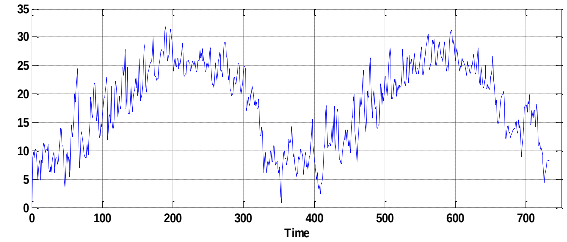
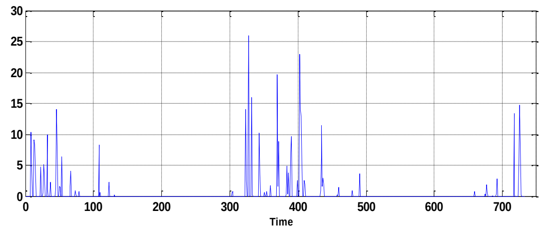
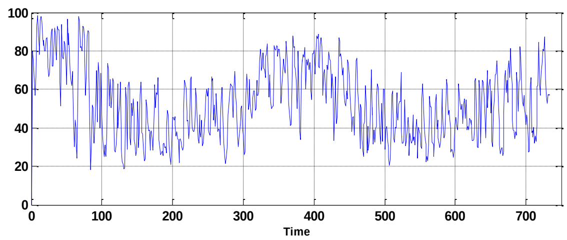


Daily Mean Temperature C° (t-1)



Precipitation, Daily Total 'mm'(t-1)



Relative humidity % (t-1)

Figure 2. The Inputs of Amman Airport Models

7.1.1. Neural Network Model: Amman airport NN model was developed using one of the most familiar of neural network architectures which is feed forward type with back-propagation training. The network consists of one input layer, one hidden layer, and one output layer, respectively in the arrangement. The input layer consists of three neurons that represent three parameters as inputs for the network, daily mean temperature C° (t-1), total daily precipitation (t-1), 'mm', and relative humidity % (t-1). The output of the model is the daily mean Temperature C° (t). The general structure of NN Amman airport model is shown in Figure 3.

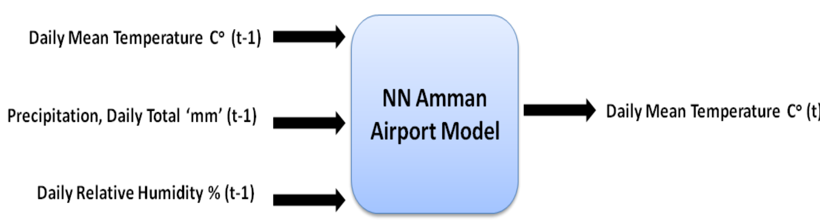


Figure 3. Block Diagram for Amman Airport NN Model

The output layer has one neuron that represents one desired parameter which is the daily mean temperature °C (t-1). Through many experiments we find the efficient number of neurons in the hidden layer is 20 as shown in Table 1. Table 2 shows the number of layers and neurons in the networks.

Table 1. Number of Hidden Neurons of Amman Airport NN Model

No of Hidden Neurons Neurons	VAF for Training	VAF for Testing
10	92.808	92.689
15	93.093	92.087
20	**93.128**	**92.305**
25	93.062	92.107
30	93.679	91.715

Table 2. The Layers and Neurons of Amman Airport NN Model

Number of layers = 3	Number of neurons
One input layer	Three neurons
One hidden layer	Twenty neurons
One output layer	One neuron

Before the training stage, the data were scaled into a range between (0.1 to 0.9). Scaling of data is useful and/or necessary under certain circumstances (*e.g.*, when values span different ranges), after that, the data is descaled (re-transformed) to the original form. The FF neural network was trained using Levenberg-Marquardt Back propagation algorithm, it updates weight and bias values according to Levenberg-Marquardt optimization and it is often the fastest back propagation algorithm in the toolbox. Figure 4 shows the error difference was calculated.

Figure 4. Estimated Error of Amman Airport NN Model / Training Case

Once the network is efficiently trained, it able to produce a better result. Hence, in the testing case the network was tested using the second part of data (January to December / 2005). Figure 5 shows the calculated difference error in the testing case.

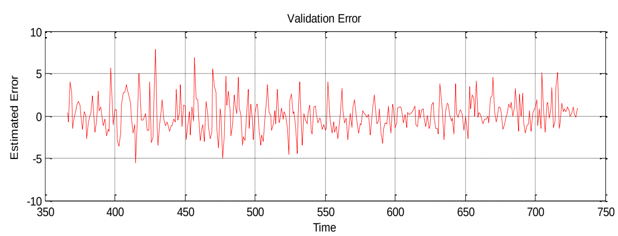


Figure 5. Estimated Error of Amman Airport NN Model / Testing Case

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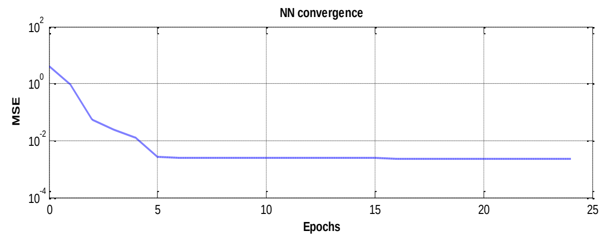

Figure 6. The Converegence of Amman Airport NN Model

The performance of the network was evaluated and the achieved results show that this model achieves better results. The Variance Accounted for (VAF) in the training case is 93.074, and the Mean Absolute Error = 1.436. In the testing case the VAF is 92.484, and the Mean Absolute Error = 1.462. Figure 6 shows the convergence of the network which reflects the ration of epochs to MSE.

7.1.2. Fuzzy Logic Model: In the fuzzy logic model, we used FMID toolbox that is available in MATLAB software. With the same inputs that were showed previously in figure 10. The inputs for the network, daily mean temperature C° (t-1), total daily precipitation (t-1), 'mm', and relative humidity % (t-1). The output of the model is the daily mean Temperature C° (t). The general structure of the model is shown in Figure 7. The setting parameter, consequent parameters, and cluster centers for this model are shown in Table 3, Table 4, and Table 5 respectively.

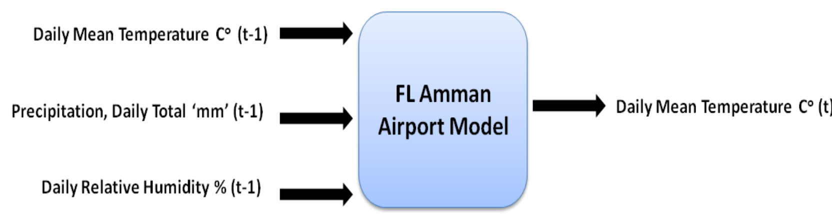

Figure 7. Block Diagram for Amman Airport FL Model

Table 3. Parameter Settings for Amman Airport FL Model

Parameter	Value
Number of Clusters	4
Fuzziness Parameter	2
Termination criterion	0.01
Type of antecedent	2
Type of Consequent	1

Table 4. Consequent Parameters for Amman Airport FL Model

Rule	*u*1	*u*2	*u*3	Offset
1	$-8.51 . 10^{-1}$	$-6.14 . 10^{-1}$	$-1.19 . 10^{-1}$	$2.68 . 10^{1}$
2	$3.27 . 10^{-1}$	$6.69 . 10^{-3}$	$2.63 . 10^{-1}$	$-1.84 . 10^{1}$
3	$3.99 . 10^{-1}$	$2.24 . 10^{-1}$	$6.73 . 10^{-2}$	$-7.26 . 10^{-1}$
4	$8.84 . 10^{-1}$	$-1.36 . 10^{0}$	$1.91 . 10^{-3}$	$2.46 . 10^{0}$

Table 5. Cluster Centers for Amman Airport FL Model

Rule	*u*1	*u*2	*u*3
1	$8.38 . 10^{0}$	$4.09 . 10^{0}$	$9.04 . 10^{1}$
2	$8.81 . 10^{0}$	$9.75 . 10^{0}$	$8.01 . 10^{1}$
3	$1.39 . 10^{1}$	$8.64 . 10^{-1}$	$5.41 . 10^{1}$
4	$1.92 . 10^{1}$	$4.44 . 10^{-18}$	$5.15 . 10^{1}$

The results that obtained by using fuzzy logic model are shown in Figures 8 and 9 which represents the error in estimated daily temperature for (2004). The Mean Absolute Error (MAE) for the model in the training case = 1.4866, and in the testing case = 1.4862.

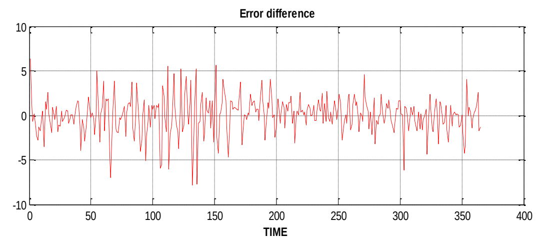

Figure 8. Estimated Error of Amman Airport FL Model / Training Case

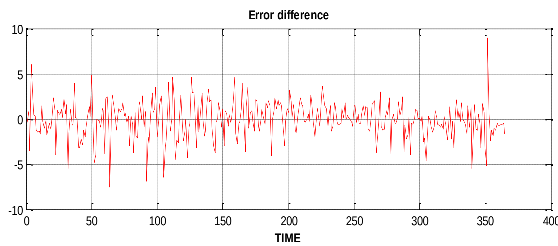

Figure 9. Estimated Error of Amman Airport FL Model / Testing Case

The Fuzzy logic model for Amman airport was generated from 365 data samples. It has 3 inputs and 1 output. The sampling period is 1 s. The termination tolerance of the clustering algorithm was 0.01, and the random initial partition was generated with seed equal to -3. In the following, the rules are shown.

Rules:
1. If $u1$ is A_{11} **and** $u2$ is A_{12} **and** $u3$ is A_{13} **Then**
$Y(k) = -8.51 . 10^{-1}\, u1 - 6.14 . 10^{-1}\, u2 - 1.19 . 10^{-1}\, u3 + 2.68 . 10^{1}$
2. If $u1$ is A_{21} **and** $u2$ is A_{22} **and** $u3$ is A_{23} **Then**
$Y(k) = 3.27 . 10^{-1}\, u1 + 6.69 . 10^{-3}\, u2 + 2.63 . 10^{-1}\, u3 - 1.84 . 10^{1}$
3. If $u1$ is A_{31} **and** $u2$ is A_{32} **and** $u3$ is A_{33} **Then**
$Y(k) = 3.99 . 10^{-1}\, u1 + 2.24 . 10^{-1}\, u2 + 6.73 . 10^{-2}\, u3 + 7.26 . 10^{-1}$
4. If $u1$ is A_{41} **and** $u2$ is A_{42} **and** $u3$ is A_{43} **Then**
$Y(k) = 8.84 . 10^{-1}\, u1 + 1.36 . 10^{0}\, u2 + 1.91 . 10^{-3}\, u3 + 2.46 . 10^{0}$

7.27.2 Taipei \ China Models

This section demonstrates the two implemented models that are established using data sets of Taipei city/china from [7]. The data sets that were used in these models are in the period of June-Sep/ 1995 and June-Sep/ 1996. The entire data sets were divided into two parts, the first part (June-Sep/ 1995) for training, and the second part (June-Sep/ 1996) for testing. The models were developed using two techniques, artificial neural networks (ANNs), and fuzzy logic (FL). Figure 10 shows inputs that were used in the two models.

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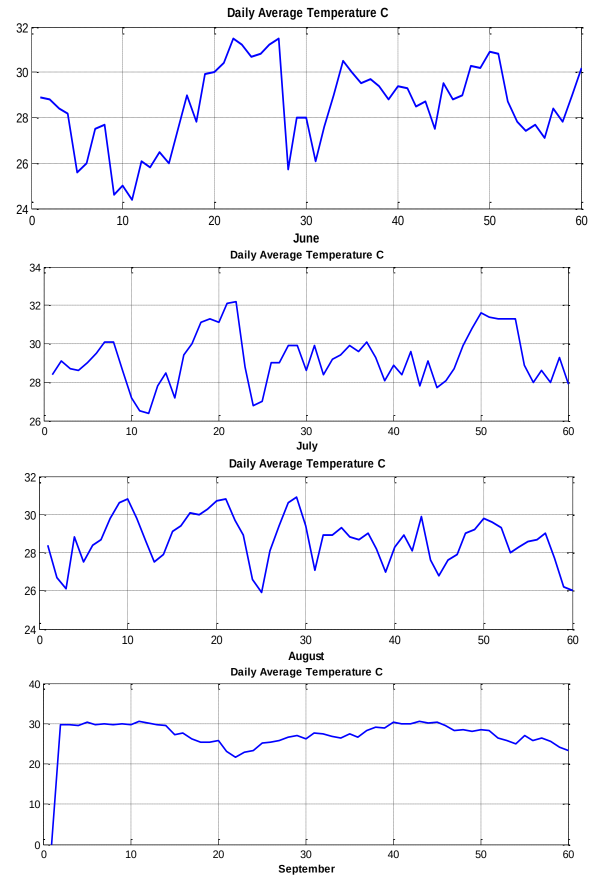

Figure 10. The Inputs of Taipei \ China Models

7.2.1. Neural Network Model: Taipei\ China NN model was developed using one of the most familiar of neural network architectures which is feed forward type with back-propagation training. The network consists of one input layer, one hidden layer, and one output layer, respectively in the arrangement. The input layer consists of four neurons that represent four parameters as inputs for the network, June average daily temperature °C(t), July average daily temperature °C(t), August average daily temperature °C(t), and September average daily temperature C° (t-1). The output of the model is the September average daily temperature C° (t).

The output layer has one neuron that represents one desired parameter which is the daily mean temperature °C (t-1). Through many experiments we find the efficient number of neurons in the hidden layer is 10 as shown in Table 6. Table 7 shows the number of layers and neurons in the networks.

Table 6. Number of Hidden Neurons of Taipei NN Model

No of Hidden Neurons	VAF for Training	VAF for Testing
10	**99.9859**	**98.2926**
15	99.9997	95.2981
20	99.9981	92.5545
25	99.9917	93.6710
30	99.8713	81.5386

Table 7. The Layers and Neurons of Taipei NN Model

Number of layers = 3	Number of neurons
One input layer	Four neurons
One hidden layer	Ten neurons
One output layer	One neuron

Before the training stage, the data was scaled into a range between (0.1 to 0.9), and then they were descaled (re-transformed) to the original form. The FF neural network was trained using Levenberg-Marquardt back propagation algorithm, it updates weight and bias values according to Levenberg-Marquardt optimization and it is often the fastest back propagation algorithm in the toolbox. Figure 11 shows the actual and estimated temperatures through training case and the error difference was calculated as shown in Figure 12.

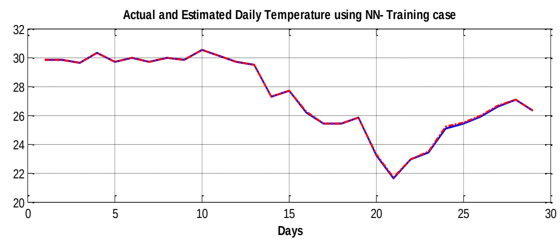

Figure 11. Actual and Estimated Temperatures of Taipei NN Model / Training Case

Figure 12. Estimated Error of Taipei NN Model / Training Case

Once the network is efficiently trained, it able to produce a better result. Hence, in the testing case the network was tested using the second part of data (June to Sep / 1996). Figure 13 shows the calculated difference error in the testing case.

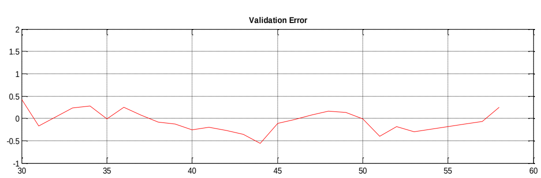

Figure 13. Estimated Error of Taipei NN Model / Testing Case

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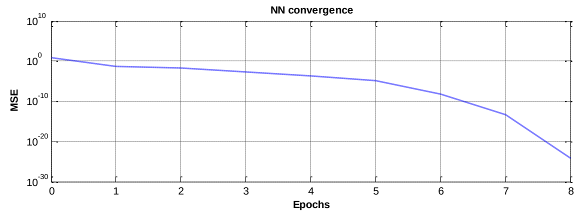

Figure 14. The Converegence of Taipei NN Model

The performance of the network was evaluated and the achieved results show that this model achieves better results. The Variance Accounted For (VAF) in the training case is 99.9859 and the Mean Absolute Error = 0.0013. In the testing case the VAF is 98.2926 and the Mean Absolute Error = 0.0542. Figure 14 shows the convergence of the network which reflects the ration of epochs to MSE.

7.2.2 Fuzzy Logic Model: In the fuzzy logic model, we used FMID toolbox that is available in MATLAB software. The inputs for the model, June average daily temperature °C(t), July average daily temperature °C(t), August average daily temperature °C(t), and September average daily temperature C° (t-1). The output of the model is the September average daily temperature C° (t). The setting parameter, consequent parameters, and cluster centers for this model are shown in Table 8, Table 9, and Table 10 respectively.

Table 8. Parameter Settings for Taipei FL Model

Parameter	Value
Number of Clusters	3
Fuzziness Parameter	2
Termination criterion	0.01
Type of antecedent	1
Type of Consequent	1

Table 9. Consequent Parameters for Taipei FL Model

Rule	*u*1	*u*2	*u*3	*u*4	Offset
1	$-3.59 . 10^{-1}$	$-6.10 . 10^{-1}$	$2.72 . 10^{-1}$	$1.33 . 10^{-1}$	$4.32 . 10^{1}$
2	$4.69 . 10^{-1}$	$-2.06 . 10^{-1}$	$2.93 . 10^{-1}$	$1.39 . 10^{0}$	$-2.64 . 10^{1}$
3	$-3.43 . 10^{-1}$	$-2.12 . 10^{0}$	$1.70 . 10^{0}$	$-1.86 . 10^{-1}$	$5.18 . 10^{1}$

Table 10. Cluster Centers for Taipei FL Model

Rule	*u*1	*u*2	*u*3	*u*4
1	$2.72 . 10^{1}$	$2.90 . 10^{1}$	$2.97 . 10^{1}$	$2.75. 10^{1}$
2	$2.84. 10^{1}$	$2.90 . 10^{1}$	$2.81 . 10^{1}$	$2.82 . 10^{1}$
3	$3.00 . 10^{1}$	$2.96 . 10^{1}$	$2.91 . 10^{1}$	$1.80 . 10^{1}$

The results that obtained by using fuzzy logic model are shown in Figures 15, 16 and 17. The Mean Absolute Error (MAE) for the model in the training case = 0.3955, and in the testing case = 0.7458.

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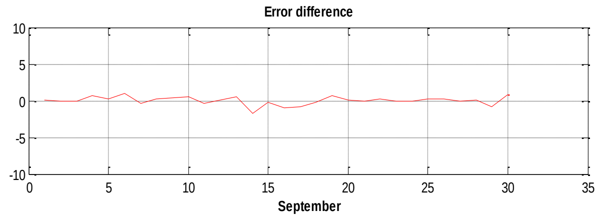

Figure 15. Estimated Error Taipei FL Model / Training Case

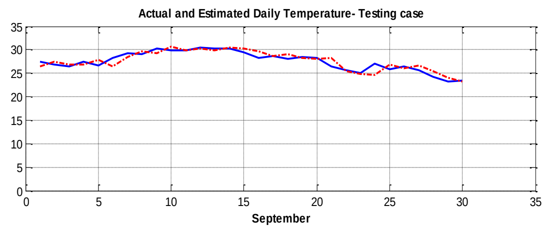

Figure 16. Actual and Estimated Temperatures of Taipei FL Model / Testing Case

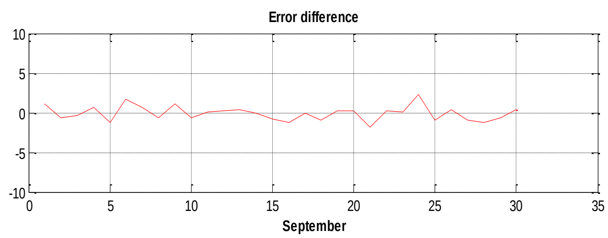

Figure 17. Estimated Error of Taipei FL Model / Testing Case

The Fuzzy logic model for Amman airport was generated from 30 data samples. It has 4 inputs and 1 output. The sampling period is 1 s. The termination tolerance of the clustering algorithm was 0.01, and the random initial partition was generated with seed equal to 8. In the following, the rules are shown.

Rules:

1. If $u1$ is A_{11} **and** $u2$ is A_{12} **and** $u3$ is A_{13} **Then**
$Y(k) = -3.59 . 10^{-1} u1 - 6.10 . 10^{-1} u2 - 2.72 . 10^{-1} u3 + 1.33 . 10^{-1} u4 + 4.32 . 10^{1}$

2. If $u1$ is A_{21} **and** $u2$ is A_{22} **and** $u3$ is A_{23} **Then**
$Y(k) = 4.69 . 10^{-1} u1 - 2.06 . 10^{-1} u2 + 2.93 . 10^{-1} u3 + 1.39 . 10^{0} u4 + 2.64 . 10^{1}$

3. If $u1$ is A_{31} **and** $u2$ is A_{32} **and** $u3$ is A_{33} **Then**
$Y(k) = -3.43 . 10^{-1} u1 - 2.12 . 10^{0} u2 + 1.70 . 10^{0} u3 - 1.86 . 10^{-1} u4 + 5.18 . 10^{1}$

8. Conclusion

We have proposed novel models for weather forecasting using two techniques; artificial neural networks and fuzzy logic. These models have been established on two different regions, Amman airport and Taipei \ China. In the development of these models, feed forward neural network is architecture of used neural network and it was trained using back propagation algorithm. We evaluate the efficiency of weather forecasting models using two measures; Variance Accounted For (VAF), and Mean Absolute Error (MAE). Experimental results showed that the proposed models can forecast with more accurate results.

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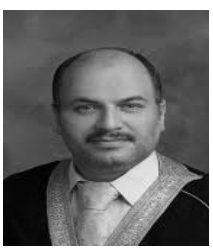

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