Weather Forecasting Using Fuzzy Logic

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Abstract

Logic is the study of the methods and principle of reasoning in all its possible forms. Logic for humans is a way to quantitatively develop a reasoning process that can be replicated and manipulated with mathematical precepts. The interest in logic is the study of the truth in logical proposition; in classical logic this truth is binary- a proposition is either true or false. From this perspective, fuzzy logic is a method to formalize the human capacity of imprecise reasoning, or approximate reasoning. Such reasoning represents the human ability to reason approximately and judge under uncertainty.
KEYWORD : Multivalued logic, fuzzy proposition, fuzzy logic connectives, factors affecting rain, weather forecast using fuzzy logic

INTRODUCTION

Fuzzy logic is a form of many valued-logic or probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions.

Fuzzy logic was first proposed by Lotfi A. Zadeh of the University of California at Berkeley in a 1975 paper. He elaborated on his ideas in a 1973 paper that introduced the concept of "linguistic variables", which in this article equates to a variable defined as a fuzzy set. Other research followed, with the first industrial application, a cement kiln built in Denmark, coming on line in 1975. Fuzzy logic has been applied to many fields, from control theory to artificial intelligence. Fuzzy logics however had been studied since the 1920s as infinite-valued logics notably by Lukasiewicz and Tarski.

INTRODUCTION TO FUZZY LOGIC

1.1. MULTIVALUED LOGIC

The basic assumption upon which classical logic(or two-valued logic) is based- that every proposition is either true or false has been questioned since Aristotle.

It is become desirable to explore generalization into *n-valued logic* for an arbitrary number of truth values ($n \geq 2$). For any given *n*, the truth values in these generalization logic are usually labeled by rational numbers in the unit interval [0,1]. These values are obtained evently dividing the interval between 0 and 1 exclusive. The set T_n of truth values of a n-valued logic is thus defined as

$$T_n = \{0=\frac{0}{n-1}, \frac{1}{n-1}, \frac{2}{n-1}, \dots \dots .., \frac{n-2}{n-1}, \frac{n-1}{n-1} = 1\} \quad (2.1)$$

These values can be interpreted as degree of truth.

1.2. FUZZY PROPOSITIONS

A fuzzy logic proposition, *P* is a statement involving some concept without clearly defined boundaries. The truth value assigned to *P* can be any value on the interval [0,1].

Fuzzy propositions are assigned to fuzzy sets. Suppose proposition *P* is assigned to fuzzy set *A*; then, the truth value of a proposition, denoted *T(P)*, is given by

$$T(P) = \mu_A(X) \qquad where \quad 0 \leq \mu_A \leq 1$$

This indicates that the degree of truth for the proposition $P : x \epsilon A$ is equal to the membership grade of *x* in the fuzzy set *A*.

1.3. FUZZY LOGIC CONNECTIVES

For two simple propositions, proposition *P* defined on set *A* and proposition *Q* defined on fuzzy set *B*, the following fuzzy logic connectives are defined

1. Negation

   Let $\underline{P}$ be the negation of the proposition *P*, then the truth value of $\underline{P}$ is defined by

   $$T(\underline{P}) = 1 - T(P)$$

2. Disjunction

   The disjunction of *P* and *Q*, denoted by *P* v *Q*, is defined by *P* v *Q : x* is *A* or *B*, and the truth value of *P* v *Q* is given by

   $$T(P \vee Q) = max\,(\,T(P),\, T(Q)\,)$$

3. Conjunction

   The conjunction of *P* and *Q*, denoted by $P \wedge Q$, is defined by $P \wedge Q$:x is *A* and *B*, and the truth value of $P \wedge Q$ is given by

   $$T(P \wedge Q) = min(\, T(P), T(Q)\,)$$

4. Implication

   The implication connective P → Q is defined by P → Q : x is A, then x is B, the truth value of P → Q is given by

   $$T(P \rightarrow Q) = T(\underline{P} \vee Q) = max(\,T(\underline{P}), T(Q)\,)$$

   The implication connective can be modelled in rule-based form;

   P → Q : IF x is A, THEN y is B and it is equivalent to the fuzzy relation

   $$R = (AxB) \cup (\underline{A} \text{ x } Y)$$

   The membership function of R is expressed by the following formula,

   $${}_R(x, y) = max\,[\,(\mu_A(x) \wedge \mu_B(y), (1 - \mu_A(x))]$$

1.4. OTHER FORMS OF IMPLICATION OPERATION

There are other techniques for obtaining the fuzzy relation R based on the IF A, THEN B or R = $A \rightarrow B$, these are known as fuzzy implication operations, and they are valued for all values of $x \in Y$ and $y \in Y$. The following forms of implication operator shows different techniques for obtainng the membership function value of fuzzy relation R defined on the Cartesian product $X \times Y$.

(a) (Classical implication)

$${}_R(x, y) = max\,[\mu_B(y), 1 - \mu_A(x)]$$

(b) (Correlarion minimum or Mamdanis implication)

$${}_R(x, y) = min[\mu_A(x), \mu_B(y)]$$

(c) (Lukasiewicz implication)

$$_R(x, y) = min\,\{1, [1 - \mu_A(x) + \mu_B(y)]\}$$

1.5. TYPES OF UNQUALIFIED FUZZY PROPOSITION

In this section we focus on simple unqualified fuzzy proposition which will classified into following two types.

1. Unconditional and unqualified proposition
2. Conditional and unqualified proposition

1.5.1. UNCONDITIONAL AND UNQUALIFIED FUZZY PROPOSITION

The canonical form of fuzzy proposition of this type, P is expressed by the sentence

P :X is A

Where X is a variable that takes values x from some universal set X, and A is fuzzy set on X that represent a fuzzy predicate, such as tall, expensive, low, normal and so on. Give a particular value of X (say x), this value belongs to A with membership grade $_A(x)$, this membership grade is then interpreted as the degree of truth T(P), of proposition P. That is,

T(P) = $_A(x)$

for each given particular value x of value X in proposition P.

1.5.2. CONDITIONAL AND UNQUALIFIED FUZZY PROPOSITION

Proposition P of this type are expressed by the canonical form

P :If X is A, then Y is B

whereX,Y are variables whose values are in sets X,Y, respectively, and A,B are fuzzy sets on X,Y, respectively. These propositions may also be viewed as propositions of the form

(X,Y) is R

Where R is a fuzzy set on X ×Y that is determined for each $x \in X\ and\ y \in Y$ by the formula

$_R(x, y)$ =I[$_A(x), \mu_B(y)$]

Where I denotes a binary operation on [0,1] representing a suitable fuzzy implication. Here which is defined as

I (a,b) = min (1, 1 – a + b) (Lukasiewicz implication)

INTRODUCTION TO WEATHER FORECAST

2.1. FACTORS AFFECTING RAIN

There are mainly five factors affecting effective rainfall, they are

1. Atmospheric temperature
2. Atmospheric humidity
3. Wind speed
4. Cloud amount

2.1.1. ATMOSPHERIC TEMPERATURE

Temperature is a fundamental development of climate from many points of view, the most important in controlling the distribution of life on the earth. Most of the weather elements are dependent on it, directly or indirectly. Air of atmosphere receives the heat energy from the sun and its temperature increases. Due to different amount of heat energy receipt at different places, the air temperatures at different places also vary.

Factors affecting atmospheric temperature :

1. Latitude
2. Altitude
3. Season
4. Winds

2.1.2. ATMOSPHERIC HUMIDITY

The term humidity describes the fact that the atmosphere can contain water vapour. The amount of humidity found in air varies because of a number of factors. Two important factors are evaporation and condensation. At the water / atmosphere interface over our planet's oceans large amounts of liquid water are evaporated into atmospheric water vapour.

This process is mainly caused by absorption of solar radiation and the subsequent generation of heat at the ocean's surface. In our atmosphere, water vapour is converted back into liquid form when air masses lose heat energy and cool. This process is responsible for the development of most clouds and also produces the rain that falls to the Earth's surface.

2.1.3. WIND

Wind is the flow of gases on a large scale. On Earth, wind consists of the bulk movement of air. In meteorology, winds are often referred to according to their strength, and the direction from which the wind is blowing. The two main causes of large scale atmospheric circulation are the differential heating between the equator and the poles, and the rotation of the planet. Wind is caused by differences in atmospheric pressure. When a difference in atmospheric pressure exists, air moves from the higher to the lower pressure area, resulting in winds of various speeds.

2.1.4. CLOUD AMOUNT

Cloud cover (also known as cloudiness, cloudage or cloud amount) refers to the fraction of the sky obscured by clouds when observed from a particular location. In addition to their role as rain- and snow-makers in Earth's water cucle, clouds play a major part in Earth's energy budgets-the balance of energy that enters and leave the climate system. Clouds may have a warming or cooling influence depending on their altitude, type, and when they form. Clouds reflects sunlight back into space, which causes cooling.

2.2. METHODS FOR WEATHER FORECASTING

There are several different methods that can be used to create a forecast. The method a forecaster choosesdepends upon the experience of the forecaster, the amount of information available to the forecaster, the level of difficulty that the forecast situation presents, and the degree of accuracy or confidence needed in the forecast. Some of them are discussed below:

2.2.1. THE PERSISTENCE METHOD

The persistence method assumes that the conditions at the time of the forecast will not change. For example, if it is sunny and 87 degrees today, the persistence method predicts that it will be sunny and 87 degrees tomorrow. If two inches of rain fell today, the persistence method would predict two inches of rain for tomorrow.

2.2.2. TRENDS METHOD

The trends method involves determining the speed and direction of movement for fronts, high and low pressure centers, and areas of clouds and precipitation. Using this information, the forecaster can predict where he or she expects those features to be at some future time. For example, if a storm system is 1000 miles west of your location and moving to the cast at 250 miles per day, using the trends method you would predict it to arrive in your area in 4 days.

2.2.3. CLIMATOLOGY

The Climatology method is another simple way of producing a forecast. This method involves averaging weather statistics accumulated over many years to make the forecast. For example, if you were using the climatology method to predict the weather for Thiruvananthapuram on April 1, you would go through all the weather data that has been recorded for every April 1st and take an average. If you were making a forecast for temperature and precipitation, then you would use this recorded weather data to compute the averages for temperature and precipitation.

2.2.4. ANALOG METHOD

The Analog Method is a slightly more complicated method of producing a forecast. It involves examining today's forecast scenario and remembering a day in the past when the weather scenario looked very similar (an analog). The forecaster would predict that the weather in this forecast will behave the same as it did in the past.

2.2.5. NUMERICAL WEATHER PREDICTION

Numerical Weather Prediction (NWP) uses the power of computers to make a forecast. Complex computer programs, also known as forecast models, run on supercomputers and provide predictions on many atmospheric variables such as temperature, pressure, wind, and rainfall. A forecaster examines how the features predicted by the computer will interact to produce the day's weather.

WEATHER FORECAST USING FUZZY LOGIC

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 countries and half-dozen major cities. Local weather can vary considerably within a forecast zone.

3.1. THE MERIT OF USE FUZZY LOGIC TO PREDICT THE WEATHER

Even a shallow analysis of language (linguistic variable) used in conventional forecasts will be more than sufficient to demonstrate that they are inherently and intentionally fuzzy, and fuzzy logic is known to work in this domain. It is a domain where the value and range of important variables (e.g., wind direction, amount of cloud cover, temperature) can be represented numerically.

3.2. WEATHER LORE AND FUZZY RULES

In the early days people, especially the farmers, are predict the rain other weather phenomenon by looking to the sky, this is because of their knowledge and attachment to the nature, they know many facts about the weather, this type of knowledge

commonly known as weather lore. Most of is these are uncertain and have imprecise knowledge. Thus we can easily
convert it to fuzzy set and, eventually, we can predict the weather conditions. An additional advantage of weather lore, for us, is that it is nearly always expressed in rules of thumb that embody prototypically fuzzy input/output relationships.

3.3. MEMBERSHIP FUNCTIONS OF WEATHER VARIABLE

Membership functions are functions defined for the degree of membership of elements. For weather forecast we fuzzify the weather variables such as atmospheric temperature, relative humidity, wind speed, cloud fraction and rainfall. They are given below:

1. Membership function for rainfall (figure 5.1)

μ
light moderate heavy
1

2 3 7 10
16
Rainfall (mm/hr)

Figure 5.1: Membership function for Rainfall

2. Membership function for temperature (figure 5.2)

μ

1 low moderate high

15 20 30 35

Figure 5.2: Membership function for Temperature

3. Membership function for relative humidity (figure 5.3)

μ
1 low moderate high

70 75 85 90
Relative humidity (in %)

Figure 5.3: Membership function for relative humidity

4. Membership function for wind speed (figure 5.4)

μ

light moderate fresh strong

1

18 20 28 30 38 40

Wind speed (km/hr)

Figure 5.4 : Membership function for Wind speed

5. Membership function for cloud fraction (figure 5.5)

μ

low moderate large

1

20 30 60 70

Cloud fraction (in %)

Figure 5.5 : membership function for Cloud fraction

3.4. FUZZY RULES FOR WEATHER

From historical data of any location we can construct fuzzy rules such as IF-THEN rules. For instance we can take the rules whose antecedent as combination of the weather variables, like Temperature (T), Relative humidity (H), Cloud fraction (C) and Wind speed (W), which connect by the connective AND, and whose consequent is of the weather variable Rainfall (R), which describe below:

1. IF T is moderate AND H is moderate AND Cis moderate AND W is fresh THEN R is moderate
2. IF T is moderate AND H is moderate AND C is moderate AND W is strong THEN R is moderate
3. IF T is moderate AND H is moderate AND C is large AND W is fresh THEN R is moderate
4. IF T is moderate AND H is moderate AND C is large AND W is strong THEN R is heavy
5. IF T is moderate AND H is high AND C is large AND W is fresh THEN R is heavy

3.5. WEATHER PREDICTION

Using these rules and membership functions of weather variable we can forecast Rainfall by using the methods describe in sec:3.6.

For example, we have to predict the amount of rainfall from the data, provided from weather measurement instruments:

Relative humidity = 87.5%

Temperature = 30°C
Cloud fraction = 80%
Wind speed = 35 km/h

From the membership functions of these weather variable we get
T is moderate with membership grade 1
H is moderate with membership grade 0.5 OR high with membership grade 0.5
C is large with membership grade 1
W is fresh with membership grade 1
Then there exist two cases.

Case A: T is moderate (1)
H is moderate (0.5)
C is large (1)
W is fresh (1)
Then from the Rule :3 we get Rainfall is moderate

Case B: T is moderate (1)
H is high (0.5)
C is large (1)
W is fresh (1)
Then from the Rule :5 we get Rainfall is heavy

CONCLUSION

In our daily life we like to know the past conditions. Thus people are more interesting in the weather forecasting report for knowing tomorrow's natural behavior. For that we have to forecast a credible result for taking appropriate decision. I try to do a simple procedure for forecast the rainfall. The method using fuzzy logic allows some short of accuracy, thus we can include our experience and weather lore for forecasting more credibly.

I conclude that we can predict the complex system of weathers using the fuzzy logic. The procedure can also be improved by introducing other types of weather variables which relate the rainfall such as atmospheric pressure, slope of the lands, etc., then we can improve the forecast.

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