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WEATHER PREDICTION BY THE USE OF FUZZY LOGIC

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Abstract:

In this paper, a Fuzzy Knowledge – Rule base technique is used to predict the ambient atmospheric temperature. The present study utilizes historical temperature as well as database of various meteorological parameters to develop a prediction process in fuzzy rule domain to estimate temperature. Daily observations of Rain, Atmospheric Pressure, and Relative Humidity are analyzed to predict the Temperature.

The topic of Fuzzy Logic as a decision-making technique is introduced. It is recommended that applications of this technique could be effectively applied in the area of operational meteorology. An example of such an application, the forecast of the probability of temperature, is discussed and examples of the method are presented. Other possible meteorological applications are suggested. Additionally, a software package which aids in the development of such applications is briefly described.

Keywords and phrases : Fuzzy Logic, atmospheric temperature, Atmospheric Pressure, Relative Humidity, probability of temperature.

বিমূর্ত সার *(Bengali version of the Abstract)*

এই পত্রে পরিবেষ্টক বায়ুমন্ডলীয় তাপমাত্রার ভবিষ্যদ্বানী করার জন্য ফাজি জ্ঞান যুক্ত নিয়ম (Fuzzy Knowledge – Rule) *নির্ভর কৃৎকৌশলকে ব্যবহার করা হয়েছে । বর্তমান অনুসন্ধানে ঐতিহাসিক তাপমাত্রা এবং বহুবিধ আবহবিদ্যাগত প্রাচলের তথ্যসমূহকে ব্যবহার করা হয়েছে ফাজি নিয়মভুক্ত অঞ্চলে তাপমাত্রার সম্ভাব্য হিসাব করার ক্ষেত্রে ভবিষ্যদ্বানী পদ্ধতিকে উন্নত করার জন্য । তাপমাত্রার ভবিষ্যদ্বানী করার জন্য বৃষ্টিপাত , বায়ুমন্ডলীয় চাপ, এবং আপেক্ষিক আর্দ্রতার দৈনিক পর্যবেক্ষনকে বিশ্লেষণ করা হয়েছে । ফাজি ন্যায়বিদ্যার বিষয়কে সিদ্ধান্ত নির্ণায়ক কৃৎকৌশল হিসাবে উপস্থাপন করা হয়েছে । কার্য সম্পাদনকারী আবহবিদ্যার ক্ষেত্রে এই কৃৎকৌশলের প্রয়োগ কার্যকরী করার সুপারিশ করা হচ্ছে । সম্ভাব্য তাপমাত্রার পূর্বাভাস দেওয়ার ক্ষেত্রে এই ধরণের একটি প্রয়োগের উদাহরণ আলোচনা করা হয়েছে এবং এই পদ্ধতির উদাহরণগুলিকে পরিবেশন করা হয়েছে । অন্যান্য সম্ভাব্য আবহবিদ্যাগত প্রয়োগের সঙ্কেঁত দেওয়া হয়েছে । অধিকন্তু , এই ধরণের প্রয়োগের উন্নয়নের সহায়ক হিসাবে একটি সফ্‌টওয়্যার পুটুলীর* (software package) *সংক্ষিপ্ত বর্ণনা দেওয়া হয়েছে ।*

1. Introduction:

Forecast of Meteorological Parameter is one of the most significant tasks all over the world. Weather condition is observed to be a highly complex system which is nonlinear. It includes expertise in multiple disciplines [1]. The prediction of atmospheric parameters is essential for various applications. Some of them include climate monitoring, drought detection, severe weather prediction, agriculture and production, planning in energy industry, aviation industry, communication, pollution dispersal etc. Accurate prediction of weather parameters is a difficult task due to the dynamic nature of atmosphere. Various techniques like linear regression, auto regression, Multi Layer Perceptron, Radial Basis Function networks are applied to predict atmospheric parameters like temperature, wind speed, rainfall, meteorological pollution etc [2].

Also, soft computing techniques have opened up new avenues to the complex system researches. It has three basic components, e.g., Fuzzy Logic, Artificial Neural Network (ANN) and Genetic Algorithm [3]. Artificial Neural network can obtain abilities of the expression, memory, summing up and association of knowledge through learning. However, those abilities of the ANN manifest in its connection weight coefficient and its interior expression of knowledge is difficult to understand. In contrast, the theory and method of fuzzy aggregation of fuzzy systems have powerful logic expression ability and are able to directly express logic, even to express inaccurate information [4]. Here, Fuzzy Logic has been used for predicting the ambient temperature as fuzzy logic can handle uncertainties and complexities of atmospheric conditions without dealing with complex mathematical expressions.

Temperature is identified as the dominant abiotic factor directly affecting herbivorous insects; therefore extremes of temperature may negatively affect insects. In the last decade it has become clear that the timing of many phonological processes, like the start of flowering and leaf unfolding in spring, have changed. The increase in temperature is believed to be the main cause. Millions of people world-wide will therefore experience the impact of climate change in their daily lives during spring and summer [5].

Even as rigorous numerical modeling of meteorological processes continues to improve in both spatial and temporal resolution, the processes likely to be continued are the ones that elude explicit analytic solutions. Physical processes not yet well understood or those beyond the resolution of the models still need alternative methods for their analysis and subsequent prognosis. Most experienced forecasters will quickly suggest that experience is the best tool for forecasting such events. With the rapidly evolving technologies in the field of meteorology, it is desirable to merge the experience of many forecasters with algorithms that may aid in difficult forecasting situations. *Cognitive computing* has been an emergent set of problem solving algorithms that attempt to imitate natural problem solving techniques. One such method is called *Fuzzy Logic*.

Fuzzy Logic is a simple yet very powerful problem solving technique with extensive applicability. It is currently used in the fields of business, systems control, electronics and traffic engineering. The technique can be used to generate solutions to problems based on "*vague, ambiguous, qualitative, incomplete or imprecise information."*

Fuzzy Logic is an extension of Fuzzy set theory that was developed approximately 30 years ago. The intent of Fuzzy set theory was to alleviate problems associated with traditional binary logic, where statements are exclusively true or false. Fuzzy Logic allows something to be partially true and partially false.

Those are many instances within weather forecasting which cannot be easily handled by methods other than statistical methods, "perfect prog" methods, pattern recognition, and other less analytic methods. In some cases, decision trees or flow charts have been developed. However, these are based on traditional logic. Fuzzy Logic can account for the effect upon the output of a system due to various input values, without the need for a definite threshold value.

The meteorological phenomenon chosen here to demonstrate this method is that of the prediction of temperature from the occurrence of rain. This particular weather phenomenon was chosen as it is the most important aspect of the Indian climate owing to its necessity in the agricultural practices and thereby plays an important role in the production cycle of crops. Within the context of the current example, general terms associated with Fuzzy Logic will be introduced. In general, a problem to be solved is referred to as a *system*. *System inputs* are those physical variables that are thought to completely determine the solution(s) to the problem, or *system outputs*. In the current example the system output is the prediction of temperature from the amount of rain. Hence, system inputs to be used in this case is the amount of rain.

Over the past ten years, weather predictions have improved greatly in accuracy because of the convergence of satellite data, numerical models, and real-time computer processing power. These forecast engines, while impressive, have some important limitations.

First, commonly available public forecasts are issued for relatively large "zones" covering perhaps a dozen counties and half-dozen major cities. Local weather can vary considerably within a forecast zone.

Second, commonly available public forecasts are based on observations that may be as much as eight hours old. Indeed, base data for some of the widely-used atmospheric models could be as much as twelve hours old. Given this lag time, we conclude that data obsolescence will continue to be a compromising factor for the foreseeable future, and that this lag will continue to limit the validity of forecasts, especially toward the end of the forecast window.

Given this situation, we believe that commonly available public forecasts could become more reliable if, as a last step, they were adjusted by an expert system that could take better account of current and changing local conditions.

Given sufficient data, our system issues one forecast for the next 12 hours and a separate forecast for the next 12-24 hours. Within each of these two time periods, given sufficient data, our system forecasts a "general trend" and "detailed weather." Each element of the forecast is listed with an associated fuzzily-determined probability. It is important to note that, in a fuzzy system, these forecast elements are not mutually exclusive.

2. Fuzzy Logic and Fuzzy Sets:

Since 1970, the applications of fuzzy mathematical theories and methods to agro-climatic regionalization, long and medium term forecasting, interpretation of numerical weather prediction products and climate analysis etc. in meteorological science have been explored [4].

The pioneering work concerning the processing of the linguistic uncertainties by the use of fuzzy sets has opened a wide spectrum of applications in many diverse fields [6]. Fuzzy application areas include estimation, prediction, and control, approximate reasoning, intelligent system design, machine learning, image processing, machine vision, pattern recognition, medical computing, robotics, optimization, civil, chemical and industrial engineering [7]. Unfortunately, fuzzy applications in meteorology domain are rather very rare and there is a great future in its application to solve atmospheric and meteorological problems.

The atmospheric events are complex, ambiguous and vagueness embedded in their nature. This is mainly due to the fact that earth and atmospheric scientists are involved basically with traditional uncertainty techniques among which are the statistics, probability and stochastic processes with control implementations through adaptive Kalman filtering. However, there is an unlimited scope application possibility in natural sciences for the fuzzy principles.

Fuzzy Sets are collection of all objects with the same properties whereas in crisp sets the objects either belong to the set or otherwise. In practice the characteristic value for an object belonging to the set considered is coded as 1 and if it does not belong to the set then the coding is 0. In fuzzy sets, an object with membership degree 1 belongs to the set with no doubt and those with 0 membership values again absolutely do not belong to the set but objects with intermediate membership degrees belong to the same set partially. The greater is the membership degree the more the object belongs to the set. Meteorological data contains many uncertainties. So, in present study, to handle these uncertainties, Fuzzy Logic is used for prediction of temperature from the amount of Rain. We have observed In India, 3 distinct seasons are observed of viz. summer, winter and monsoon. The present study explores the data of these all three seasons for the data base, Fuzzy Knowledge – Rule base is developed. The system developed has one input variable Rain and one output variable-Temperature. This Fuzzy Knowledge – Rule base model can predict the temperature of inland cities over India from the data of their Rain. In the combination, Fuzzy sets of input parameter- Rain and expressed with 4 linguistic variables and output parameter- Temperature is taken with 3 linguistic variables (4-3 combination). The Fuzzy sets of all three parameters are shown below with their ranges:

- **Amount of rainfall (mm):**

  No rain: 0 to 0.15mm.

  Low rain: 0.1mm to 11mm.

  Medium rain: 10mm to 21mm.

  High rain: 20mm and above.

- **Temperature (°C):**

  Low Temperature: 5°C to 25°C.

  Medium Temperature: 15°C to 40°C.

  High temperature: 25°C and above.

  The fuzzy graphs of above sets are shown in figure:

  Fig 1: Fuzzy set of rainfall

  Fig 2: Fuzzy set of temperature

Development of Fuzzy Knowledge - Rule Base (FKRB):

The strength of a rule is the value of its least true antecedent, or *If* portion, which is simply the degree of membership of each system input in the corresponding fuzzy set(s). More than one rule can lead to the same consequence. In this case, the rule with the highest strength is used. The rule base is a set of rules of the *If-Then* form. The *If* portion of a rule refers to the degree of membership in one of the fuzzy sets. The *Then* portion refers to the consequence, or the associated system output fuzzy set.

FKRB constitute an extension of classical rule-based system, as they deal with fuzzy rules instead of classical logic rules. In this approach, fuzzy IF-THEN rules are formulated and a process of fuzzification, inference and de-fuzzification leads to a final decision of the system. The FKRB is then considered as an approach used to model a system making use of a descriptive language based on fuzzy logic with fuzzy prediction. The fuzzy rules used – also called linguistic rules- have the following structure:

IF X1 is A1 and ……and Xn is An THEN Y is Bi

With X1, ……, Xn and Y being the input and output linguistic variables, respectively and A1, ……, An and B being linguistic labels, each one of them having associated a fuzzy set defining its meaning. Some of the fuzzy Rules of this FKRB are as follows:

Rule 1: IF Rainfall is NO RAINFALL THEN Temperature is LOW.

Rule 2: IF Rainfall is LOW THEN Temperature is MEDIUM.

Rule 3: IF Rainfall is MEDIUM THEN Temperature is HIGH.

Rule 4: IF Rainfall is HIGH THEN Temperature is HIGH.

After fuzzification of the parameters, probability of occurrence of each rule is found out and is formulized into a Matrix.

For rainfall, we are defining the membership function as given below:

	0	0.1	5	10	15	20	25	30
$\mu_{Rain\ N}$ =	[1	0.1	0	0	0	0	0	0]
$\mu_{Rain\ L}$ =	[0	0.1	1	0.2	0	0	0	0]
$\mu_{Rain\ M}$ =	[0	0	0	0.1	1	0.2	0	0]
$\mu_{Rain\ H}$ =	[0	0	0	0	0	0.2	1	1]

For rainfall, we are defining the membership function as given below:

	5	10	15	20	25	30	35	40	45
$\mu_{Temp\ L}$ =	[1	1	0.8	0.3	0	0	0	0	0]
$\mu_{Temp\ M}$ =	[0	0	0	0.4	1	0.5	0.1	0	0]
$\mu_{Temp\ H}$ =	[0	0	0	0	0	0.3	0.6	1	1]

Development of relational model between membership functions:

We are developing the relational matrix from the rule base as described below:

A. The first one is between $\mu_{Temp\ L}$ and $\mu_{Rain\ N}$ giving relation $R_{N\text{-}L}$ **:**

$\mu_{T\text{-}L}$

1 1 0.8 0.3 0 0 0 0 0

$\mu_{R\text{-}N}$

$$R_{N\text{-}L} = \begin{matrix} 1 \\ 0.1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{matrix} \begin{bmatrix} 1 & 1 & 0.8 & 0.3 & 0 & 0 & 0 & 0 & 0 \\ 0.1 & 0.1 & 0.1 & 0.1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

B. The second one is between $\mu_{Temp\ M}$ and $\mu_{Rain\ L}$ giving relation $R_{L\text{-}M}$ **:**

$\mu_{T\text{-}M}$

0 0 0 0.4 1 0.5 0.1 0 0

$\mu_{R\text{-}L}$

$$R_{L\text{-}M} = \begin{array}{c} 0 \\ 0.1 \\ 1 \\ 0.2 \\ 0 \\ 0 \\ 0 \\ 0 \end{array} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.1 & 0.1 & 0.1 & 0.1 & 0 & 0 \\ 0 & 0 & 0 & 0.4 & 1 & 0.5 & 0.1 & 0 & 0 \\ 0 & 0 & 0 & 0.2 & 0.2 & 0.2 & 0.1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

C. The third one is between $\mu_{\text{Temp H}}$ and $\mu_{\text{Rain M}}$ giving relation $R_{M\text{-}H}$ **:**

$\mu_{T\text{-}H}$

0 0 0 0 0 0.3 0.6 1 1

$\mu_{R\text{-}M}$

$$R_{M\text{-}H} = \begin{array}{c} 0 \\ 0 \\ 0 \\ 0.1 \\ 1 \\ 0.2 \\ 0 \\ 0 \end{array} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0.3 & 0.6 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.1 & 0.1 & 0.1 & 0.1 \\ 0 & 0 & 0 & 0 & 0 & 0.3 & 0.6 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0.2 & 0.2 & 0.2 & 0.2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Prediction of Temperature Using Fuzzy Knowledge-Rule Base:

The prediction of Temperature is done from Fuzzy Knowledge - Rule Base using Fuzzy Min.-max Rule. For a given data of Rainfall, fuzzy set and its membership value is found out. Viz. here as shown in fuzzy graphs, Rainfall of 6mm will be in fuzzy set with membership value 0.8.

$\mu_{N=0}$ = [0 0 0 0 0 0 0 0]

$\mu_{L=0.8}$ = [0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8]

$\mu_{M=0}$ = [0 0 0 0 0 0 0 0]

Thus defining the composite function,

$y_L = \mu_N \circ R_{N-L}$ = [0 0 0 0 0 0 0 0 0]

$y_M = \mu_L \circ R_{L-M}$ = [0 0 0 0.4 0.8 0.5 0.1 0 0]

$y_H = \mu_M \circ R_{M-H}$ = [0 0 0 0 0 0 0 0 0]

Thus by union the final function becomes,

$Y = y_L \cup y_M \cup y_H$ = [0 0 0 0.4 0.8 0.5 0.1 0 0]

From this function we can plot the temperature vs rainfall membership function curve.

Hence finally we can conclude the expression of temperature using De-Fuzzification,

$$\text{Temp} = \frac{\forall_i \sum x_i \ \mu(x_i)}{\forall_i \sum \mu(x_i)}$$

$$= \frac{0+0+0+(20\times0.4)+(25\times0.8)+(30\times0.5)+(35\times0.1)+0+0}{0.4+0.8+0.5+0.1} = 25.83 \cong 26°\text{C}$$

When, x_i = [5 10 15 20 25 30 35 40 45]

And, $\mu(x_i)$ = [0 0 0 0.4 0.8 0.5 0.1 0 0]

4.1 CONCLUSION:

In the present paper, Fuzzy set theory has been used for predicting atmospheric temperature for inland cities of India from meteorological parameters viz. Rainfall. Database of one year comprising of 19,140 sets of daily observations of Temperature, Rainfall and has been utilized to develop a knowledge Rule base in Fuzzy domain.

The previous example demonstrates the use of a Fuzzy system in operational meteorology. It also suggests the experience of the developer is very important. Careful construction of the membership functions as well as the rule base is necessary. These parameters will likely have to be patiently calibrated during development so reasonable results are obtained. Perhaps an extensive data search could be employed in numerous cases where radiation fog did occur, and the limits of the data could be used to deduce suitable fuzzy sets and rules.

The effect of the shape of membership functions upon the solution is very important. Broader input membership functions, those with an extended domain with membership of 100%, have a larger weighting during the rule evaluation. This will be reflected in the final solution. Narrow output membership functions, the consequences of the rules, map the solution into a more restricted domain but the associated weighting by area is less.

This decision-making method is very flexible and could be applied in a variety of forecasting situations. Other mesoscale situations for which fuzzy systems could be developed include stratus formation and dissipation, (non-frontal) thunderstorm development, snow squall situations and ice crystal formation.

This procedure could be easily automated and used in such projects as **Scribe**, **FPA** and the **FTAUTO** program. The code which accompanies this document is easily adaptable to a number of platforms. Very little computing resources are required to implement this type of system. A number of such systems could be developed and inserted into the *cron table* of any UNIX system and could be run hourly. Alerts messages could be displayed if a system recognized the possibility of the development of some meteorological element.

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