Real Time Prediction of Temperature using ANFIS-SUGENO Model

Rashmi Bhardwaj, Varsha Duhoon

Abstract: Temperature patterns are continuously change over time and but dependences on the temperature of most of the industries has not yet changed hence making it important for the scientists to predict temperature on a regular basis as most share of the industries in GDP of the economy of country has its dependence on the weather and hence the average of the weather patterns known as climate. In relation to this, the need is to generate a system which can foretell the temperature so that it can help in the various policy making and foreseeing the upcoming catastrophic event. AdaptiveNeuroFuzzyInferenceSystem (ANFIS) and SUGENOmodel a tools & techniques under Artificial Intelligence used for analyzing the data set and foretell the behavior for upcoming reference. ANFIS-SUGENO model used to analyses weather parameters like Humidity, Maximum & Minimum temperature, speed of wind, Bright sunshine (BSS), Evaporation for Delhi daily data set from January 1, 2017 up till February 28, 2018 and further from January 1, 2017 up till November 30, 2018 is used for foretelling and it is observed that the observed and predicted values are much related.

Key words: Artificial Intelligence, AdaptiveNeuroFuzzyInferenceSystem (ANFIS), SUGENO Model, Fuzzy Logic, Non-linear

I. INTRODUCTION

Temperature patterns are continuously change over time and but dependences on the temperature of most of the industries has not yet changed hence making it important for the scientists to predict temperature on a regular basis as most share of the industries in GDP of the economy of country has its dependence on the weather and hence the average of the weather patterns known as climate. Weather Forecasting is the most taken but difficult task at the same time and so scientists have been working is this field to attain the highest accuracy. Artificial Intelligence is the ability of man-made machines that is computers to deal in a way human mind would do. Weather forecasting is the most difficult task due to its chaotic nature as Earth's climate is chaotic in nature, hence the vagueness, uncertainty and intuitions are looked by the Artificial Intelligence. Fuzzy deals with vagueness in the time series which is most seen and observed in Meteorological data for forecasting. Meteorological data's prediction involves set of reasoning, rules, concepts for prediction. Temperature being a stochastic process makes it a rigid rather complex parameter to be predicted as it involves analysis and involvement of other weather affecting parameters too. Fuzzy Logic works with the same nature as it includes set of rules for it to function and hence generate output based on the analysis of other parameters. Weather on Earth is considered to be Chaotic in nature and hence has large impact even if there is some minute change at any point on the surface. Scientist have worked rigorously in the field of climate change analysis and weather prediction using different mathematical models. Climate change is the most challenging problem faced in the present time. The climate has been affected adversely result of which can be seen as the monsoons have shifted and the rainfall also has decreased as compared to the past 10 years. The change in the Climate is result of increasing global warming which has affected the raise in temperature annually.Climate change has significantly affected the rate of growth of a developing country like India, where agriculture is the most taken occupation. Aim is to analyze the relationship between various climatic factors and temperature in the capital of India. Bai. et.al. (2018) applied Artificial Intelligence model, Numerical forecast Methods and Hybrid Models and predicted air pollutants using the forecasting models by comparing statistical models [1]. Chow et.al. (1996) studied application of fuzzy logic to predict load [2]. Ebert et.al. (2008) studied that the High-resolution forecasts from numerical models, further compared to traditional metrics [3]. Grauel et.al. (1999) application of fuzzy sets and system in various aspects [4]. Hossain et.al. predicted air pollution using hidden markov model [5]. Kaloop et.al. (2017) compared ANFIS and ANFIS-WNN models [6]. Kan et.al. (2002) studied a novel fuzzy KNN algorithm for weather prediction [7]. Jing et.al. (2014) applied NFIS-WPM based model to predict daily fuzzy precipitation hence proving traditional ANN had less predictive accuracy [8]. Mukhopadhyay et.al. (2018) applied fuzzy logic to forecast future load on short-term-basis further to predict the electricity load [9]. Setyaningurum et.al. (2015) applied ANFIS to forecast weather parameters ANFIS showed 100% accuracy [10]. Telesca et.al. (2017) applied stochastic weather generator & neuro-fuzzy network; efficiency was tested on basis of the RMSE and MAE [11]. Tilva et.al. (2014) studied climate data in order to help the farmers using Fuzzy-Logic structure to forecast plant disease [12]. Williams et.al. (2009) studied environmental science problems using fuzzy approach [13].
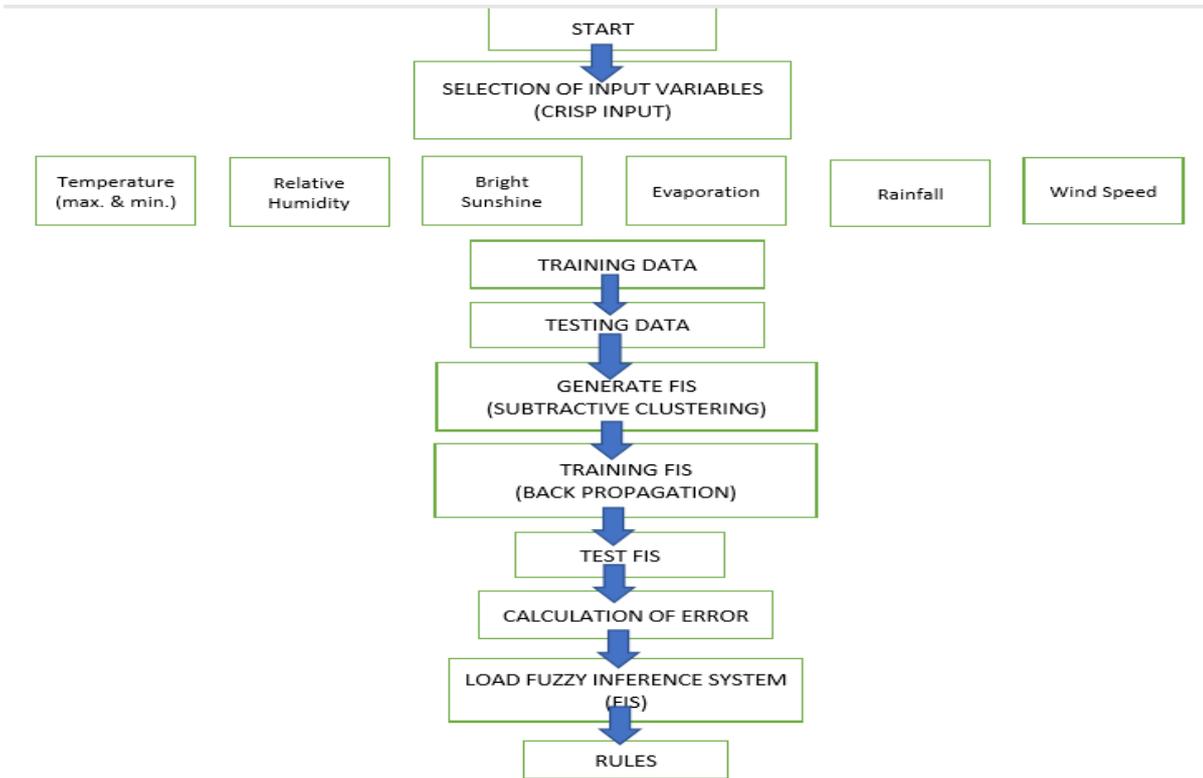
II. METHODOLOGY:

Rashmi Bhardwaj*, Professor of Mathematics, University School of Basic & Applied Sciences (USBAS), Head, Non-Linear Dynamics Research Lab, Guru Gobind Singh Indraprastha University, Delhi, India.

Varsha Duhoon, Research Scholar(s), USBAS, GGS Indraprastha University, Delhi, India,

Retrieval Number: A9555109119/2019©BEIESP
DOI: 10.35940/ijeat.A9555.109119

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Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

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Flow Chart 1:   Application of the ANFIS SUGENO Model

A.   Subtractive Clustering

This method allows fast processing by calculating number of clusters and centre in clusters in data set. Calculation of clusters helps to process the iterative Optimisation based clustering method and model identification. Subtractive clustering method finds clusters using the GenFIS type 2 function. Rules sets functioning of fuzzy system based on inputs, outputs and membership functions. Consider a data set of α values having x-dimensional vectors Aα; such that:

$$\alpha = 1, 2, 3, 4, \ldots\ldots\ldots\ldots, \beta$$

The data points are considered normalised; further density measure for Aα is:

$$X_\varepsilon = \sum_{i=1}^{\alpha} \exp\left(-\frac{\|A_\alpha - A_i\|}{(\varphi / 2)^2}\right)$$

φ is the positive constant, only the fuzzy neighbourhood with in φ radius leads to density measure. After calculating point of highest density is considered as first cluster centre Ap is the point selected γ is density measure. Now, density is calculated:

$$X_\alpha = X_\varepsilon - \gamma \exp\left(-\frac{\|A_\alpha - A_i\|}{(\mu / 2)^2}\right)$$

μ is a positive value.

B.   Adaptive Neuro Fuzzy Inference System

Takagi-SUGENO system is base of ANFIS. Neural networks and Fuzzy logic principles combine together to form ANFIS as it includes the potential of both. It has the capability to solve Non-Linear function by the application of fuzzy If-Then rules. ANFIS structure can be presented in the format of the rules in SUGENO model:

R1: "If a isA$_1$, AND b isB$_1$" THEN

$$O_{n,i} = w_i = \frac{\sum_i w_i f_i}{\sum_i w_i}, i = 1, 2, \ldots$$

R2: "If a isA$_2$, AND b isB$_2$" THEN

$$z = \frac{\sum_{i=1}^{n} \alpha_i f_i(x_1, x_2, x_3, \ldots, x_q)}{\sum_{i=1}^{n} \alpha_i}$$

Such that: a, b are inputs; A$_i$, B$_i$: fuzzy sets; f$_i$: output on basis of fuzzy rules: p$_i$, q$_i$: parameters considered.

Membership function of both A and B is bell shaped of the form:

$$O_{Ai}(a) = \frac{1}{1 + \left[\left(\frac{a_i - d_i}{e_i}\right)\right]} g_i, i = 1, 2, \ldots$$

Output Layer is given by;

output of 2 layers:

$$O_{2,i} = w_i = \mu_{Ai}(a) * \mu_{Bi}(b), i = 1, 2, ..$$

Output of 3 layers:

$$O_{3,i} = w_i = \frac{w_i}{w_1 + w_2}, i = 1, 2, ..$$

Final output:

$$O_{n,i} = w_i = \frac{\sum_i w_i f_i}{\sum_i w_i}, i = 1, 2, ..$$

C. Sugeno Model

The TSK model attains its objective by replacing the set of fuzzy into a linear equation of input variable. The TSK model interpolates all belongingness linear models. The degree of belongingness of a model is estimated by the degree to which input data belongs to fuzzy subspace in correspondence to the Model. Consider a non-linear system with α inputs; $a \in A \subset X^{\alpha}$ and 1 output, $b \in B \subset X$.

Now, model is represented as 'n' rules, in which the jth rule for p^{th} time instant values are as follows:

$$X^j : if\ \beta_1 is\phi_1^j, \beta_2 is\phi_2^j, ..., \beta_m is\phi_m^j$$

Then,

$$b^j(p) = x_0^j + x_1^j \beta_1 + x_2^j \beta_2 + ... + x_m^j \beta_m$$

$$= x_i^j + \sum_{j=1}^{m} x_m^j \beta_i$$

ϕ_i^j is the fuzzy set of ith input value, $\beta(k) = [\beta_1, \beta_2, ..., \beta_m]$ is vector input variable and b^j is output variable of jth rule, x_i^j are the parameters.

The final output of T-S model post defuzzification of jth time is as follows:

$$b = \sum_{j=1}^{n} \tau^i b^j \Big/ \sum_{i=1}^{n} \tau^i \qquad \text{n is number of fuzzy}$$

rules.

τ^i is firing strength of jth rule which can be defined as follows:

$$\tau^i(b) = \prod_{i=1}^{m} \phi_i^j(b_i),$$

Where, $\prod$ is the fuzzy minimizing operation. Further, $\phi_i^j(b_i)$ is the grade of membership function.

Final output is:

$$b = \sum_{j=1}^{n} \tau^i b^j \Big/ \sum_{i=1}^{n} \tau^i$$

$$b = \sum_{i=1}^{n} \xi_j b^i = a \sum_{i=1}^{n} \xi_j (b_0^j + b_1^j \beta_1 + b_2^j \beta_2 + ... + b_m^j \beta_m)$$
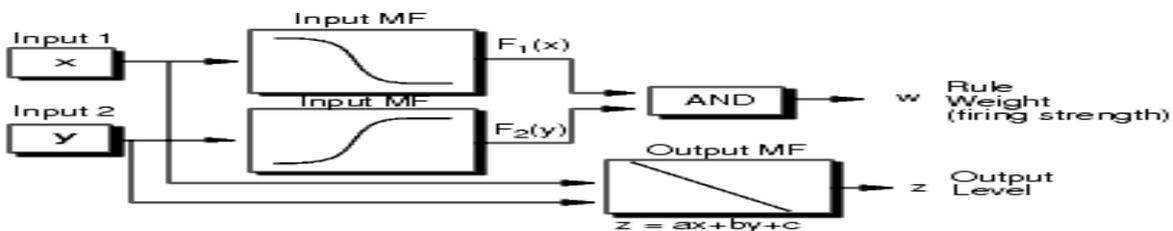

Fig 1: Processing of data in T-S model

D. Backpropagation

It is based on Gradient-Descent-Method for error minimization. Error is of the form given below:

$$E = \frac{1}{2} \left\| e_\beta + \frac{\partial e_\alpha}{\partial \phi_j} \left(\phi_{j+1} - \phi_j\right)^2 \right\| + \omega \left\| \phi_{j+1} - \phi_j \right\|^2$$

e_α : error α^{th} : pattern ℓ : vector e_α : element. Error function is expanded as

$$E = \frac{1}{2} \left\| e_\beta + \frac{\partial e_\beta}{\partial \phi_\gamma} \left(\phi_{\beta+1} - \phi_\beta\right) \right\|^2$$

Reducing error function w.r.t new weight vectors:

$$du \leq dv$$

where,

$$A_{\alpha_j} = \frac{\partial e_\alpha}{\partial \phi_j}$$

Hence, the error function is:

$$(B)_{\gamma\beta} = \frac{\partial^2 E}{\partial \phi_\gamma \partial \phi_\beta} = \sum \left[\frac{\partial e_\alpha}{\partial \phi_j}\right]\left(\frac{\partial e_\alpha}{\partial \phi_j}\right) + e_\alpha \frac{\partial^2 e_\alpha}{\partial \phi_\gamma \partial \phi_\beta}$$

The steps are taken small to guarantee authenticity of linear approximation. Further, modified error function is used

$$E = \frac{1}{2} \left\| e_\beta + \frac{\partial e_\alpha}{\partial \phi_j} \left(\phi_{j+1} - \phi_j\right)^2 \right\| + \omega \left\| \phi_{j+1} - \phi_j \right\|^2$$

where, ω : parameter checking step size. Reducing modified error w.r.t ϕ_{j+1} :

$$\phi_{\beta+1} = \phi_\beta - \left(A^T A + \omega I\right)^{-1} A^T e_\beta$$

E. Fuzzy Inference System

FuzzyRuleBase System refers to a method of mapping input to output by the application of Fuzzy Logic. Rule-base system includes inputs & associated membership functions along with output and their corresponding membership functions which also includes the set of rules. The subclust function constructs GenFIS type 2 function for the fast processing of intaking of the inputs and the membership functions along with rules. FIS is selected on the basis of the method of set of rules. GenFIS type 2 function is loaded in to the SUGENO model for the further processing of data, by analysis the pattern of data based on rules generated.

IF-THEN rules are used in order to describe the non-linear models of real system by generating input and output relations. For Example:
"If Wind Speed taken as High, & Humidity taken as Medium, & rainfall taken as Medium, then Temperature taken as Medium"

Each fuzzy IF-THENrule is of the form:

Rule: $P : If\ \tilde{x}\ is\ \tilde{F},\ Then\ \tilde{y}\ is\ \tilde{G}$ such that: x, y are variables of set U, V also $\tilde{F}$ & $\tilde{G}$ are FuzzySets on U,V.

Fuzzy Inference System's algorithm includes:

1. Degree of match: calculating the degree to which the input matches the fuzzy rules conditions.

2. Inference: On the basis of the matching degree calculate the rule-based conclusion

3. Compiling: Drawing final conclusion on the basis of conclusions drawn from all fuzzy rules.

4. Defuzzifying: convert fuzzy conclusion in crisp conclusion.

F. The Rule-Base

Rule base comprises of IF–THEN form of set of rules. IF refers to the belongingness in fuzzy set. THEN part deals with consequence or associated-system-output fuzzy set. Fuzzy-Rule-Base contains all possible combinations of input & output data. Parameters as input & output, selected on self-choice basis. SUGENO-rule-system, consist of before part of fuzzy rule, expressed in the form of mathematical function of the input variable and such a system is considered as reliable in Neuro-fuzzy-Systems:

1. A set of IF–THEN rules it is to satisfy the following condition: that if any combination of inputvalues result in correct outputvalue.

2. "IF $\alpha\beta$ is A-THEN- β is B," this implies a fuzzy relation Rule 2, then A & B consisting does not deliver.

III. RESULTS AND DISCUSSION

Daily data of Mean Temperature, Max.-Min. Temperature, RelativeHumidity at 2 intervals of 12 hours, mean relative humidity, evaporation, wind speed, rainfall, wind speed, bright sun shine for Delhi with coordinates Longitude 77^0 09' 27'' Latitude 28^0 38 '23'' N Altitude :228.61m has been taken from January 1, 2017 up till February 28, 2018 and further from January 1, 2017 up till November 30, 2018.
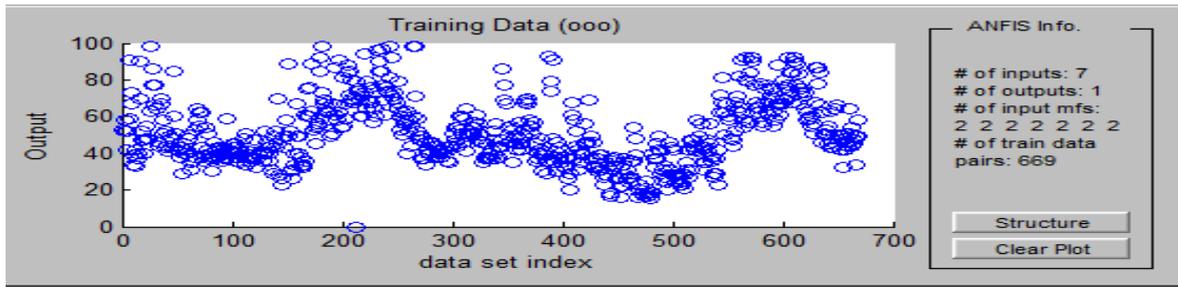
Fig 2: The data is processed in ANFIS using subtractive clustering

In the above fig 2 the training data set which is the 70% of the total data has been taken and above plot is obtained.
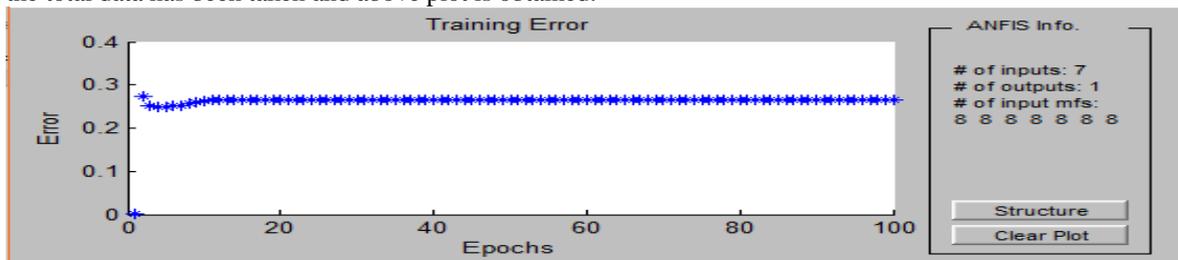

Fig 3: Training Error in the ANFIS

In the above fig 3, the training error is calculated in which the error is very minimal hence after multiple changes in of number of epochs in order to attain least error the final cluster is taken and further T-S model is applied to the FIS generated.
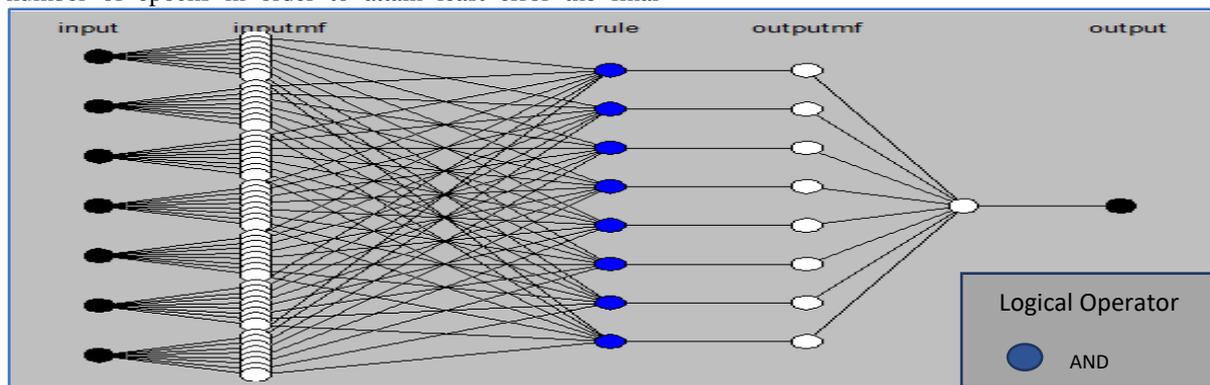

Fig 4: Adaptive Neuro Fuzzy Inference System Map

Above fig 4, represents how input data is processed to form the clustering in ANFIS to generate clusters using Subtractive clustering method.
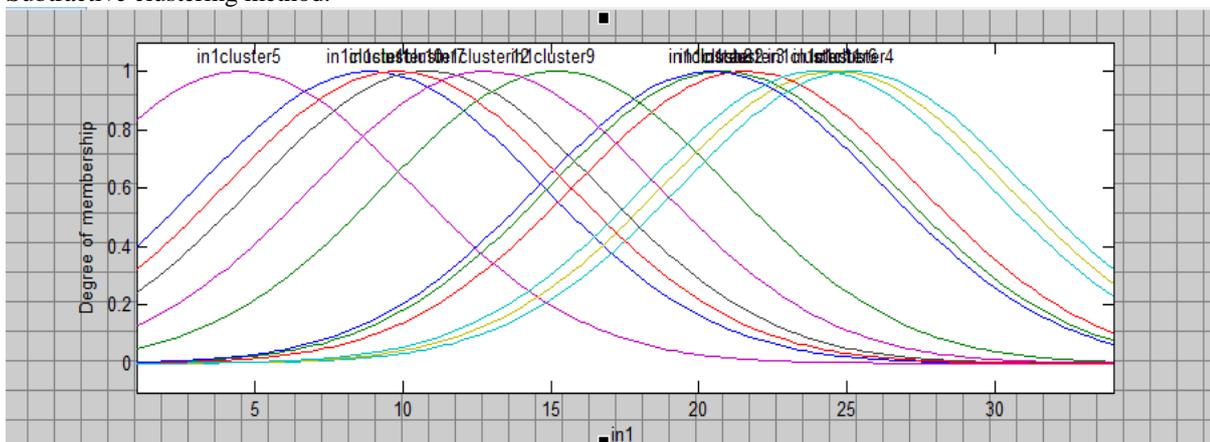
Fig 5: plot of clusters along with degree of membership

In the fig 5, the clusters are generated with the degree of membership for all the parameters Mean temperature, max. evaporation, wind speed, rainfall, wind speed, bright sun shine.

& min. temperature, relative humidity at 2 intervals of 12 hours, mean relative humidity,
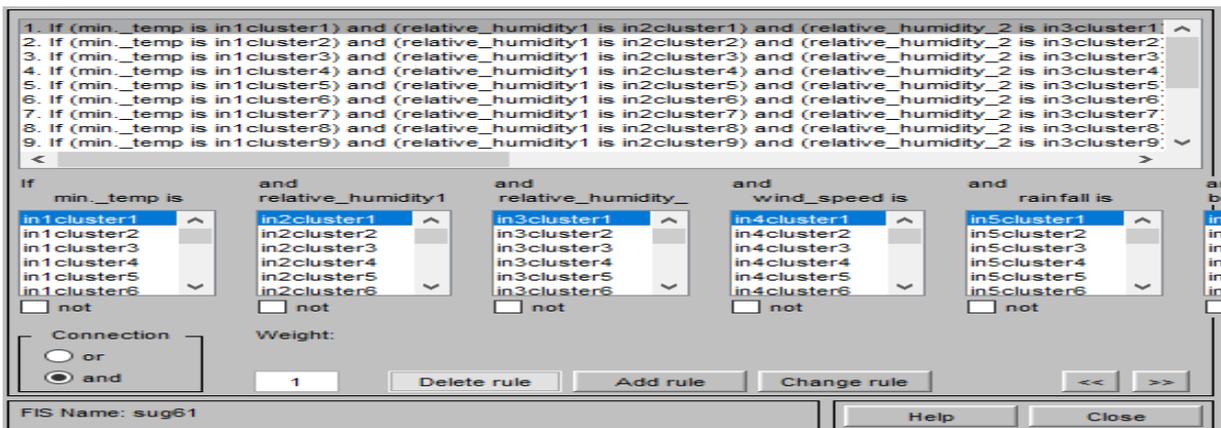

Fig 6: Rule Editor

SUGENOfuzzy model: If I1 = F & I2 = G, Output is z = xF + yG + q.

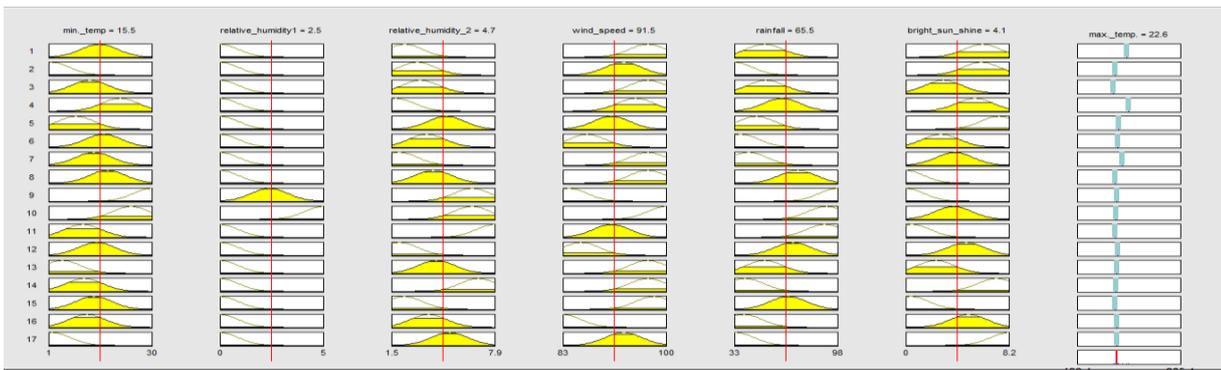For, zero-order, the output measure z is persistent (x=y =0).

Fig 7: Rule Viewer

The surface view of interaction has been shown in in

Fig 8 the graph includes combination of Max. Temp., Min. Temp., Wind Speed.
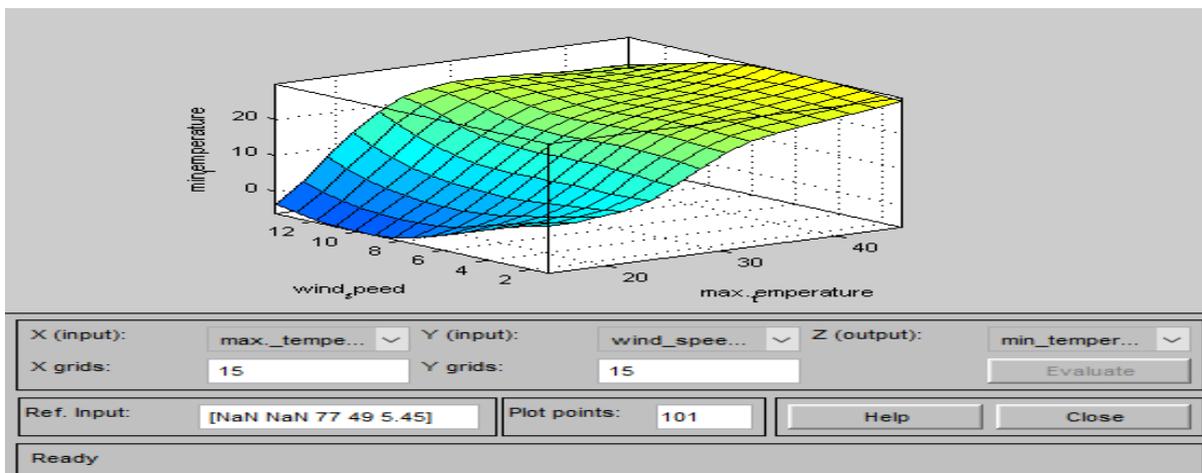

Fig 8: Surface View

After the process of Defuzzification the output is hence obtained. Calculation was done to evaluate the daily maximum temperature and minimum temperature data using (FIS).

Table I: Actual and predicted values of Temperature (Max. and Min.) from 21.02.2018 till 28.02.2018

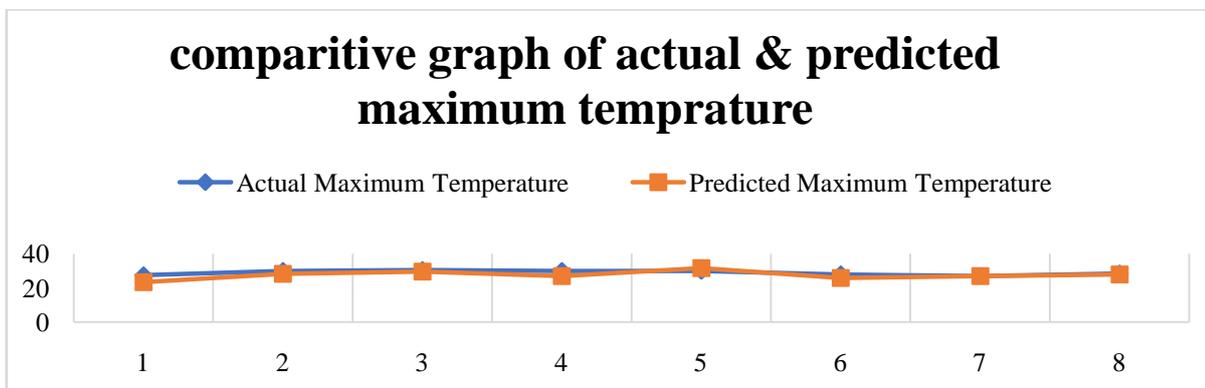| Date	Actual Max.Temperature	Predicted Max.Temperature	Actual Min.Temperature	Predicted Min.Temperature
21.02.2018	27.5	23.5	9	8.2
22.02.2018	30	28.4	9.8	9
23.02.2018	30.5	29.7	12	9.3
24.02.2018	30	27	14	13.2
25.02.2018	30	31.7	16	15.1
26.02.2018	28	26	13.4	10.1
27.02.2018	27	27.1	12.8	12.2
28.02.2018	28.5	28	12	12.5

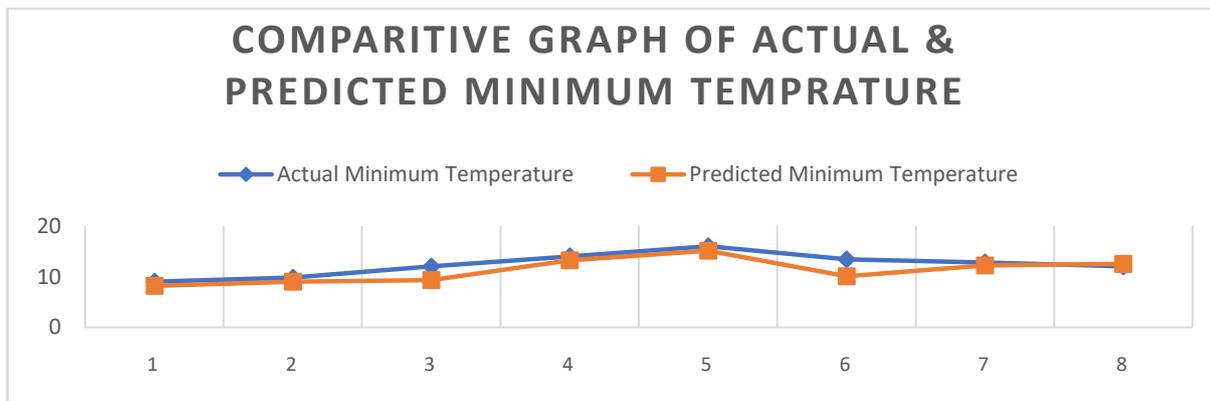**Fig 9: Graph of actual and predicted maximum temperature**

Fig 10: Graph of actual and predicted minimum temperature

Table II: Actual and predicted values of Temperature (Max. and Min.) from 23.11.2018 till 30.11.2018

Real Time Prediction of Temperature using ANFIS-SUGENO Model

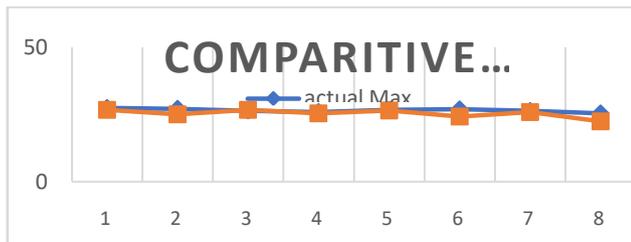| Date	Actual Max.Temperature	Predicted Max.Temperature	Actual Min.Temperature	Predicted Min.Temperature
23.11.2018	27.5	26.8	8.6	8.0
24.11.2018	27.2	25.1	13.0	13.5
25.11.2018	26.5	26.8	8.0	10.2
26.11.2018	26.0	25.5	8.1	7.9
27.11.2018	26.8	26.6	8.9	8.6
28.11.2018	27.0	24.3	11.9	11.2
29.11.2018	26.4	26.0	10.4	9.5
30.11.2018	25.5	22.5	8.9	9.0

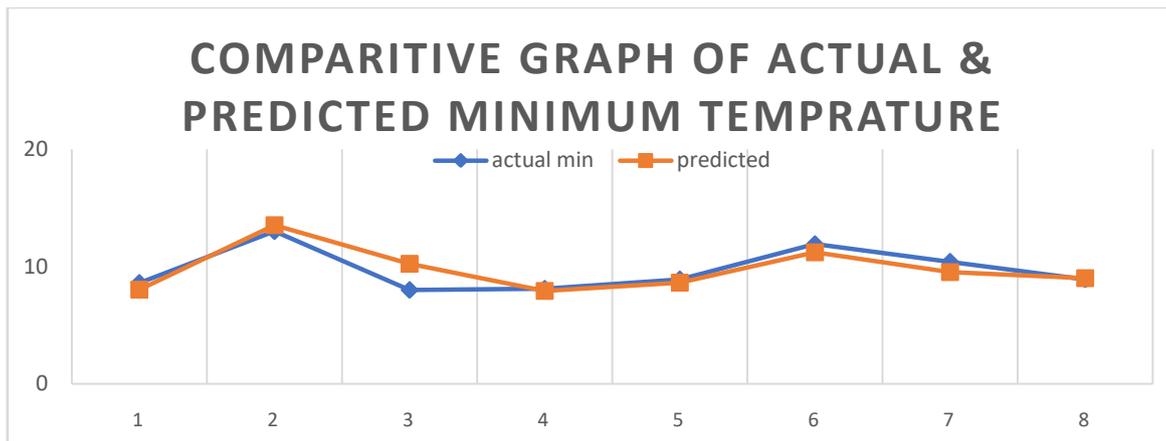**Fig 11: Graph of actual and predicted maximum temperature**

Fig 12: Graph of actual and predicted minimum temperature

IV. DISCUSSION

SUGENO method is ComputationallyEffective & works efficiently using optimization & AdaptiveTechniques. ANFIS-SUGENO, well applicable for the objective of easily-incorporating-definite-gains that would be applied across the input space.

ANFIS-SUGENOmodel can be used as a tool to predict the daily temperature as ANFIS when integrated with the SUGENO model reduces the error in the output. Temperature prediction is not only important for agricultural production but for the common people, the tourists, the aviation sector and other sectors which are either directly or indirectly affected by the day to day temperature.

ACKNOWLEDGMENT

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AUTHORS PROFILE

Prof. Rashmi Bhardwaj working as Professor of Mathematics at GGS Indraprastha University (GGSIPU), Delhi. Topper of University of Delhi with 100% marks in Integral equation & Boundary value problem. Government of India, IMD 27th Biennial MAUSM Award. Visiting Associate of IUCAA, Young Scientist Award of AICTE., Best Researcher Award of GGSIPU (3 consecutive years). 125 research papers, 3 books. 12 Ph.D. supervised and 4 are working. Visited, attended and delivered invited Lectures in International/National conferences. Subject Reviewer for many International/ National Journals. Life member of several International /National recognized Organizations in the sphere of Mathematical Sciences. Established Nonlinear Dynamics Research Lab and Mathematics Lab in GGSIPU.

Varsha Duhoon, research scholar under the guidance of Prof. Rashmi Bhardwaj Professor of Mathematics at GGS Indraprastha University (GGSIPU), Delhi. B.Sc. Mathematics (Hons) from Delhi University 1st division. M.Sc. Mathematics from Mewar University 1st division. Published 2 research papers in National and international Journal. Working on "Non-Linear Time Series Analysis for Weather Forecasting".