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Forecasting of Fog by using Fuzzy Interference Systems

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Abstract- In this study the method of fuzzy interference systems are used to evaluate fog forecasting. Input variables used in this study included the situation of fog parameters dew point, dew point spread, rate of change of dew point spread wind speed and sky coverage. The membership functions are generally trapezoids, although simpler functions such as triangles and rectangles and even delta functions are often used. The degrees of membership of the system inputs are also examined. The strength of a rule has been derived from the corresponding degrees of membership of the system inputs. Only 16 rules of the entire set of 144 would have non-zero values, or strengths. The techniques indicate some preliminary results using real data. The final system output is then calculated as the weighted average of the centroid of each membership function with the area of the enclosed set used as the weighting factor. These centroids and weighting areas of the current values were calculated to find the forecasting of fog. The result of this study would hopefully help the planners and program managers to take necessary actions and to development air, marine, and road traffic etc.

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FORECASTING OF FOG BY USING FUZZY INTERFERENCE SYSTEMS

Ref

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I. Introduction

Fog forecasting is one of the most important and demanding operational responsibilities carried out by meteorological services worldwide. It is a difficult process that includes numerous specialized technological fields. Fog is a type of weather phenomenon that reduces the atmospheric horizontal visibility to below 1 km due to the suspending of ice or water droplets in the atmosphere near the surface [1]. Fog is an observable aerosol consisting of little water droplets or ice crystals floating in the air at or near the Earth's surface. It can be considered a type of low-lying cloud generally similar to stratus, and is seriously influenced by nearby bodies of water, topography and wind conditions. In turn, fog has affected many human activities, such as shipping, travel, aircraft communication and warfare [2]. The effect of fog on human life was recognized in the early ages of mankind but its impact has significantly increased during recent decades due to increasing air, marine, and road traffic. In fact, the financial and human losses connected to fog and low visibility became similar to the losses from other weather events, e.g., tornadoes or, in some situations, even hurricanes. Moreover, when the fog contains heavy pollutants, it is also harmful to human health [3].

Recently, many studies revealed that when stern fog formed, it generally showed obvious volatile features, including sudden surge of fog drop number density, obvious increase in the fog drop scale and water content, sharp plunge of visibility from several hundred meters to below 50 meters, and fast changing from heavy fog to severe fog

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within a very short time period (about 30 min) [4]. With the improvement of temporal resolution of droplet spectrometer, [5] analyzed microphysics processes and macroscopic situation of fog droplet spectrum widening. He pointed out that the former stage of fog droplet spectrum widening mainly occupied nucleation and condensation processes, while the latter stage mainly involved coagulation and concentration processes. Turbulence not only plays a significant role in heat, momentum, and moisture vertical transfers but also is the necessary condition for coagulation and increase of fog droplet. Radioactive cooling alone cannot produce large fog droplets, while greater super saturation and turbulence can promote the formation of large droplets [6]. Although fog and haze are different weather phenomena, their formations have similarity. They all form under breeze, high humidity, and static stability condition [7]. The haze aerosols can be transformed to fog droplets under certain conditions [8]. With the increasingly heavy traffic, there has been a recent increase in demand for accurate fog forecasting. However, fog forecasting is currently still challenging. Current performance of fog forecasting is much lower than that of precipitation forecasting from the same operational prediction systems at the national centers for environmental prediction [9]. Beside model resolutions, fog forecasting has also shown to be highly sensitive to initial conditions [10]. With the rapid 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 [11]. One such method is called fuzzy logic. Fuzzy logic is a simple yet powerful problem solving technique with widespread capabilities. 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 [12].

There are many weather forecasting difficulties that fit the previous description where precise, analytical solutions do not exist. How precise the culturally built original climate knowledge of extreme climatic events is, and how acquiescent it is to fuzzy logic [13]. Fuzzy set theory is a tool for modeling the kind of uncertainty associated with ambiguity, feeling and/or with a lack of information regarding particular element of the problem in hand [14]. Developed fuzzy logic model is made up of two functional components; the knowledge base and the fuzzy reasoning or decision making unit [15]. Fuzzy inference is the actual procedure of mapping with a given set of input and output through a set of fuzzy systems [16]. Two operations were performed on the fuzzy logic model; the fuzzification operation and defuzzification operation. Fuzzy logic based forecasting method by using the Mamdani fuzzy inference system may be successively used for different environmental problem assessment to moderate unexpected meteorological problems [17]. Hence the study is based on the application of Mamdani fuzzy inference system in one of the meteorological procedure, which is fog in order to get forecasting of the region. The aim of this study is to develop a fuzzified model for fog forecast and explores the use of fuzzy logic in fog forecasting.

II. Methodology

Fuzzy logic is a methodology to delicacy uncertainty in systems whose variables are rather qualitative, imprecise or ambiguous. Over the past few years, this methodology has been increasingly adopted as a constructive technique in a variety of environmental issues but has restricted applications in weather prediction. The appropriateness of fog occurrence for conduct with fuzzy logic has been tested with hopeful results [18, 19]. More recently, a fuzzy logic is system for the analysis and prediction of cloud ceiling and visibility [20]. Also reports on the use of such a

Ref

5. Z. Li, J. Yang, C. Shi and M. Pu, Urbanization effects on fog in china: field research and modeling, *Pure and Applied Geophysics*, 2012, 169(5):927–939.

forecasting system to forecast ceiling and visibility and concludes that the fuzzy system outperforms persistence-based forecasts [21]. Fuzzy sets are the collection of objects with the same properties, and in crisp sets the objects either belong to the set or do not. In practice, the characteristic value for an object belonging to the considered set is coded as 1 and if it is outside the set then the coding is 0. In crisp sets, there is no ambiguity or vagueness about each object belongs to the considered set. So uncertainty always arises concerning the assessment of membership values 0 or 1. In order to assuage such situations generalized the crisp set membership degree as having any value continuously between 0 and 1 [22]. An object with membership function 1 belongs to the set with no doubt and those with 0 membership functions again absolutely do not belong to the set, but objects with transitional membership functions partially belong to the same set. Fuzzy set theory has been examined in hydrological modeling such as fog forecasting, inflow prediction and reservoir operation. Several reservoir operation techniques based on fuzzy systems and fuzzy control systems for reservoir operations can be found in the literature along with the use of genetic algorithms. These models include fuzzy optimization techniques, fuzzy rule based systems and hybrid fuzzy systems. In these models, fuzzy rules were created using expert knowledge or observed data. In fuzzy logic, values of variables are expressed by linguistic terms, the relationship is defined in terms of IF-THEN rules and the outputs are also fuzzy subsets which can be made crisp using defuzzification techniques [23]. Finally, it is expected that the findings of the study will support fog observing and the outcomes will demonstrate weather forecasting in the future.

Ref

21. B. K. Hansen, Analog forecasting of ceiling and visibility using fuzzy sets, 2nd Conference on Artificial Intelligence, *American Meteorological Society*, 2000, 1–7.

III. Fuzzy Set

Let X be a universal set. Then A is called a (fuzzy) subset of X if A is a set of ordered pairs.

$$A = \{(x, \mu_A(x)) : x \in X, \mu_A(x) \in [0,1]\}$$

where μ_A is the membership function of A and $\mu_A(x)$ is the grade of the membership of x in A.

The linguistic expression for the variables and their membership functions are evaluated from the following triangular membership functions and it is defined by a lower limit a, an upper limit b and a value m, where $a \le m \le b$. The value of the membership function $\mu(x)$, ranges from 0 to 1, with 0 denoting no membership, 1 for full membership and values in between has partial membership as shown in figure 1.

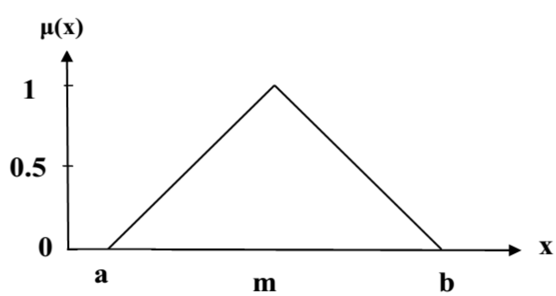

Figure 1: Basic graph of Fuzzy membership function

The methodology employed is referred to as the centre-of-gravity method of trapezoidal diagram in which the area of all applicable output sets, limited in height by the applied rule strength, are evaluated and a weighted mean value of the output is calculated.

Therefore the fog forecasting $= \frac{\sum C_i A_i}{\sum A_i}$, where $C_i =$ weighted average of the centroid of each membership function and $A_i =$ area of the trapezium enclosed set used as the weighting factor.

Notes

IV. Fuzzy Interference Systems

The fuzzy inference system is an important part of the fuzzy logic system. Decision-making is the main work of it performs. It makes use of the rules of IF and THEN along with the AND and OR connectors which represent some essential rules for decision making. It is a framework which depicts the actual procedure of converting an input into an output using fuzzy logic. Fuzzification, defuzzification, membership function are the building blocks of fuzzy inference system. Employing fuzzy IF-THEN rules to express input–output relationships and model the qualitative inputs and logic procedure for creating the output. The fuzzy inference systems include a set of precursor and consequential fuzzy membership functions as well as a set of Fuzzy IF–THEN rules which considered a firm basis for developing the core of any system which strength be used for making decisions in vague and inaccurate situations. A fuzzy inference system is impersonating human intelligence for quantify the ambiguity in real world situation through proper modeling of the fuzziness of real world data by suitable rule bases. 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 which is discussed below. One rule could be stated:

IF (dry AND unsaturated AND drying AND light AND cloudy) THEN (low probability of fog).

The rules must be constructed for each system and must rely on the experience of the forecaster. The total number of rules is the product of the number of fuzzy sets characterizes the system.

V. Fuzzy Systems Input

The meteorological observable fact select here to reveal this method is that of the occurrence of fog. Several techniques have been developed and used over the years to assist in the forecasting of the beginning of the fog. Although no analytic method has yet been discovered, the basic physical principles involved in fog forecasting are thought to be well understood. Perspective of the current model of fog forecasting, 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 substantial variables that are thought to completely determine the solution to the problem, or system outputs. In the current model the system output is the probability of the occurrence of fog within the next (approximately) six hours. System inputs to be used in this study are the situation of fog parameters dew point, dew point spread, rate of change of the dew point spread, wind speed and sky coverage. These system inputs are readily available, and their values are naturally measured when a forecaster decides if or when fog will develop. It is understood that there are other substantial variables that forecasters may judge important in the formation of fog. Fuzzy inference is the actual procedure of mapping with a given set of input and output through a set of fuzzy systems. The system inputs are categorized into actually significant domains called fuzzy sets. Fuzzy sets are simply qualitative descriptions of the selected domains of the inputs, each of which is thought to have a specific effect on the output. Table 1 show the fog parameters which used in this study.

Table 1: Situation of fog parameters

Dew Point	Dew Point Spread (DPS)	Rate of change of the DPS	Wind Speed	Sky
Dry	Very Saturated	Drying	Light	Cloudy
Moderate	Saturated	Saturating	Excellent	Clear
Moist	Unsaturated		Strong	
Very Moist				

The interpretation of the qualitative description of these fuzzy sets, and the substantial effect on the probability of occurrence of fog should be apparent. Dew point is closely associated to relative humidity, which is the ratio of the pressure of water vapor in a parcel of air relative to the saturation pressure of water vapor in that same parcel of air at a specific temperature. Relative humidity is expressed as a percentage. The value of the current dew point is categorized into one of four fuzzy sets: dry, moderate, moist and very moist. Similarly, the value of the dew point spread is described as unsaturated, saturated or very saturated. The rate of change of the dew point spread (ﬂC/hour) is only characterized by one of two categories, whether the atmosphere is drying (a positive rate) or shows a saturating trend (a negative rate). The wind speed effect upon the probability of fog formation is described as either strong or excellent or light, whose are unfavorable conditions, or being in the range that is favorable for fog formation. Similarly the sky conditions are classified into either cloudy or clear. The determination of the fuzzy sets is derived solely from experience. A developer of a fuzzy system must sensibly decide these categories such that logical systems outputs will be obtained. The fuzzy sets are quantitatively defined by membership functions. These functions are typically very simple functions that cover a specified domain of the value of the system input. The functions are generally trapezoids, although simpler functions such as triangles and rectangles and even delta functions are often used. The fuzzy sets of the fog parameters in this study are shown in Figures 2 through 6.

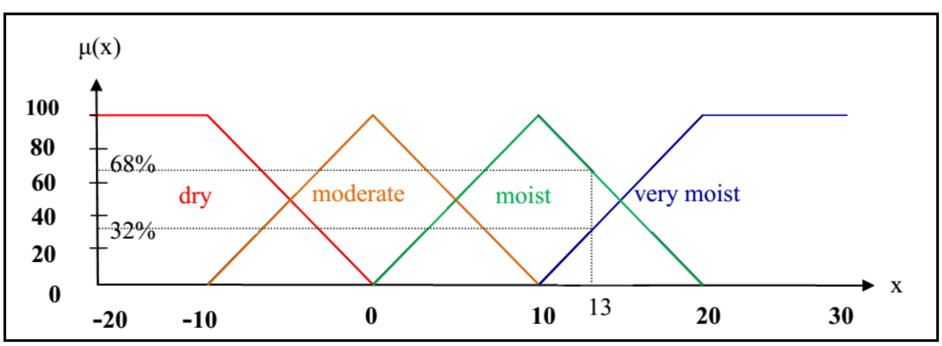

Figure 2: Graph of the membership function of dew point and corresponding fuzzy levels (dry, moderate, moist, very moist)

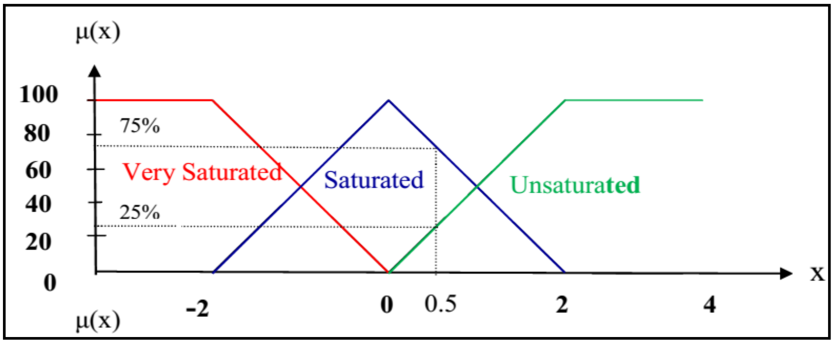

Figure 3: Graph of the membership function of dew point spread and corresponding fuzzy levels (very saturated, saturated, unsaturated)

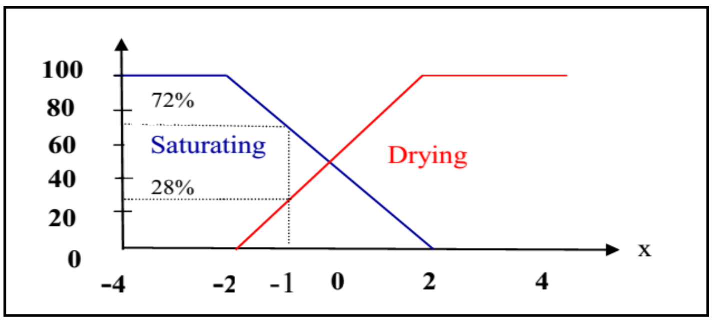

Figure 4: Graph of the membership function of the rate of change dew point spread and corresponding fuzzy levels (saturating and drying)

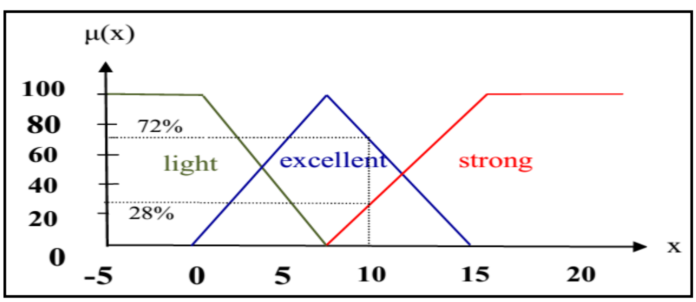

Figure 5: Graph of the membership function of wind speed and corresponding fuzzy levels (light, excellent and strong)

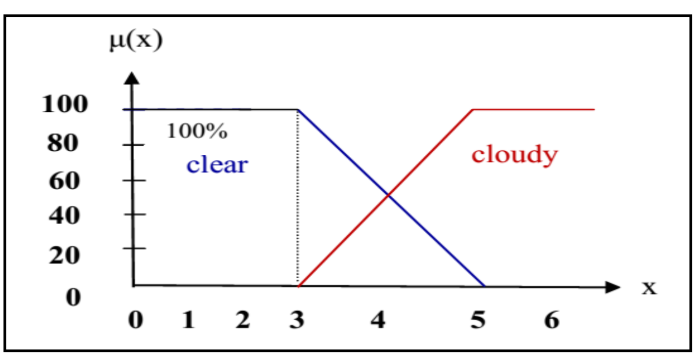

Figure 6: Graph of the membership function of sky condition and corresponding fuzzy levels (clear, cloudy)

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Each value of system input will belong to at least one fuzzy set and more than one fuzzy set. This is possible because during construction the adjacent fuzzy sets are made to overlap. A rule of thumb is to ensure that the sets overlap by approximately 25 percent. This is the foundation of the technique of fuzzy logic. Dew point value as indicated of 13ºC is seen to be both a member of the moist and the very moist sets in Figure 2. The membership function associated with each fuzzy set provides a quantitative value of the degree of membership of the input into each fuzzy set. In Figure 2 a value of 13ﬂC is a 32% member of the moist set, a 68% member of the very moist set. Otherwise dew point spread value surround 0.5ºC is seen to be both a member of the saturated and unsaturated sets. In Figure 3, the value of 0.5ºC is 75% member of the saturated set and 25% member of the unsaturated set. Whereas the rate of change of dew point spread value contains -1ºC/hour is a show to be both a member of the saturating and drying sets. In Figure 4, the value of -1ºC/hour is 72% member of the saturating set and 28% member of the drying set. Similarly, the wind speed value indicated 10 kts is a demonstrated to be a member of the light, excellent and strong sets. In Figure 5, the value of 10 kts is 72% member of the excellent set and 28% member of the strong set. The sky condition value indicated 3 oktas is to be a member of the clear and cloudy sets. In Figure 6, the value of 3 oktas is 100% member of the clear set and 0% member of the cloudy set.

The degrees of membership of the system inputs are evaluated as discussed above. The determination of the system outputs (probability of fog formation) follows from the evaluation of a set of predefined rules. The strength of a rule is derived from the corresponding degrees of membership of the system inputs. Since an input can be member of multiple fuzzy sets, then different rules involving these sets can be applied. The higher degrees of membership result in corresponding rules which have more strength in the final estimated procedure. In other words, the number of rules equals all possible permutations of categorized system inputs. Here there are four sets associated with the dew point, three with the dew point spread, two with the rate of change of the spread, three with the wind speed and two with the sky condition. The total number of rules that completely define the set then is 4x3x2x3x2=144. It is easy to see how the number of rules rapidly expands with each system input and related fuzzy sets. 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 sets. More than one rule can lead to the same consequence. In this case, the rule with the highest strength is used.

VI. System Outputs

The system outputs are also defined by membership functions similar to the inputs. The sets for the present pattern are given in Figure 7.

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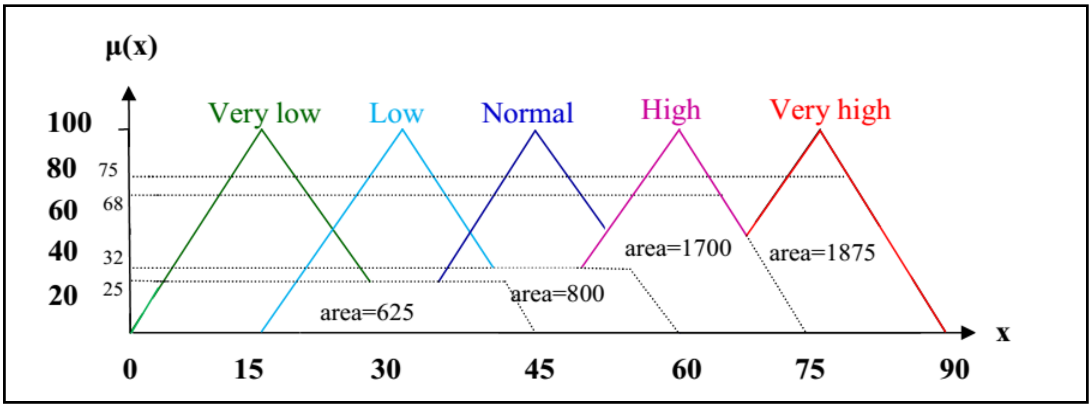

Figure 7: Graph of output membership function of the probability of fog formation

The output membership functions assist in determining a final value of the system output. The procedure is basically the inverse of the evaluation of the degrees of membership. The methodology in use is referred to as the centre-of-gravity method of trapezoidal diagram in which the area of all appropriate output sets, limited in height by the useful rule strength, are evaluated and a weighted mean value of the output is calculated.

VII. Results

In this section will demonstrate an explicit case of the technique as well as indicate some preliminary results using real data. It is indicate the procedure as applied to the current forecast of the probability of fog. The membership assignment above: the dew point, dew point spread, rate of change of the dew point spread and wind speed each involve two fuzzy sets while the sky coverage only involves one set $(2\times2\times2\times2\times1)=1$. There are only 16 rules of the entire set of 144 will have non-zero values, or strengths. The antecedents of all applicable rules along with the predefined corresponding output sets are:

1. IF (moist AND unsaturated AND drying AND strong AND clear) THEN (low probability of fog)
2. IF (moist AND unsaturated AND drying AND excellent AND clear) THEN (medium probability of fog)
3. IF (moist AND unsaturated AND saturating AND strong AND clear) THEN (medium probability of fog)
4. IF (moist AND unsaturated AND saturating AND excellent AND clear) THEN (high probability of fog)
5. IF (moist AND saturated AND drying AND strong AND clear) THEN (medium probability of fog)
6. IF (moist AND saturated AND drying AND excellent AND clear) THEN (very high probability of fog)
7. IF (moist AND saturated AND saturating AND strong AND clear) THEN (very high probability of fog)
8. IF (very moist AND saturated AND saturating AND excellent AND clear) THEN (very high probability of fog)
9. IF (very moist AND unsaturated AND drying AND strong AND clear) THEN (low probability of fog)

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10. IF (very moist AND unsaturated AND drying AND excellent AND clear) THEN (low probability of fog)
11. IF (very moist AND unsaturated AND saturating AND strong AND clear) THEN (low probability of fog)
12. IF (very moist AND unsaturated AND saturating AND excellent AND clear) THEN (medium probability of fog)
13. IF (very moist AND saturated AND drying AND strong AND clear) THEN (low probability of fog)
14. IF (very moist AND saturated AND drying AND excellent AND clear) THEN (high probability of fog)
15. IF (very moist AND saturated AND saturating AND strong AND clear) THEN (very high probability of fog)
16. IF (very moist AND saturated AND saturating AND excellent AND clear) THEN (very high probability of fog)

Determine the rule strengths are the value of its weakest or least valued antecedent. In the first applicable rule above the value of its antecedents are, in order: 68% (moist dew point), 25% (saturated spread), 28% (drying rate), 28% (excellent wind speed) and 100% (clear sky). The rule strength is then 25. In a similar way, the other rule strengths are evaluated and are listed below

Table 2: Rule Strengths in the current value

Rule	Value	Rule	Value
(i)	25	(ix)	25
(ii)	25	(x)	25
(iii)	25	(xi)	25
(iv)	25	(xii)	25
(v)	28	(xiii)	28
(vi)	28	(xiv)	28
(vii)	28	(xv)	28
(viii)	68	(xvi)	32

This is the applicable rules of the system output for probability of fog formation. The several sets of rules above share the same consequence, or system output. The value of the output is assigned the value of the ”most true”, or strongest, rule. To illustrate, rules one and two above have as their consequence a low probability of fog formation. Table 2 shows that rules one and two both have a strength of 25, and consequently then the limiting value associated with a low probability of fog is assigned 25. It will be seen next how this limiting value is working. Table 3 shows the values for each of the system output fuzzy sets.

Table 3: Limiting values for each of the system output fuzzy sets

Very Low	Low	Medium	High	Very High
0	25	28	32	68

Figure 7 denotes how these limiting values for each output fuzzy set are used. An individual output membership function is restricted in height by its corresponding limiting value. Then the remaining area of the membership function is calculated. The final system output is then calculated as the weighted average of the centroid of each membership function, with the area of the enclosed set used as the weighting factor. Table 4 shows centroids and weighting areas of the current values.

Table 4: Centroids and weighting areas of output fuzzy sets

Output fuzzy set	very low	low	medium	high	very high
Centroid (C_i)	15	30	45	60	75
Area (A_i)	0	625	800	1700	1875

Hence the final system output $= \frac{\sum C_i A_i}{\sum A_i} = 59.5$ which value represents the probability of fog. Finally in this study the fog forecasting is 60%.

Notes

XVII. Conclusion

In this study obtained five input variables are dew point, dew point spread, the rate of change of the dew point spread, wind speed and sky condition at a particular time and output variable is the probability of fog. These five input variables are selected because which is the main factors of the influence the occurrence of fog. Within the context of the current model of fog forecasting, general terms associated with fuzzy logic introduced. The main work that it performs is decision-making. It makes use of the rules of IF and THEN along with the AND connectors which in turn lets it draw some essential rules for decision making. It is a framework which depicts the actual process of converting an input into an output using fuzzy logic. The fuzzy sets are quantitatively defined by membership functions. These functions are typically very simple functions that cover a specified domain of the value of the system input. The functions are generally trapezoids, although simpler functions such as triangles and rectangles and even delta functions are often used. The graphs of the membership function are shown in Figures 2 to 6. The output membership functions assist in determining a final value of the system output. The methodology employed is referred to as the centre-of-gravity method of trapezoidal diagram in which the area of all applicable output sets, limited in height by the applied rule strength, are evaluated and a weighted mean value of the output is calculated. There are only 16 rules of the entire set of 144 will have non-zero values, or strengths. The technique as well as indicate some preliminary results using real data. It is indicate the procedure as applied to the current forecast of the probability of fog. In figure 6, the limiting values for each output fuzzy set are used. An individual output membership function is restricted in height by its corresponding limiting value. Then the remaining area of the membership function is calculated. The final system output is then calculated as the weighted average of the centroid of each membership function, with the area of the enclosed set used as the weighting factor (Table 4). These centroids and weighting areas of the current values are calculated to find the probability of fog. Finally, this study attempted to forecast the fog based on Situation of fog parameters and fuzzy logic.

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