Similarity-Based Fuzzy Reasoning For Radiation Fog Prediction

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by

Nandigama Venkatesh

under the supervision of

Professor Kumar Sankar Ray
Electronics and Communication Sciences Unit
Indian Statistical Institute
Kolkata-700 108.

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Nandigama Venkatesh

Abstract

Conventional modus ponens is not sufficient enough to draw conclusion when the antecedent of the implication rule does not exactly match the given fact. Zadeh's generalization of modus ponens in fuzzy logic can overcome this drawback. Thus, the consequent can still be drawn even if the fact does not match with the antecedent of the IF-THEN rule. Zadeh's generalized modus ponens uses CRI(COMPOSITIONAL RULE OF INFERENCE) to get the conclusion. Many existing fuzzy reasoning methods are based on Zadeh's CRI, which requires setting up a relation between the antecedent and the consequent part. There are some other fuzzy reasoning methods which do not use Zadeh's CRI. Among them, The similarity-based fuzzy reasoning methods, which make use of the degree of similarity between a given fact and the antecedent of the rule to draw a conclusion. In this work first we consider an approach for prediction of radiation fog by Zadeh's fuzzy reasoning.For this purpose we have developed a fuzzy rule based approach for the prediction where we can capture the large experience and intuition of an expert fog predictor. But the results we got were not satisfactory after the execution of this process. So we have adapted the similarity based reasoning in which we measure the degree of similarity between the given fact(sensor values) and the antecedent part of the rules and draw the conclusion which is much better than the method mentioned previously. Prediction of radiation fog helps airlines maintain their schedule and also helps in avoiding run way accidents.

Contents

Chapter 1

Introduction

Expert systems have been one of the first commercial products resulting from research in Artificial Intelligence. Expert systems are computer programs that model the knowledge of experts and that are able to solve concrete problems where knowledge of experts is needed. Radiation Fog forecasting is one such application where the knowledge of experts is needed.
Radiation Fog is formed by the cooling of land after sunset by thermal radiation in calm conditions with clear sky. The cool ground produces condensation in the nearby air by heat conduction. In perfect calm condition the fog layer can be less than a meter deep but turbulence can promote a thicker layer. Radiation fogs occur at night, and usually does not last long after sunrise.
Radiation fog can reduce visibility to less than $1km$. Since it reduces the visibility, It may contribute to accidents, particularly with the modes of transportation. Trains, Cars, Planes cannot see each other and collide. So there is need for Radiation fog prediction system to avoid such accidents, to maintain the travelling schedules.

Radiation Fog has always been difficult to forecast, Although there has been a lot of improvement in the numerical modeling techniques, still There exists difficulties in giving accurate predictions. This is due to fact that physical processes behind this are not yet well understood and are beyond the resolution of the existing models. Hence the need for alternative methods for analysis and subsequent prognosis. Most experienced forecasters will quickly suggest that experience is the best tool for forecasting such events.

Most of the expert knowledge is pervaded with imprecision(i.e using linguistic instead of numerical values for the variables involved) and uncertainty (i.e using specifications such as possible, probable, more-or-less, very, etc) One way of representing the knowledge of experts in building a particular expert system is by using IF-THEN rule. For instance in case of Radiation Fog expert may say something like this

IF "Dewpoint is DRY" AND "Dewpointspread is VERY SATURATED" AND "Rateofchangeofdewpointspread is DRYING" AND "Windspeed is TOO-LIGHT" AND "Skycondition is CLEAR" THEN
"Visibility is HIGH."

Expert system models this rules in such a way that, from this set of IF-THEN rules and a fact(real-time situation) expert system gives us the conclusion.
chapter 2 deals with Introduction of Radiation fog
Radiation Fog Prediction is done in terms of visibility. We find some parameters that effects the Radiation Fog (Dew point,Dew point Spread,Rate of change of Spread,Wind Speed and Sky Condition) described in **chapter 3**. And we collected expert knowledge of how these parameters effects the radiation fog stated in terms of IF-THEN rule described in **chapter 3**.It also deals with some basic definitions of fuzzy sets,primary fuzzy sets of radiation fog parameters and preliminaries to know.
chapter 4 deals with Algorithms used for deduction of visibility from these rules , primary fuzzy sets of parameters and sensor input. It essentially deals with Zadeh's fuzzy reasoning , Similarity reasoning and a combined method .
chapter 5 deals with comparison of results of methods .
chapter 6 deals with conclusion of our work.

Chapter 2

Radiation Fog

Radiation Fog is formed by the cooling of land after sunset by thermal radiation in calm conditions with clear sky. The cool ground produces condensation in the nearby air by heat conduction. In perfect calm the fog layer can be less than a meter deep but turbulence can promote a thicker layer. Radiation fogs occur at night, And usually does not last long until sunrise because as the land heats up, The air gets warmer and dew point increases. However, do not be complacent when dealing with it. Cloudy days can make it longer for the land to heat up, thus, Fog will not disperse quickly. Radiation fog is common in autumn, and early winter. Examples of this phenomenon include the Tule fog.

Tule fog is a radiation fog, which condenses when there is a high relative humidity - typically after a heavy rain - calm winds, and rapid cooling during the night. The nights are longer in the winter months, which creates rapid ground cooling, and thereby a pronounced temperature inversion at a low altitude. Tule fog is a thick ground fog that settles in the San Joaquin Valley and Sacramento Valley areas of California's Great Central Valley. Tule fog forms during the late autumn and winter (California's rainy season) after the first significant rainfall. The official time frame for tule fog to form is from November 1 to March 31. This phenomenon is named after the tule grass wetlands (tulares) of the Central Valley. Accidents caused by the tule fog are the leading cause of weather-related casualties in California. Radiation fog is the most serious and persistent type of fog hazard for the road user as it tends to be localized and dense, producing unexpectedly low visibilities which can cause trouble even to the most attentive driver.

The variability in visibility is the cause of many chain-reaction pile-ups on

roads and freeways. In one such accident on Interstate 5 near Elk Grove south of Sacramento, 25 cars and 12 big-rig trucks collided inside a fog bank in December 1997. Five people died and 28 were injured. In February 2002, two people were killed in an 80-plus car pile-up on State Route 99 between Kingsburg and Selma. The visibility at the time of the accident was zero. On the morning of November 3, 2007, heavy tule fog caused a massive pile-up that included 108 passenger vehicles and 18 big rig trucks on Northbound State Route 99 between Fowler and Fresno. Visibility was cut to about 200 feet at the time of the accident. There were two fatalities and 39 injuries in the crash.
Usual parameters responsible for Radiation Fog are Dew point, Dew point Spread, Rate of change of Dew point spread,wind speed and sky coverage (as described in **chapter 3**.

Chapter 3

Preliminaries

3.1 Definitions

3.1.1 Fuzzy Sets and Operations

Definition :
A fuzzy set A in a universe of discourse $X = \{ x \}$ is denoted by $A \subseteq X$ and is defined as the following set of pairs,

$$A = \{(\mu_A(x), x)\} \qquad \text{for all } x \in X \tag{3.1}$$

where $\mu_A : X \to [0, 1]$ is the membership function of A and $\mu_A(x)$ is the grade of membership of $x \in X$ in A. Thus, a fuzzy set is a set of pairs consisting of the particular elements of the universe of discourse and their membership grades.
For practical reasons, we will use in the sequel only finite universes of discourse , e.g., $X = \{x_1, \dots, x_n\}$. In this case the pair $(\mu_A(x), x)$ is usually denoted by $\mu_A(x)/x$ and the fuzzy set written as
$A = \{(\mu_A(x), x)\} = \{\mu_A(x)/x\} = \mu_A(x_1)/x_1 + \cdots + \mu_A(x_n)/x_n = \sum_{i=1}^{n} \mu_A(x_i)/x_i$.
where "+" and "$\sum$" are in the set-theoretic sense.
Example:
fuzzy set defined on a universe of discourse X={set of integers}.
" integer numbers more or less equal to 6. "
$A \approx 0.05/2 + 0.2/3 + 0.4/4 + 0.8/5 + 1/6 + 0.8/7 + 0.4/8 + 0.2/9 + 0.1/10 + 0.05/11$.
at remaining points $\mu_A(x) = 0$.

operations on fuzzy sets :

As in the conventional(nonfuzzy)set theory , the basic operations in the theory of fuzzy sets are the complement, union, intersection. The following definitions of these operations were originally proposed by Zadeh.

For brevity, the definitions will be given in terms of the respective membership functions.

The **complement** of a fuzzy set $A \subseteq X$, written as $\neg A$, is defined as $\mu_{\neg A}(x) = 1 - \mu_A(x)$

Example. if $X = \{1, 2, 3\}$. and $A = 0.1/1 + 0.7/2 + 1/3$ then $\neg A = 0.9/1 + 0.3/2$.

The **union** of two fuzzy sets $A, B \subseteq X$, written $A + B$,is defined as $\mu_{A+B}(x) = \mu_A(x) \vee \mu_B(x)$

where "$\vee$" is the maximum operator.

Example. If $X = \{1, 2, 3, 4\}$ and $A = 0.2/1 + 0.5/2 + 0.8/3 + 1/4$ and $B = 1/1 + 0.8/2 + 0.5/3 + 0.2/4$, then

$A + B = 1/1 + 0.8/2 + 0.8/3 + 1/4$

The **intersection** of two fuzzy sets $A, B \subseteq X$, written $A \cap B$,is defined as

$\mu_{A\cap B}(x) = \mu_A(x) \wedge \mu_B(x)$

where "$\wedge$" is the minimum operator.

Example. If $X = \{1, 2, 3, 4\}$ and $A = 0.2/1 + 0.5/2 + 0.8/3 + 1/4$ and $B = 1/1 + 0.8/2 + 0.5/3 + 0.2/4$, then

$A \cap B = 0.2/1 + 0.5/2 + 0.5/3 + 0.2/4$

A **fuzzy relation** R between the two(nonfuzzy) sets X and Y is a fuzzy set in the Cartesian product $X \times Y$, hence is defined as

$R = \{(\mu_R(x, y), (x, y))\} = \{\mu_R(x, y)/(x, y)\}$ for all $(x, y) \in X \times Y$

Example. Let $X = \{$ horse, donkey $\}$ and $Y = \{$ mule, cow$\}$ the fuzzy relation R labeled similarity may be, e.g., as follows

"similarity"= 0.8/(horse, mule) + 0.4/(horse, cow) + 0.9/(donkey, mule) + 0.2/(donkey, cow).

The **max-min composition** of two fuzzy relations $R \subseteq X \times Y$ and $S \subseteq Y \times Z$, written $R \circ S$, is defined as a fuzzy relation $R \circ S \subseteq X \times Z$, such that

$\mu_{R\circ S} = max_{y\in Y}(\mu_R(x, y) \wedge \mu_S(y, z))$ for all $x \in X, z \in Z$

The **Cartesian product** of two fuzzy sets $A \subseteq X and B \subseteq Y$, written $A \times B$, is defined as a fuzzy set in $X \times Y$, such that

$\mu_{A\times B}(x, y) = \mu_A(x) \wedge \mu_B(y)$ for each $x \in X, y \in Y$.

3.1.2 Parameters of the Radiation Fog and their Fuzzy Sets

a)**Dew point:** The temperature to which humid air can be cooled at constant pressure without causing condensation is called the dew point temperature or dew point. It is represented by T_d and measured in $(°C)$. Here the domain of dewpoint is $T_d = \{-300°cto300°c\}$. Primary fuzzy sets defined over the said domain are DRY, MODERATE, MOIST, VERY MOIST. this fuzzy sets defined below in Table 3.1.

b) **Dew point spread:** The difference between the air temperature T and dew point (T_d) is termed as dew point spread. It is represented by $\triangle\ T$ and measured in $(°C)$. Here domain of dew point spread is $\triangle\ T = \{-120°to120°\}$. Primary fuzzy sets defined over the domain are VERY SATURATED, SATURATED , and UNSATURATED. this fuzzy sets defined in Table 3.2.

c)**The rate of the change of dew point spread per day :** The difference between the dew point spreads of two consecutive days is defined as the rate of the change of spread per day. It is represented by $\triangle T'$ and measured in $(°C)$. Here domain of $\triangle T' = \{-50°Cto60°C\}$. Primary fuzzy sets defined over the said domain are DRYING, SATURATING .this fuzzy sets defined in Table 3.3.

d) **Wind Speed :** Wind speed is the speed of wind in kms/hr. represented by W. Here domain of $W = \{-5kms/hrto25kms/hr\}$. Primary fuzzy sets defined over the domain are TOO LIGHT,EXCELLENT, and TOO STRONG. This fuzzy sets defined in Table 3.4.

e) **Sky Condition :** Sky condition is in terms of percentage of cloud coverage perceptually judged by inspection. It is represented by S and measured in (%). Here domain of $S = 0\%to0\%$. Primary fuzzy sets defined over the said domain are CLEAR ,PARTIALLY CLOUDY, CLOUDY. This fuzzy sets defined in Table 3.5.

f) **Visibility :** As no standard or well established visibility versus fog(haze) classification exists we consider the following ranges of visibility from international definition of fog(V≤1 km). Primary fuzzy sets defined over the said domain are VERYLOW, LOW, MEDIUM, HIGH, VERYHIGH. This fuzzy sets defined in Table 3.6

T_d	DRY	$MODERATE$	$MOIST$	$VERYMOIST$
$-30 \le Td < -25$	1.0	0.5	0.2	0
$-25 \le Td < -20$	0.9	0.6	0.3	0
$-20 \le Td < -15$	0.8	0.7	0.5	0
$-15 \le Td < -10$	0.7	0.8	0.6	0.1
$-10 \le Td < -5$	0.6	0.9	0.7	0.2
$-5 \le Td < 0$	0.5	1.0	0.8	0.3
$0 \le Td < 5$	0.3	0.9	0.9	0.5
$5 \le Td < 10$	0.2	0.8	1.0	0.6
$10 \le Td < 15$	0.1	0.7	0.9	0.7
$15 \le Td < 20$	0	0.6	0.8	0.8
$20 \le Td < 25$	0	0.5	0.7	0.9
$25 \le Td < 30$	0	0.3	0.6	1

Table 3.1: primary fuzzy sets and their membership functions of Dewpoint

δT	$VERYSATURATED$	$SATURATED$	$UNSATURATED$
$-12 \le \delta T < -10$	1.0	0.3	0
$-10 \le \delta T < -8$	0.9	0.5	0
$-8 \le \delta T < -6$	0.8	0.6	0
$-6 \le \delta T < -4$	0.7	0.7	0.1
$-4 \le \delta T < -2$	0.6	0.8	0.2
$-2 \le \delta T < 0$	0.5	0.9	0.3
$0 \le \delta T < 2$	0.3	1.0	0.5
$2 \le \delta T < 4$	0.2	0.9	0.6
$4 \le \delta T < 6$	0.1	0.8	0.7
$6 \le \delta T < 8$	0	0.7	0.8
$8 \le \delta T < 10$	0	0.6	0.9
$10 \le \delta T < 12$	0	0.5	1.0

Table 3.2: primary fuzzysets and their membership functions of DewpointSpread

δt	$SATURATING$	$DRYING$
$-5 \leq \delta t < -4$	1.0	0
$-4 \leq \delta t < -3$	0.9	0
$-3 \leq \delta t < -2$	0.8	0.1
$-2 \leq \delta t < -1$	0.7	0.2
$-1 \leq \delta t < 0$	0.6	0.3
$0 \leq \delta t < 1$	0.5	0.5
$1 \leq \delta t < 2$	0.3	0.6
$2 \leq \delta t < 3$	0.2	0.7
$3 \leq \delta t < 4$	0.1	0.8
$4 \leq \delta t < 5$	0	0.9
$5 \leq \delta t < 6$	0	1.0

Table 3.3: primary fuzzysets and their membership functions of Rate of change of DewpointSpread

W	$TOOLIGHT$	$EXCELLENT$	$TOOHIGH$
$-5 \leq W < -2.5$	1.0	0.5	0.6
$-2.5 \leq W < 0$	0.9	0.6	0
$0 \leq W < 2.5$	0.8	0.7	0
$2.5 \leq W < 5$	0.7	0.8	0.1
$5 \leq W < 7.5$	0.6	0.9	0.2
$7.5 \leq W < 10.0$	0.5	1.0	0.3
$10.0 \leq W < 12.5$	0.3	0.9	0.5
$12.5 \leq W < 15.0$	0.2	0.8	0.6
$15.0 \leq W < 17.5$	0.1	0.7	0.7
$17.5 \leq W < 20.0$	0	0.6	0.8
$20.0 \leq W < 22.5$	0	0.5	0.9
$22.5 \leq W < 25.0$	0	0.3	1.0

Table 3.4: primary fuzzysets and their membership functions of Rate of change of WindSpeed

S	$CLEAR$	$PARTIALLYCLOUDY$	$CLOUDY$
$0 \leq S < 10$	1.0	0.6	0
$10 \leq S < 20$	0.9	0.7	0.1
$20 \leq S < 30$	0.8	0.8	0.2
$30 \leq S < 40$	0.7	0.9	0.3
$40 \leq S < 50$	0.6	1.0	0.5
$50 \leq S < 60$	0.5	0.9	0.6
$60 \leq S < 70$	0.3	0.8	0.7
$70 \leq S < 80$	0.2	0.7	0.8
$80 \leq S < 90$	0.1	0.6	0.9
$90 \leq S < 100$	0	0.5	1.0

Table 3.5: primary fuzzysets and their membership functions of Sky Coverage

V	$VERYLOW$	LOW	$MEDIUM$	$HIGH$	$VERYHIGH$
$V < 1$	1.0	0.7	0.5	0.3	0.1
$1 \leq V < 5$	0.7	1.0	0.7	0.5	0.3
$5 \leq V < 10$	0.5	0.7	1.0	0.7	0.5
$10 \leq V < 16$	0.3	0.5	0.7	1.0	0.7
$V > 1$	0.1	0.3	0.5	0.7	1.0

Table 3.6: primary fuzzysets and their membership functions of Visibility

3.1.3 Similarity Measures

In this section, we provide some standard Similarity Measures used in our application.
let A and B are two fuzzy sets.

Measure based on the maximum difference :

$$L_{A,B} = 1 - max_i(|a_i - b_i|) \tag{3.2}$$

Measure based on the difference and the sum :

$$S_{A,B} = 1 - \frac{\sum_{i=1}^{n} |a_i - b_i|}{\sum_{i=1}^{n} |a_i + b_i|} \tag{3.3}$$

Measure based on the Union and Intersection :

$$M_{A,B} = 1 - \frac{|A \cap B|}{|A \cup B|} \tag{3.4}$$

Measure based on Geometric distance :

$$W_{A,B} = 1 - \frac{\sum_{i=1}^{n} |a_i - b_i|}{n} \tag{3.5}$$

Measure based on Set-theoretic :

$$T_{A,B} = max_{x \in U}((A \cap B)(x)) \tag{3.6}$$

Measure based on Matching :

$$P_{A,B} = \frac{\sum_{i=1}^{n} a_i.b_i}{max(\sum_{i=1}^{n} a_i.a_i, \sum_{i=1}^{n} b_i.b_i)} \tag{3.7}$$

3.2 IF-THEN Rule

One way of representing knowledge of experts is by using IF-THEN Rule. Modeling of this rules gives us the expert system.
Example:
suppose in designing computer-controlled car

IF "traffic signal is red" THEN "stop the car."

by some how we have to model this rule to design a computer-controlled car.

Rules of Radiation Fog: The five parameters which decides the Visibility as described in **section 3.1** with the possible set of values .

DEW POINT $\{DRY, MODERATE, MOIST, VERYMOIST\}$.
DEW POINT SPREAD $\{VERYSATURATED, SATURATED, UNSATURATED\}$.
RATE OF CHANGE OF DEW POINT SPREAD $\{DRYING, SATURATING\}$.
WIND SPEED $\{TOOLIGHT, EXCELLENT, TOOSTRONG\}$.
SKY CONDITION $\{CLEAR, PARTIALLYCLOUDY, CLOUDY\}$.
and the
VISIBILITY OF FOG $\{VERYLOW, LOW, MEDIUM, HIGH, VERYHIGH\}$

Number of possible rules is the product of combinations of the number of primary sets taking one at time from each of them.

$$4_{C_1} \times 3_{C_1} \times 2_{C_1} \times 3_{C_1} \times 3_{C_1} = 216$$

The antecedents of all possible rules along their corresponding consequents are give in Table 3.7-3.10.

DP	DPSP	ROCSP	WNDS	SKYC	VISS
DRY	VERYSATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
DRY	VERYSATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
DRY	VERYSATURATED	DRYING	TOOLIGHT	CLOUDY	VERYHIGH
DRY	VERYSATURATED	DRYING	EXCELLENT	CLEAR	HIGH
DRY	VERYSATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	HIGH
DRY	VERYSATURATED	DRYING	EXCELLENT	CLOUDY	HIGH
DRY	VERYSATURATED	DRYING	TOOSTRONG	CLEAR	HIGH
DRY	VERYSATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
DRY	VERYSATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
DRY	VERYSATURATED	SATURATING	TOOLIGHT	CLEAR	MEDIUM
DRY	VERYSATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
DRY	VERYSATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
DRY	VERYSATURATED	SATURATING	EXCELLENT	CLEAR	MEDIUM
DRY	VERYSATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	HIGH
DRY	VERYSATURATED	SATURATING	EXCELLENT	CLOUDY	HIGH
DRY	VERYSATURATED	SATURATING	TOOSTRONG	CLEAR	HIGH
DRY	VERYSATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
DRY	VERYSATURATED	SATURATING	TOOSTRONG	CLOUDY	HIGH
DRY	SATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
DRY	SATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
DRY	SATURATED	DRYING	TOOLIGHT	CLOUDY	VERYHIGH
DRY	SATURATED	DRYING	EXCELLENT	CLEAR	HIGH
DRY	SATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	HIGH
DRY	SATURATED	DRYING	EXCELLENT	CLOUDY	VERYHIGH
DRY	SATURATED	DRYING	TOOSTRONG	CLEAR	VERYHIGH
DRY	SATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
DRY	SATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
DRY	SATURATED	SATURATING	TOOLIGHT	CLEAR	MEDIUM
DRY	SATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
DRY	SATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
DRY	SATURATED	SATURATING	EXCELLENT	CLEAR	MEDIUM
DRY	SATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	HIGH
DRY	SATURATED	SATURATING	EXCELLENT	CLOUDY	HIGH
DRY	SATURATED	SATURATING	TOOSTRONG	CLEAR	HIGH
DRY	SATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
DRY	SATURATED	SATURATING	TOOSTRONG	CLOUDY	VERYHIGH
DRY	UNSATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
DRY	UNSATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
DRY	UNSATURATED	DRYING	TOOLIGHT	CLOUDY	HIGH
DRY	UNSATURATED	DRYING	EXCELLENT	CLEAR	HIGH
DRY	UNSATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	HIGH
DRY	UNSATURATED	DRYING	EXCELLENT	CLOUDY	VERYHIGH
DRY	UNSATURATED	DRYING	TOOSTRONG	CLEAR	VERYHIGH
DRY	UNSATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
DRY	UNSATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
DRY	UNSATURATED	SATURATING	TOOLIGHT	CLEAR	HIGH
DRY	UNSATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
DRY	UNSATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
DRY	UNSATURATED	SATURATING	EXCELLENT	CLEAR	MEDIUM
DRY	UNSATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	HIGH
DRY	UNSATURATED	SATURATING	EXCELLENT	CLOUDY	HIGH
DRY	UNSATURATED	SATURATING	TOOSTRONG	CLEAR	HIGH
DRY	UNSATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
DRY	UNSATURATED	SATURATING	TOOSTRONG	CLOUDY	VERYHIGH

Table 3.7: Rules for visibility of fog

MODERATE	VERYSATURATED	DRYING	TOOLIGHT	CLEAR	MEDIUM
MODERATE	VERYSATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
MODERATE	VERYSATURATED	DRYING	TOOLIGHT	CLOUDY	HIGH
MODERATE	VERYSATURATED	DRYING	EXCELLENT	CLEAR	MEDIUM
MODERATE	VERYSATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	MEDIUM
MODERATE	VERYSATURATED	DRYING	EXCELLENT	CLOUDY	HIGH
MODERATE	VERYSATURATED	DRYING	TOOSTRONG	CLEAR	HIGH
MODERATE	VERYSATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
MODERATE	VERYSATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
MODERATE	VERYSATURATED	SATURATING	TOOLIGHT	CLEAR	LOW
MODERATE	VERYSATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	MEDIUM
MODERATE	VERYSATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
MODERATE	VERYSATURATED	SATURATING	EXCELLENT	CLEAR	VERYLOW
MODERATE	VERYSATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	LOW
MODERATE	VERYSATURATED	SATURATING	EXCELLENT	CLOUDY	MEDIUM
MODERATE	VERYSATURATED	SATURATING	TOOSTRONG	CLEAR	HIGH
MODERATE	VERYSATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
MODERATE	VERYSATURATED	SATURATING	TOOSTRONG	CLOUDY	HIGH
MODERATE	SATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
MODERATE	SATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	VERYHIGH
MODERATE	SATURATED	DRYING	TOOLIGHT	CLOUDY	VERYHIGH
MODERATE	SATURATED	DRYING	EXCELLENT	CLEAR	HIGH
MODERATE	SATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	HIGH
MODERATE	SATURATED	DRYING	EXCELLENT	CLOUDY	VERYHIGH
MODERATE	SATURATED	DRYING	TOOSTRONG	CLEAR	VERYHIGH
MODERATE	SATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
MODERATE	SATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
MODERATE	SATURATED	SATURATING	TOOLIGHT	CLEAR	MEDIUM
MODERATE	SATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
MODERATE	SATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
MODERATE	SATURATED	SATURATING	EXCELLENT	CLEAR	LOW
MODERATE	SATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	MEDIUM
MODERATE	SATURATED	SATURATING	EXCELLENT	CLOUDY	HIGH
MODERATE	SATURATED	SATURATING	TOOSTRONG	CLEAR	HIGH
MODERATE	SATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
MODERATE	SATURATED	SATURATING	TOOSTRONG	CLOUDY	VERYHIGH
MODERATE	UNSATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
MODERATE	UNSATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	VERYHIGH
MODERATE	UNSATURATED	DRYING	TOOLIGHT	CLOUDY	VERYHIGH
MODERATE	UNSATURATED	DRYING	EXCELLENT	CLEAR	MEDIUM
MODERATE	UNSATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	VERYHIGH
MODERATE	UNSATURATED	DRYING	EXCELLENT	CLOUDY	VERYHIGH
MODERATE	UNSATURATED	DRYING	TOOSTRONG	CLEAR	VERYHIGH
MODERATE	UNSATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
MODERATE	UNSATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
MODERATE	UNSATURATED	SATURATING	TOOLIGHT	CLEAR	HIGH
MODERATE	UNSATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
MODERATE	UNSATURATED	SATURATING	TOOLIGHT	CLOUDY	VERYHIGH
MODERATE	UNSATURATED	SATURATING	EXCELLENT	CLEAR	MEDIUM
MODERATE	UNSATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	HIGH
MODERATE	UNSATURATED	SATURATING	EXCELLENT	CLOUDY	HIGH
MODERATE	UNSATURATED	SATURATING	TOOSTRONG	CLEAR	HIGH
MODERATE	UNSATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
MODERATE	UNSATURATED	SATURATING	TOOSTRONG	CLOUDY	VERYHIGH

Table 3.8: Rules for visibility of fog (contd..)

MOIST	VERYSATURATED	DRYING	TOOLIGHT	CLEAR	MEDIUM
MOIST	VERYSATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	MEDIUM
MOIST	VERYSATURATED	DRYING	TOOLIGHT	CLOUDY	HIGH
MOIST	VERYSATURATED	DRYING	EXCELLENT	CLEAR	LOW
MOIST	VERYSATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	MEDIUM
MOIST	VERYSATURATED	DRYING	EXCELLENT	CLOUDY	MEDIUM
MOIST	VERYSATURATED	DRYING	TOOSTRONG	CLEAR	MEDIUM
MOIST	VERYSATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	MEDIUM
MOIST	VERYSATURATED	DRYING	TOOSTRONG	CLOUDY	HIGH
MOIST	VERYSATURATED	SATURATING	TOOLIGHT	CLEAR	VERYLOW
MOIST	VERYSATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	LOW
MOIST	VERYSATURATED	SATURATING	TOOLIGHT	CLOUDY	MEDIUM
MOIST	VERYSATURATED	SATURATING	EXCELLENT	CLEAR	VERYLOW
MOIST	VERYSATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	VERYLOW
MOIST	VERYSATURATED	SATURATING	EXCELLENT	CLOUDY	MEDIUM
MOIST	VERYSATURATED	SATURATING	TOOSTRONG	CLEAR	MEDIUM
MOIST	VERYSATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	MEDIUM
MOIST	VERYSATURATED	SATURATING	TOOSTRONG	CLOUDY	HIGH
MOIST	SATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
MOIST	SATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
MOIST	SATURATED	DRYING	TOOLIGHT	CLOUDY	VERYHIGH
MOIST	SATURATED	DRYING	EXCELLENT	CLEAR	LOW
MOIST	SATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	HIGH
MOIST	SATURATED	DRYING	EXCELLENT	CLOUDY	HIGH
MOIST	SATURATED	DRYING	TOOSTRONG	CLEAR	HIGH
MOIST	SATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
MOIST	SATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
MOIST	SATURATED	SATURATING	TOOLIGHT	CLEAR	LOW
MOIST	SATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	MEDIUM
MOIST	SATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
MOIST	SATURATED	SATURATING	EXCELLENT	CLEAR	VERYLOW
MOIST	SATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	LOW
MOIST	SATURATED	SATURATING	EXCELLENT	CLOUDY	MEDIUM
MOIST	SATURATED	SATURATING	TOOSTRONG	CLEAR	MEDIUM
MOIST	SATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
MOIST	SATURATED	SATURATING	TOOSTRONG	CLOUDY	HIGH
MOIST	UNSATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
MOIST	UNSATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	VERYHIGH
MOIST	UNSATURATED	DRYING	TOOLIGHT	CLOUDY	VERYHIGH
MOIST	UNSATURATED	DRYING	EXCELLENT	CLEAR	MEDIUM
MOIST	UNSATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	HIGH
MOIST	UNSATURATED	DRYING	EXCELLENT	CLOUDY	HIGH
MOIST	UNSATURATED	DRYING	TOOSTRONG	CLEAR	HIGH
MOIST	UNSATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
MOIST	UNSATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
MOIST	UNSATURATED	SATURATING	TOOLIGHT	CLEAR	LOW
MOIST	UNSATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	MEDIUM
MOIST	UNSATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
MOIST	UNSATURATED	SATURATING	EXCELLENT	CLEAR	LOW
MOIST	UNSATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	MEDIUM
MOIST	UNSATURATED	SATURATING	EXCELLENT	CLOUDY	MEDIUM
MOIST	UNSATURATED	SATURATING	TOOSTRONG	CLEAR	MEDIUM
MOIST	UNSATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
MOIST	UNSATURATED	SATURATING	TOOSTRONG	CLOUDY	HIGH

Table 3.9: Rules for visibility of fog (contd..)

VERYMOIST	VERYSATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
VERYMOIST	VERYSATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	VERYHIGH
VERYMOIST	VERYSATURATED	DRYING	TOOLIGHT	CLOUDY	VERYHIGH
VERYMOIST	VERYSATURATED	DRYING	EXCELLENT	CLEAR	MEDIUM
VERYMOIST	VERYSATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	HIGH
VERYMOIST	VERYSATURATED	DRYING	EXCELLENT	CLOUDY	HIGH
VERYMOIST	VERYSATURATED	DRYING	TOOSTRONG	CLEAR	HIGH
VERYMOIST	VERYSATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
VERYMOIST	VERYSATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
VERYMOIST	VERYSATURATED	SATURATING	TOOLIGHT	CLEAR	LOW
VERYMOIST	VERYSATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
VERYMOIST	VERYSATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
VERYMOIST	VERYSATURATED	SATURATING	EXCELLENT	CLEAR	VERYLOW
VERYMOIST	VERYSATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	LOW
VERYMOIST	VERYSATURATED	SATURATING	EXCELLENT	CLOUDY	MEDIUM
VERYMOIST	VERYSATURATED	SATURATING	TOOSTRONG	CLEAR	MEDIUM
VERYMOIST	VERYSATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
VERYMOIST	VERYSATURATED	SATURATING	TOOSTRONG	CLOUDY	HIGH
VERYMOIST	SATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
VERYMOIST	SATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	VERYHIGH
VERYMOIST	SATURATED	DRYING	TOOLIGHT	CLOUDY	VERYHIGH
VERYMOIST	SATURATED	DRYING	EXCELLENT	CLEAR	HIGH
VERYMOIST	SATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	VERYHIGH
VERYMOIST	SATURATED	DRYING	EXCELLENT	CLOUDY	VERYHIGH
VERYMOIST	SATURATED	DRYING	TOOSTRONG	CLEAR	VERYHIGH
VERYMOIST	SATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
VERYMOIST	SATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
VERYMOIST	SATURATED	SATURATING	TOOLIGHT	CLEAR	MEDIUM
VERYMOIST	SATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
VERYMOIST	SATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
VERYMOIST	SATURATED	SATURATING	EXCELLENT	CLEAR	VERYLOW
VERYMOIST	SATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	MEDIUM
VERYMOIST	SATURATED	SATURATING	EXCELLENT	CLOUDY	HIGH
VERYMOIST	SATURATED	SATURATING	TOOSTRONG	CLEAR	MEDIUM
VERYMOIST	SATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	HIGH
VERYMOIST	SATURATED	SATURATING	TOOSTRONG	CLOUDY	HIGH
VERYMOIST	UNSATURATED	DRYING	TOOLIGHT	CLEAR	HIGH
VERYMOIST	UNSATURATED	DRYING	TOOLIGHT	PARTIALLYCLOUDY	VERYHIGH
VERYMOIST	UNSATURATED	DRYING	TOOLIGHT	CLOUDY	VERYHIGH
VERYMOIST	UNSATURATED	DRYING	EXCELLENT	CLEAR	HIGH
VERYMOIST	UNSATURATED	DRYING	EXCELLENT	PARTIALLYCLOUDY	VERYHIGH
VERYMOIST	UNSATURATED	DRYING	EXCELLENT	CLOUDY	VERYHIGH
VERYMOIST	UNSATURATED	DRYING	TOOSTRONG	CLEAR	HIGH
VERYMOIST	UNSATURATED	DRYING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
VERYMOIST	UNSATURATED	DRYING	TOOSTRONG	CLOUDY	VERYHIGH
VERYMOIST	UNSATURATED	SATURATING	TOOLIGHT	CLEAR	MEDIUM
VERYMOIST	UNSATURATED	SATURATING	TOOLIGHT	PARTIALLYCLOUDY	HIGH
VERYMOIST	UNSATURATED	SATURATING	TOOLIGHT	CLOUDY	HIGH
VERYMOIST	UNSATURATED	SATURATING	EXCELLENT	CLEAR	MEDIUM
VERYMOIST	UNSATURATED	SATURATING	EXCELLENT	PARTIALLYCLOUDY	MEDIUM
VERYMOIST	UNSATURATED	SATURATING	EXCELLENT	CLOUDY	HIGH
VERYMOIST	UNSATURATED	SATURATING	TOOSTRONG	CLEAR	HIGH
VERYMOIST	UNSATURATED	SATURATING	TOOSTRONG	PARTIALLYCLOUDY	VERYHIGH
VERYMOIST	UNSATURATED	SATURATING	TOOSTRONG	CLOUDY	VERYHIGH

Table 3.10: Rules for visibility of fog (contd..)

3.3 Zadeh's Approximate Reasoning

The first attempt(Zadeh, 1973) for modeling deductive processes with fuzzy propositions is the so-called "Generalized Modus Ponens"(GMP). It involves fuzzy categories rather than classical predicates and it allows to infer a non-trivial conclusion even in case of imperfect match of the available information with the IF-part of a rule.

Generalized Modus Ponens(GMP):

$$IF\, x\, is\, A\; THEN\, y\, is\, B$$

$$x\, is\, A'$$

$$- -$$

$$\therefore y\, is\, B'$$

B' will of course depend on A', A, and B

Deriving B' from A', A, B is by using CRI(Compositional Rule of Inference). The consequence B' is deduced from IF-THEN rule and the Fact ,by taking the $\max - \min$ composition $\circ$ of the fuzzy set A' and the fuzzy relation $A \rightarrow B$ obtained from the fuzzy implication "IF A THEN B" that means ,we get,

$$B' = A' \circ (A \rightarrow B).$$
$$\mu_{B'}(v) = \vee_u \{\mu_{A'} \wedge \mu_{A \rightarrow B}\}$$

several fuzzy implications $A \rightarrow B$ are there,listed in Table 3.11.

Example:

Let $X = \{x\} = \{1, 2, 3\}$ and $Y = \{y\} = \{1, 2, 3, 4\}$ .suppose The fuzzy conditional statement

IF x is "low" THEN y is "high"

where "low"= 1/1+0.7/2+0.3/3, "high"= 0.2/1+0.5/2+0.8/3+1/4 .
and is equivalent to the fuzzy relation

$$R = (''low'') \circ (''high'') = \begin{pmatrix} 0.2 & 0.5 & 0.8 & 1.0 \\ 0.2 & 0.5 & 0.7 & 0.7 \\ 0.2 & 0.3 & 0.3 & 0.3 \end{pmatrix}$$

$R_c:$	$\mu_A(u_0) \wedge \mu_B(v)$	Mamdani
$R_p:$	$\mu_A(u_0) \bullet \mu_B(v)$	Larsen
$R_{b_p}:$	$0 \vee [\mu_A(u_0) + \mu_B(v) - 1]$	boundedproduct
$R_a:$	$1 \wedge [1 - \mu_A(u_0) + \mu_B(v)]$	Zadeh's arithmeticrule
$R_m:$	$[\mu_A(u_0) \wedge \mu_B(v)] \vee [1 - \mu_A(u_0)]$	Zadeh's maximum rule
$R_b:$	$[1 - \mu_A(u_0)] \vee \mu_B(v)$	Boolean implication
$R_{d_p}:$	$\mu_A(u_0), \quad \mu_B(v) = 1$ $\mu_B(v), \quad \mu_A(v) = 1$ $0, \quad \mu_A(u_0), \mu_B(v) < 1$	drastic product
$R_s:$	$1, \quad \mu_A(u_0) \leq \mu_B(v)$ $0, \quad \mu_A(u_0) > \mu_B(v)$	standard sequence
$R_g:$	$1, \quad \mu_A(u_0) \leq \mu_B(v)$ $\mu_B(v), \quad \mu_A(u_0) > \mu_B(v)$	Godelian logic
$R_\delta:$	$1, \quad \mu_A(u_0) \leq \mu_B(v)$ $\mu_B(v)/\mu_A(u_0), \quad \mu_A(u_0) > \mu_B(v)$	Gougen logic
$R*:$	$1 - \mu_A(u_0) + \mu_A(u_0) \bullet \mu_B(v)$	Bandlerlogic
$R_\#:$	$[1 - \mu_A(u_0) \vee \mu_B(v)] \wedge [\mu_A(u_0) \vee (1 - \mu_A(u_0))] \wedge$ $[\mu_B(v) \vee (1 - \mu_B(v))]$	bandlerlogic

Table 3.11: Several fuzzy implications

now IF x is "medium"$= 0.5/1{+}1/2{+}0.5/3$ THEN then y is given by

$$B' = (\text{"}medium\text{"}) \circ R = \max_{x \in \{1,2,3\}} (\mu_m(x) \wedge \mu_R(x,y)) = 0.2/1{+}0.5/2{+}0.7/3{+}0.7/4.$$

3.4 Similarity-Based Reasoning

From an IF-THEN rule and a given fact, regardless of the relation between antecedent and consequent, it finds the degree of similarity between fact and the antecedent of a rule to draw the conclusion. In this methods do not require the construction of a fuzzy relation between antecedent and consequent of a IF-THEN rule. To draw a conclusion it might use some modification procedures

Generalized Modus Ponens(GMP):

$$IF\, x\, is\, A\, THEN\, y\, is\, B$$

$$x\, is\, A'$$

$$-----------------------------$$

$$\therefore y\, is\, B'$$

we know that B' depends on A,A',B.

Deriving B' from B, similarity(A, A')(let it be s.)

if $s \geq \tau_0$, the rule will be fired and the consequent is modified by a modification function which could appear in one of the two forms:

1) **more or less form :**

$$B' = \min\{1, B/s\}.$$

2) **membership value reduction form:**

$$B' = B * s.$$

some threshold (τ_0) defined,to decide when to fire a rule.

Example:
Let $X = \{x\} = \{1, 2, 3\}$ and $Y = \{y\} = \{1, 2, 3, 4\}$ .suppose The fuzzy conditional statement

IF x is "low" THEN y is "high"

where "low"= 1/1+0.7/2+0.3/3, "high"= 0.2/1+0.5/2+0.8/3+1/4 .
now IF x is "medium" =0.5/1+1/2+0.5/3 THEN
first find the similarity between antcedent and fact.

using similarity measure $W_{A,B} = 1 - \frac{\sum_{i=1}^{n} |a_i - b_i|}{n}$

s("low","medium")=1-$\frac{1}{3}$[0.5 + 0.3 + 0.2] = 2/3

let the threshold $\tau_0 = 0.5$,$s \geq 0.5$ so we can fire the rule, Thus the conclusion we will get by using modification procedure **more or less form** is

B' = 0.3/1 + 0.75/2+ 1/3 + 1/4.

Chapter 4

Algorithm for Radiation Fog Prediction

4.1 Using Zadeh's Approximate Reasoning

Expert System for Radiation Fog prediction can be developed by using Zadeh's Approximate Reasoning(as explained in **chapter 3**). As we know to develop a Expert system, Knowledge of Experts is needed. Knowledge of experts of Radiation Fog are described in terms of the IF-THEN rules. This Algorithm takes input from sensor(five parameter value) and get the conclusion or takes the decision by using CRI.

CRI(Compositional Rule of Inference).
The consequence B' is deduced from IF-THEN rule and the Fact ,by taking the $\max - \min$ composition $\circ$ of the fuzzy set A' and the fuzzy relation $A \rightarrow B$ obtained from the fuzzy implication "IF A THEN B" that means ,we get,

$$B' = A' \circ (A \rightarrow B).$$

$$\mu_{B'}(v) = \vee_u \{\mu_{A'} \wedge \mu_{A \rightarrow B}\}$$

Algorithm $(rules, fuzzyvalues, sensorinput)$

$input : rules, fuzzyvalues, sensorinput(fiveparameters)$

$output : conclusion$

begin

1. *Read the Rules and corresponding fuzzy values.*
2. *Read the input sensor values and fuzzify the input data(using triangulation).*
3. *let the five parameters after fuzzification* A', B', C', D', E'.
4. *for each rule i*
5. *do*
   - *let the primary fuzzy sets of five parameters antecedents of a rule i are* A_i, B_i, C_i, D_i, E_i *and consequent* F_i.
   - *apply CRI on* A_i, F_i, A' *to get conclusion ,let it be* C_{A_i}
   - *similarly apply CRI on corresponding input data and primary fuzzy sets to get conclusion, let it* C_{B_i},C_{C_i},C_{D_i},C_{E_i}
   - $F_i' = C_{A_i} \cap C_{B_i} \cap C_{C_i} \cap C_{D_i} \cap C_{E_i} \qquad (a \wedge b) \rightarrow c\, is\, eqiv.\, to (a \rightarrow c) \wedge (b \rightarrow c)$
6. $F' = F_1' \cup F_2' \cup \cup \ldots \cup F_n'$.

end

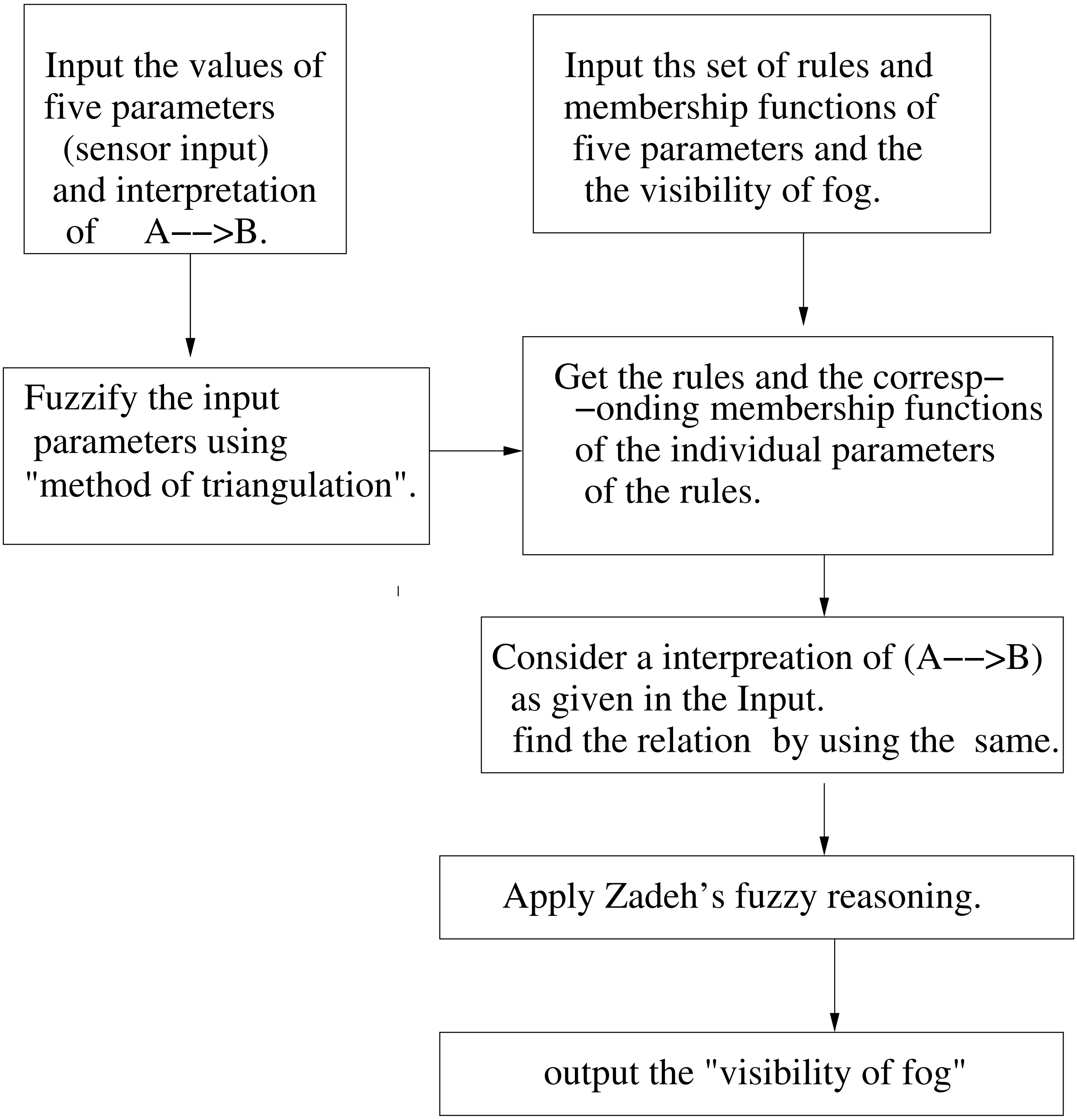

fig 3.1 Schematic representation of radiation fog prediction by using zadeh's method.

4.2 Using Similarity-Based Reasoning

Expert System for Radiation Fog prediction can be developed by using Similarity-Based Reasoning(as explained in **chapter 3**).As we know to develop a Expert system, Knowledge of Experts is needed. Knowledge of experts of Radiation Fog are described in terms of the IF-THEN rules.
This Algorithm takes input from sensor(five parameter value) and get the conclusion or takes the decision by finding the similarity between antecedent and fact.
let the five parameters similarity values with correspanding sensor data are S_A,S_B,S_C,S_D,S_E we have taken a weighted sum to find which rule is almost matching to the given fact(sensor data).

S =W_A*S_A+W_B*S_B+ W_C*S_C+W_D*S_D+W_E*S_E

W_A, W_B, W_C, W_D, W_E weights associated with antecedent of a rule.
generally $W_A = W_B = W_C = W_D = W_E = 1$.

Algorithm $(rules, fuzzyvalues, sensorinput)$
$input : rules, fuzzyvalues, sensorinput(fiveparameters)$
$output : conclusion$

begin

1. *Read the Rules and corresponding fuzzy values.*
2. *Read the input sensor values and fuzzify the input data(using triangulation).*
3. *let the five parameters after fuzzification* A', B', C', D', E'.
4. *for each rule i*
5. *do*
   - *let the primary fuzzy sets of five parameters antecedents of a rule i are* A_i, B_i, C_i, D_i, E_i *and consequent* F_i.
   - *Find the similarity between* A_i, A' *,let it be* S_{A_i}*(by using some similarity measure)*
   - *similarly find similarity between corresponding input data and primary fuzzy sets , let those are* S_{B_i},S_{C_i},S_{D_i},S_{E_i}
   - *overall similarity of rule i is* $S_i = S_{A_i} + S_{B_i} + S_{C_i} + S_{D_i} + S_{E_i}$
6. *select a rule x at which* S_i *is maximum.*
7. *apply modifaction-procedure on rule x to get a conclusion*

end

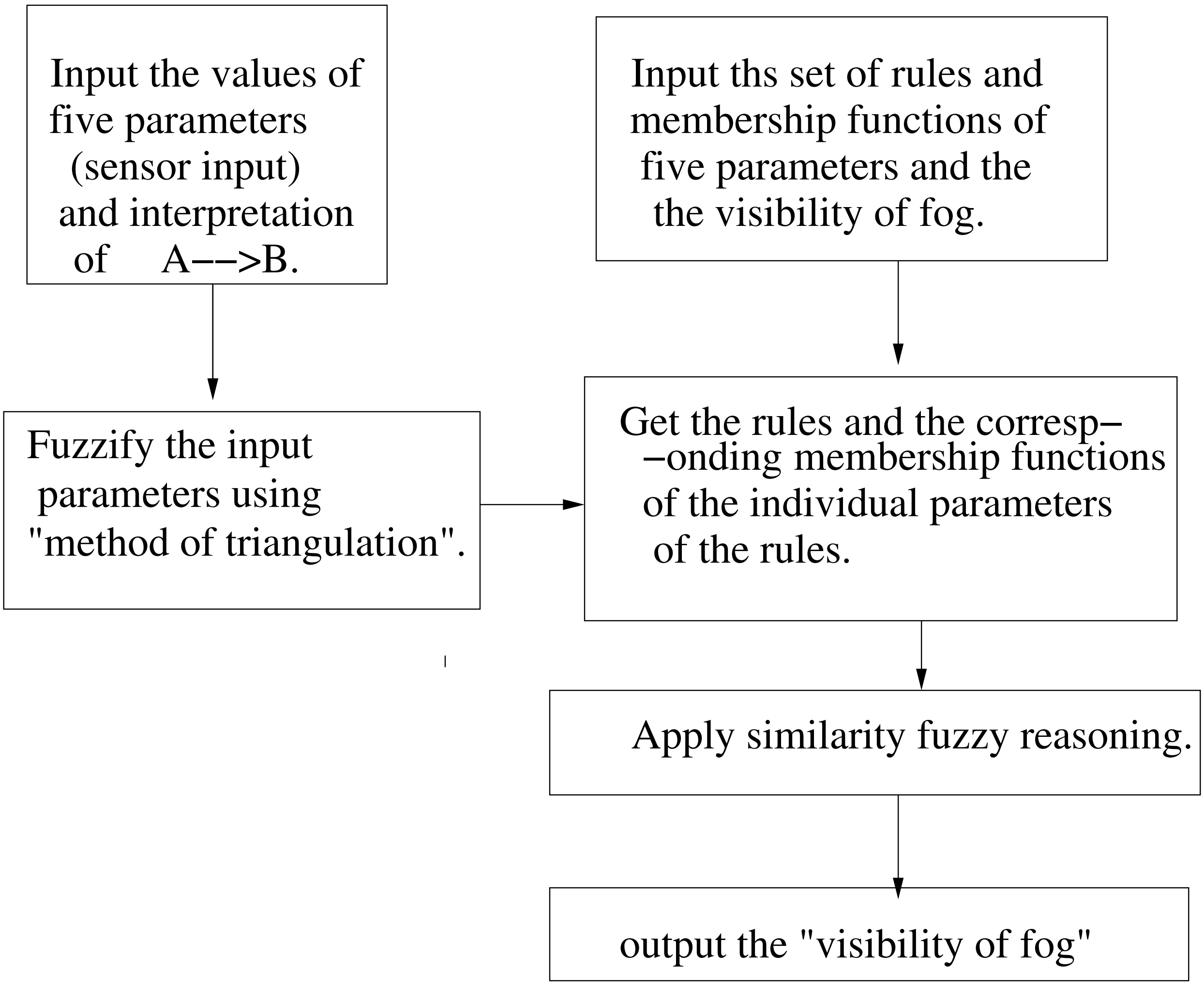

fig 3.2 Schematic representation of radiation fog prediction by using similarity-based method.

4.3 Combined Method

For a given fact, to find which rule to fire from a set of rules it uses Similarity-Based Reasoning and to get the conclusion it uses Zadeh's CRI.

Chapter 5

Results And Discussion

Radiation Fog Prediction system using Zadeh's approximate reasoning:

INPUTDATA :SENSOR DATA	
DEW POINT	25.0
DEW POINT SPREAD	-4.0
RATE OF CHANGE OF DEWPOINT SPREAD	-2.0
WIND SPEED	7.0
SKY CONDITION	10.1%

and the rules,primary fuzzy values(as described in **chapter 3**)OUTPUT of a expert system.

fuzzification of Sensordata(triangular).......

Dewpoint value
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.5 1.0
DewpointSpread value
0.0 0.0 0.0 0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0
RateofChangeSpread value
0.0 0.0 0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0
WindSpeed value 0.0 0.0 0.0 0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0
SkyCondition value
0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0

(after applying sensordata on all rules) in **Table 5.1-5.3**.

conclusion from rule : 1	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 2	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 3	0.5 0.7 0.9 1.0 1.0
conclusion from rule : 4	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 5	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 6	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 7	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 8	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 9	0.5 0.7 0.9 1.0 1.0
conclusion from rule : 10	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 11	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 12	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 13	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 14	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 15	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 16	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 17	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 18	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 19	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 20	0.5 0.7 0.9 1.0 0.9
conclusion from rule : 21	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 22	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 23	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 24	0.3 0.5 0.6 0.8 1.0
conclusion from rule : 25	0.3 0.5 0.6 0.8 1.0
conclusion from rule : 26	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 27	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 28	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 29	0.5 0.7 0.9 1.0 0.9
conclusion from rule : 30	0.5 0.7 0.9 1.0 0.9
conclusion from rule : 31	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 32	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 33	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 34	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 35	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 36	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 37	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 38	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 39	0.7 0.9 1.0 1.0 1.0
conclusion from rule : 40	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 41	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 42	0.3 0.5 0.6 0.8 1.0
conclusion from rule : 43	0.3 0.5 0.6 0.8 1.0
conclusion from rule : 44	0.5 0.6 0.8 1.0 1.0
conclusion from rule : 45	0.9 1.0 1.0 1.0 1.0
conclusion from rule : 46	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 47	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 48	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 49	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 50	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 51	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 52	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 53	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 54	0.5 0.6 0.8 1.0 1.0
conclusion from rule : 55	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 56	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 57	0.7 0.9 1.0 1.0 1.0
conclusion from rule : 58	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 59	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 60	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 61	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 62	0.5 0.6 0.8 1.0 1.0
conclusion from rule : 63	0.5 0.7 0.9 1.0 1.0
conclusion from rule : 64	0.8 1.0 0.8 0.6 0.5
conclusion from rule : 65	0.8 1.0 1.0 1.0 0.8
conclusion from rule : 66	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 67	1.0 0.8 0.6 0.5 0.3
conclusion from rule : 68	0.8 1.0 0.8 0.6 0.5
conclusion from rule : 69	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 70	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 71	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 72	0.6 0.8 1.0 1.0 1.0

Table 5.1: Conclusion from zadeh's reasoning

conclusion from rule : 73	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 74	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 75	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 76	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 77	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 78	0.3 0.5 0.6 0.8 1.0
conclusion from rule : 79	0.3 0.5 0.6 0.8 1.0
conclusion from rule : 80	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 81	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 82	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 83	0.5 0.7 0.9 1.0 0.9
conclusion from rule : 84	0.5 0.7 0.9 1.0 0.9
conclusion from rule : 85	0.8 1.0 0.8 0.6 0.5
conclusion from rule : 86	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 87	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 88	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 89	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 90	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 91	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 92	0.5 0.6 0.8 1.0 1.0
conclusion from rule : 93	0.5 0.7 0.9 1.0 1.0
conclusion from rule : 94	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 95	0.3 0.5 0.6 0.8 1.0
conclusion from rule : 96	0.3 0.5 0.6 0.8 1.0
conclusion from rule : 97	0.3 0.5 0.6 0.8 1.0
conclusion from rule : 98	0.5 0.6 0.8 1.0 1.0
conclusion from rule : 99	0.8 1.0 1.0 1.0 1.0
conclusion from rule : 100	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 101	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 102	0.5 0.6 0.8 1.0 1.0
conclusion from rule : 103	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 104	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 105	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 106	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 107	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 108	0.5 0.6 0.8 1.0 1.0
conclusion from rule : 109	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 110	0.8 1.0 1.0 1.0 0.8
conclusion from rule : 111	0.7 0.9 1.0 1.0 1.0
conclusion from rule : 112	0.8 1.0 0.8 0.6 0.5
conclusion from rule : 113	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 114	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 115	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 116	0.8 1.0 1.0 1.0 0.8
conclusion from rule : 117	0.7 0.9 1.0 1.0 1.0
conclusion from rule : 118	1.0 0.8 0.6 0.5 0.3
conclusion from rule : 119	1.0 1.0 1.0 0.8 0.6
conclusion from rule : 120	0.8 1.0 1.0 1.0 0.8
conclusion from rule : 121	1.0 0.8 0.6 0.5 0.3
conclusion from rule : 122	1.0 0.8 0.6 0.5 0.3
conclusion from rule : 123	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 124	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 125	0.8 1.0 1.0 1.0 0.8
conclusion from rule : 126	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 127	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 128	0.5 0.7 0.9 1.0 0.9
conclusion from rule : 129	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 130	0.8 1.0 0.8 0.6 0.5
conclusion from rule : 131	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 132	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 133	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 134	0.5 0.7 0.9 1.0 0.9
conclusion from rule : 135	0.4 0.5 0.7 0.9 1.0
conclusion from rule : 136	0.8 1.0 0.8 0.6 0.5
conclusion from rule : 137	0.7 0.9 1.0 0.9 0.7
conclusion from rule : 138	0.5 0.7 0.9 1.0 0.9
conclusion from rule : 139	1.0 0.8 0.6 0.5 0.3
conclusion from rule : 140	0.8 1.0 0.8 0.6 0.5
conclusion from rule : 141	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 142	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 143	0.5 0.7 0.9 1.0 0.9
conclusion from rule : 144	0.5 0.7 0.9 1.0 0.9

Table 5.2: Conclusion from zadeh's reasoning (contd..)

conclusion from rule : 145	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 146	0.5 0.6 0.8 1.0 1.0
conclusion from rule : 147	0.5 0.7 0.9 1.0 1.0
conclusion from rule : 148	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 149	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 150	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 151	0.5 0.6 0.8 1.0 0.8
conclusion from rule : 152	0.5 0.6 0.8 1.0 1.0
conclusion from rule : 153	0.5 0.7 0.9 1.0 1.0
conclusion from rule : 154	0.8 1.0 0.8 0.6 0.5
conclusion from rule : 155	0.8 1.0 1.0 1.0 0.8
conclusion from rule : 156	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 157	0.8 1.0 0.8 0.6 0.5
conclusion from rule : 158	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 159	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 160	0.6 0.8 1.0 0.8 0.6
conclusion from rule : 161	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 162	0.6 0.8 1.0 1.0 1.0
conclusion from rule : 163	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 164	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 165	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 166	0.5 0.7 1.0 0.7 0.5
conclusion from rule : 167	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 168	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 169	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 170	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 171	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 172	0.7 1.0 0.7 0.5 0.4
conclusion from rule : 173	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 174	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 175	1.0 0.7 0.5 0.4 0.2
conclusion from rule : 176	0.7 1.0 0.7 0.5 0.4
conclusion from rule : 177	0.5 0.7 1.0 0.7 0.5
conclusion from rule : 178	0.5 0.7 1.0 0.7 0.5
conclusion from rule : 179	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 180	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 181	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 182	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 183	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 184	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 185	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 186	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 187	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 188	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 189	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 190	0.5 0.7 1.0 0.7 0.5
conclusion from rule : 191	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 192	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 193	1.0 0.7 0.5 0.4 0.2
conclusion from rule : 194	0.5 0.7 1.0 0.7 0.5
conclusion from rule : 195	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 196	0.5 0.7 1.0 0.7 0.5
conclusion from rule : 197	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 198	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 199	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 200	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 201	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 202	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 203	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 204	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 205	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 206	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 207	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 208	0.5 0.7 1.0 0.7 0.5
conclusion from rule : 209	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 210	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 211	0.5 0.7 1.0 0.7 0.5
conclusion from rule : 212	0.5 0.7 1.0 0.7 0.5
conclusion from rule : 213	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 214	0.4 0.5 0.7 1.0 0.7
conclusion from rule : 215	0.2 0.4 0.5 0.7 1.0
conclusion from rule : 216	0.2 0.4 0.5 0.7 1.0
final conclusion :	1.0 1.0 1.0 1.0 1.0

Table 5.3: Conclusion from zadeh's reasoning (contd..)

final conclusion it is giving output as 1.0 1.0 1.0 1.0 1.0

now the expert system cannot make any decision because the visibility may be any thing(verylow to veryhigh).

Expert System for Radiation Fog prediction by using similarity reasoning

INPUTDATA :SENSOR DATA

DEW POINT	25.0
DEW POINT SPREAD	-4.0
RATE OF CHANGE OF DEWPOINT SPREAD	-2.0
WIND SPEED	7.0
SKY CONDITION	10.1%

and the rules,primary fuzzy values(as described in **chapter 3**)
OUTPUT of a expert system

fuzzification of Sensordata(triangular).......

Dewpoint value
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.5 1.0
DewpointSpread value
0.0 0.0 0.0 0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0
RateofChangeSpread value
0.0 0.0 0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0
WindSpeed value 0.0 0.0 0.0 0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0
SkyCondition value
0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0
rule to fire is 193.
conclusion:
1.0 0.7 0.5 0.3 0.1
Visibility is VERY LOW.
for the same input Zadeh's reasoning method fails to give the conclusion where as Similarity-Based method giving correct conclusion.

Expert System for Radiation Fog using Combined Method

INPUTDATA :SENSOR DATA

DEW POINT 25.0

DEW POINT SPREAD -4.0

RATE OF CHANGE OF DEWPOINT SPREAD -2.0

WIND SPEED 7.0

SKY CONDITION 10.1%

and the rules,primary fuzzy values(as described in **chapter 3**)

OUTPUT of a expert system

fuzzification of Sensordata(triangular).......

Dewpoint value

0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.5 1.0

DewpointSpread value

0.0 0.0 0.0 0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0

RateofChangeSpread value

0.0 0.0 0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0

WindSpeed value 0.0 0.0 0.0 0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0

SkyCondition value

0.5 1.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0

rule to fire is 193.

conclusion:

1.0 0.7 0.5 0.4 0.2

Visibility is VERY LOW.

$Methodname$	$Conclusionfuzzyvalue$	$Defuzzifiedconclusion$
$Zadeh's$	1.0 1.0 1.0 1.0 1.0	can't say
$SimilarityReasoning$	1.0 0.7 0.5 0.3 0.1	VERY LOW
$COMBINED-METHOD$	1.0 0.7 0.5 0.4 0.2	VERY LOW

Table 5.4: comparison of methods for same input.

Chapter 6

Conclusion

To build a Radiation Fog Prediction Expert System,First we developed a Fuzzy rule based approach.We applied Zadeh's fuzzy reasoning for deductive or decision process,we applied Similarity-Based reasoning for the same.And combined both methods ,we compared these both results and found that similarity-based reasoning is the best suitable method for this application.

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