Fuzzy Logic Based Implementation for Forest Fire Detection Using Wireless Sensor Network

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Abstract. The detection and prevention of forest fire is a major problem now a days. Timely detection allows the prevention units to reach the fire in its initial stage and thus reduce the risk of spreading and the harmful impact on human and animal life. Because of the inadequacy of conventional forest fire detection on real time and monitoring accuracy the Wireless Sensor Network (WSN) is introduced. This paper proposes a fuzzy logic based implementation to manage the uncertainty in forest fire detection problem. Sensor nodes are used for detecting probability of fire with variations during different time in a day. The Sensor nodes sense *temperature, humidity, light intensity,* CO_2 *density and time* and send the information to the base station. This proposed system improves the accuracy of the forest fire detection and also provides a real time based detection system as all the input variables are collected in real time basis.

Keywords: Wireless Sensor Network (WSN), Fuzzy Logic, Forest Fire Detection.

1 Introduction

Forest fire is a major problem due to the destruction of forests and generally wooden nature reserves [2]. A WSN is a group of specialized transducers and associated controller units which make up a system of wireless sensor nodes deployed in some geographical area, that autonomously monitor physical or environmental conditions and send the collected information to a main controller for certain action to be taken [1]. One major constraint of sensor nodes is limited battery power. This proposed system is self sufficient in maintaining a regular power supply that is provided by the solar systems.

This work proposes a real time forest fire detection method using fuzzy logic based implementation for Wireless Sensor Network (WSN). In this proposed

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model a number of sensor nodes are densely deployed in a forest. These sensor nodes collect the variations of temperature, humidity, light intensity, CO_2 density, in its vicinity throughout its lifetime and send to the nearby cluster head to forward aggregated data to the central sink node. Use of fuzzy logic can make real time decisions without having specific information about the event [10]. Since this technique deals with linguistic values of the controlling variables in a natural way instead of logic variables, it is highly suitable for applications with uncertainties. The sensed data is fed to the fuzzy inference engine to infer the possibility of forest fire.

The rest of the paper is organised as follows. Section 2 discusses the related works done so far in this area. A short discussion on the problem statement is given in Section 3. In Section 4 our proposed solution for forest fire detection is explained in detail. Section 5 gives a brief overview of network topology for energy efficient WSN. Section 6 evaluates the performance of the proposed model followed by a conclusion in Section 7.

2 Related Works

In [1], the authors discussed the general causes of increase in frequency of forest fires and describes the architecture of wireless sensor network and a scheme for data collection in real-time forest fire detection. The authors proposed two algorithms in [2] for forest fire detection. The proposed algorithms are based on information fusion techniques. The first algorithm uses a threshold method and the other uses Dempster- Shafer theory. Both algorithms reported false positives when the motes were exposed to direct sunlight. However, if the motes are covered to avoid direct sunlight exposure, the number of false positives may be reduced.

In [3], the authors have presented how to prevent the forest fires using wireless sensor network by the design of a system for monitoring temperature and humidity in the environment.The respective values of temperature and humidity in the presence of fire is required. Authors in [4] estimated total carbon release and carbon dioxide, carbon monoxide, and methane emissions through the analysis of fire statistics from North America and satellite data from Russia.

The authors in [5] proposed an improved approach to track forest fires and to predict the spread direction with WSNs using mobile agents.

In [6], the authors have discussed the causes of environmental degradation in the presence of forest and rural fires. The authors have developed a multi sensor scheme which detects a fire, and sends a sensor alarm through the wireless network to a central server. In [7], Zhang et al. discussed a wireless sensor network paradigm based on a ZigBee technique. Environmental parameters such as temperature, humidity, light intensity in the forest region monitored in real time. The authors in [9] have introduced a wireless sensor network paradigm for real-time forest fire detection where neural network is applied for data processing. Compared with the the traditional satellite-based detection approach the wireless sensor network can detect and forecast forest fire more promptly. In [11], the necessity of intelligent decision making (IDM) is discussed.The authors have focussed on predefined sensitivity levels that are needed to activate the necessary actions. They proposed fire detection to illustrate the IDM capability of the system. A fuzzy logic based algorithm is developed and simulated to obtain the results.

Effects of weather, terrain, fuels on fire severity and compared using remote sensing of the severity of two large fires in south-eastern Australian forests are discussed in [12]. The probability of contrasting levels of fire severity (fire confined to the understoryed vs. tree canopies consumed) was analysed using logistic regression.

The following section describes the problem before going to the proposed solution strategy.

3 Problem Statement

This paper aims to design a system for early detection of forest fires. It is very important to predict the direction in which the forest fires are going to spread as they can spread quickly[4]. Availability of air, heat and fuel are the main parameters that initiate a fire in a forest. The moisture content of the combustible material plays an important role in assessment and prediction of forest fire. The moisture content is related with relative humidity in the atmosphere, wind, temperature of the air and similar factors while relative humidity affects water evaporation. The physical properties of the combustible materials vary indirectly by air temperature. Temperature, humidity, light intensity also vary with time and weather. Hence, in this work we have assumed the parameters like temperature, humidity, light intensity, CO_2 density, time for forest fire detection using fuzzy logic based implementation.

4 Proposed Solution for Forest Fire Detection

The proposed solution for forest fire detection uses the concept of Fuzzy Logic System (FLS). The necessary steps used for detecting the probability of fire using FLS are fuzzification, fuzzy rules, fuzzy inference system and defuzzification process [8]. The steps are as follows:

Step 1: In the first step each crisp input is transformed into fuzzy input which is called **fuzzification**. The inputs measured by the sensor nodes in our proposed solution are the crisp inputs such as *temperature, humidity, light intensity,* CO_2 *density and time.* For each of the crisp inputs a specific range is defined. The main reason to choose these input variables are that the actual heat, moisture i.e humidity, light intensity and smoke i.e CO_2 density are the main parameters in a forecast of forest fire. Crisp inputs that are passed into the control system for processing have its own group of membership functions. The group of the membership functions for each FIS (Fuzzy Inference System) variable i.e the input fuzzy variables and the output fuzzy variables is defined

Table 1. Fuzzy variables

Variable	Range	Linguistic Values
Temperature	0 °C to 590 °C [12]	VeryHigh(VH),High(H),Moderate(M),Low(L)
Humidity	0 to 100 ppm [3]	High(H),Optimum(O),Low(L),Very Low(VL)
Light Intensity	0 to 10000 lux [12]	Very High(VH),High(H),Moderate(M),Low(L)
CO_2 Density	500 to 5000 ppm	High(H),Normal(N),Low(L)
Time	0 to 24 hours	Afternoon,Noon,Beforenoon
Fire Probability	0 to 100	Very High(VH),High(H),Medium(M),Low(L),Very Low(VL)

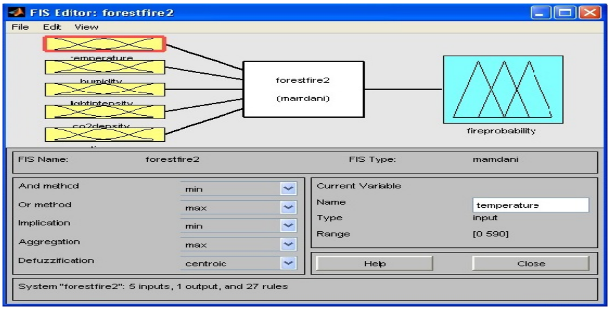

Fig. 1. FIS editor of forest fire detection

in Table 1. Each of these linguistic values represent one fuzzy set and can be defined by a membership function (MF).

Temperature, relative humidity and CO_2 density are the most important weather factors that can be used to predict and monitor fire behaviour. The danger from firebrands was lower if the ambient air temperature was below 15 °C. The corresponding temperature values in forest in the presence of fire are 100 °C - wood is dried, 230 °C - releases flammable gases, 380 °C - smoulder, 590 °C - ignite [12]. So we take the upper range of temperature value as 590 °C. There is a medium probability for a spotfire occurring when the relative humidity is below 40 percent. If the amount of CO_2 in the air of a forest is above 500ppm then only we can predict that fire has ignited [4]. The minimum and extreme light intensity in the forest when fire occurs are 500lux and 10000lux [12]. The variations in the values of these input variables in different time in day as well as seasonal variations can affect the detection process. For example the normal temperature value in the noon is much higher than the value in night. So if the sensors give same temperature value for both in day and night then it provides more information of occurrence of fire in the night. Similar situations arise for light intensity, CO_2 density. Likewise the different values of temperature in different seasons like summer, winter, spring can affect the inference system. But in this work seasons are not included.

The proposed Mamdani fuzzy inference system of forest fire detection including all input and output variables is shown in Fig. 1. The proposed membership

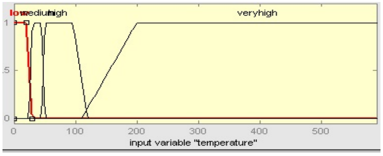

Fig. 2. Membership function for temperature

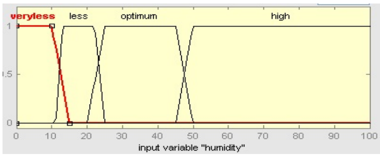

Fig. 3. Membership function for humidity

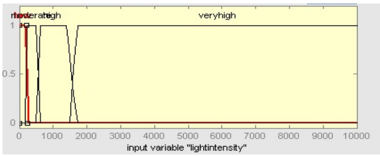

Fig. 4. Membership function for light intensity

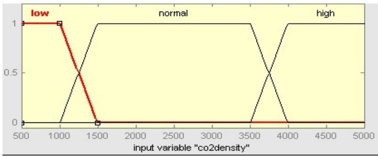

Fig. 5. Membership function for CO_2 density

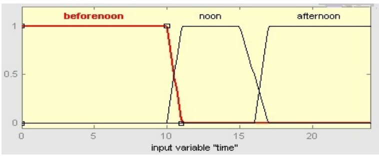

Fig. 6. Membership function for time

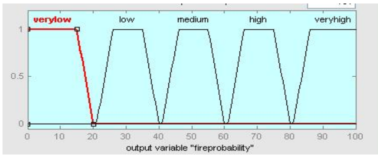

Fig. 7. Membership function for fire probability

functions for all the input and output linguistic variables are shown in figures from Fig. 2 to Fig. 7.

From Fig. 2, it is noted that if the temperature is 110 °C then the membership grade is calculated from the high and very high membership function and the rules associated with these two membership functions determines the output.

Step 2: In this step fuzzy reasoning is used to map input space to the output space. This process is called **fuzzy inference process**. The fuzzy inference process involves membership functions, logical operations and If-Then rules. Here we use Mamdani fuzzy inference method [8] for decision making. A set of fuzzy rules are defined which are a collection of linguistic statements that describe how the fuzzy inference system should make a decision regarding classifying an input or controlling an output. A series of IF-Operator-THEN rules evaluate the rule. We may assume that temperature and light intensity are very high, humidity is very low, CO_2 density is high and time is before noon. The output achieved by these assumptions is addressed to very high, i.e, for these inputs probability of fire is very high. Consequently new rules can be produced. In our proposed

Table 2. Few candidate fuzzy rules for forest fire detection

Rule#	Temp	humidity	Light	CO_2	Time	Output
1	L	H	L	L	Noon	VL
2	L	O	L	L	Noon	VL
3	M	VL	M	H	Afternoon	M
4	M	H	L	L	Noon	VL
5	H	O	H	N	Noon	M
6	H	L	H	N	Noon	H
7	VH	VL	VH	H	Beforenoon	VH
8	VH	O	VH	H	Afternoon	VH

approach we have used 5 input variables where 3 of which consist of 4 membership functions each and 2 consist of 3 membership functions each. Therefore total 4x4x4x3x3 = 576 rules can be used, which are all possible combinations of the input variables. This work uses all the rules in detecting the forest fires.

Table 2 shows some candidate fuzzy rules and represents the combinations of parameters that are used for different linguistic states to form fuzzy If-Then rules. Table 2 consists of six columns. The first five columns indicate the different conditions of inputs i.e the *temperature, humidity, light intensity, CO_2 density and time* respectively and the last column represents the probability of fire. Each row represents a rule used by our proposed FLS.

For example, the 7th rule: *If (temperature is Very high) and (humidity is Very low) and (light intensity is Very high) and (CO_2 density is high) and (time is Beforenoon) then (fire probability is very high).*

Thus the changes in values of the parameters in different time in a day can change the probability of fire accordingly. After defining the rules all the fuzzified inputs are combined according to the fuzzy rules to establish a rule strength. Here we use the “AND” operator is used for combining the fuzzified inputs. Then we find the consequence of the rule by combining the rule strength and the output membership function. Then the outputs of all the fuzzy rules are combined to obtain one fuzzy output distribution.

Step 3: In the final step a crisp value i.e a numeric digit is determined from output fuzzy set as a representative value. This process is called **defuzzification** [8]. In our work we have used “centroid of area” method.

5 Network Topology for Energy Efficient WSN

In this work the proposed WSN is based on the work as presented in [13]. Authors in [13] presented a clustering mechanism based on fuzzy communication model. The nodes in the network are randomly deployed and several clusters are determined. Each cluster contains a cluster head that communicates with the neighbouring cluster or base station. The cluster head collects data from the other member nodes in the cluster and sends directly (when it is close to base station) or indirectly (via connector nodes) to the base station. Based on this clustering method same authors also reported one k-fault tolerant topology

Table 3. conditions of fire probability

Sl No.	Output	Fire probability
1	0-20	Very Low
2	21-40	low
3	41-60	medium
4	61-80	high
5	81-100	very high

control algorithm [14] which can be used in an efficient way to send the different parameters sensed by the sensors to the base station through cluster heads and connector nodes. This communication model extends the life of the network by saving the energy of the sensors at a particular instant by using only few sensors that are active for communication.

6 Simulation and Results

In order to verify the proper functioning and the effectiveness of the proposed system with respect to the environmental conditions, MATLAB simulation is carried out. The scale of fire probability gives the results which are simply crisp numbers from 0 to 100. As shown in Fig. 7 the FIS variable fire probability has five membership functions which are distributed in the range [0, 100]. The decision of whether fire has occurred and the intensity of the fire can be made by the crisp value obtained from the defuzzification process as shown in Table 3.

Simulation results are presented in Table 4. For example an input set is taken as [80 12 1500 3000 20], where the first, second, third, fourth and fifth elements of input matrix represents *Temperature, Humidity, Light Intensity, Carbon Dioxide Density and Time* respectively. The output obtained is 91. Hence the probability of fire is *Very High*. Here temperature is 80 °C, humidity is 12ppm, light intensity is 1500lux, CO_2 density is 3000ppm and time is 6 pm and trapezoidal MFs are used for each FIS variable. So when temperature is 80 °C, it lies between *high* and *very high*. Membership grades are 1 for *high* and 0.05 for *very high*. Similarly, 12ppm humidity lies between *very low* and *low* and for *very low* sensitivity of humidity has a greater weight than *low*. In case of light intensity for 1500 ppm the membership grade of *high* is greater than *very high*. CO_2 density has higher weight in *high* compared to the *normal* level sensitivity. The time can be easily evaluated as 6pm that is 20 hours lies only in the *afternoon* region.The probability of fire is 91.3846% calculated from fuzzy logic toolbox in Matlab. For different combination of inputs, probability of fire can be calculated easily. Table 4 shows the simulation results evaluated from a variety of values of all the input variables. As an example in 1st row of Table IV temperature is 20 °C, humidity is 90ppm, light intensity is 150lux, CO_2 density is 800ppm and time is 6 pm; output is 8.55% i.e the probability of fire is *very low*. On the other hand in 6th row temperature is 85 °C, humidity is 60ppm, light intensity is 2000lux, CO_2 density is 2000ppm and time is 6 am; output is 70.50% i.e the probability of fire is *high*. Hence it is observed that the proposed approach can effectively detects the forest fire for different environmental conditions.

Table 4. Experimental output probability values for different situations

Rule#	Temp	Humidity	Light	CO_2	Time	Output(%)
1	20	90	150	800	18	8.55
2	20	40	170	900	12	8.55
3	40	60	150	900	14	8.55
4	75	10	1000	4000	19	90.00
5	80	12	1500	3000	20	91.38
6	85	60	2000	2000	6	70.50
7	300	6	5000	4500	8	91.38
8	500	40	5000	4500	20	91.94

7 Conclusion

This paper, investigates the use of fuzzy logic in determining the probability of forest fire using multiple sensors. Some vagueness related to the different environmental conditions can easily be handled by this proposed method. It gives accurate and robust result with variation of temperature, humidity, etc as all the input variables are defined by real time data.

References

1. Abraham, A., Rushil, K.K., Ruchit, M.S., Ashwini, G., Naik, V.U.: G, N.K.: Energy Efficient Detection of Forest Fires Using Wireless Sensor Networks. In: Proceedings of International Conference on Wireless Networks (ICWN 2012), vol. 49 (2012)
2. Diaz-Ramirez, A., Tafoya, L.A., Atempa, J.A., Mejia-Alvarez, P.: Wireless Sensor Networks and Fusion Information Methods for Forest Fire Detection. In: Proceedings of 2012 Iberoamerican Conference on Electronics Engineering and Computer Science, pp. 69–79 (2012)
3. Lozano, C., Rodriguez, O.: Design of Forest Fire Early Detection System Using Wireless Sensor Networks. The Online Journal on Electronics and Electrical Engineering 3(2), 402–405
4. Kasischke, E.S., Bruhwiler, L.P.: Emissions of carbon dioxide, carbon monoxide, and methane from boreal forest fires in 1998. Journal of Geophysical Research 108(D1) (2003)
5. Vukasinovic, I., Rakocevic, G.: An improved approach to track forest fires and to predict the spread direction with WSNs using mobile agents. In: International Convention MIPRO 2012, pp. 262–264 (2012)
6. Lloret, J., Garcia, M., Bri, D., Sendra, S.: A Wireless Sensor Network Deployment for Rural and Forest Fire Detection and Verification. In: Proceedings of International Conference on IEEE Sensors, pp. 8722–8747 (2009)
7. Zhang, J., Li, W., Han, N., Kan, J.: Forest fire detection system based on a ZigBee wireless sensor network. Journal of Frontiers in China 3(3), 359–374 (2008)
8. Jang, J.-S.R., Sun, C.-T., Mizutani, E.: Neuro-fuzzy and soft computing. PHI Learning
9. Yu, L., Wang, N., Meng, X.: Real-time Forest Fire Detection with Wireless Sensor Networks. In: Proceedings of International Conference on Wireless Communications, Networking and Mobile Computing, vol. 2, pp. 1214–1217 (2005)

10. Sridhar, P., Madni, A.M., Jamshidi, M.: Hierarchical Aggregation and Intelligent Monitoring and Control in Fault-Tolerant Wireless Sensor Networks. International Journal of IEEE Systems 1(1), 38–54 (2007)
11. Bolourchi, P., Uysal, S.: Forest Fire Detection in Wireless Sensor Network Using Fuzzy Logic. In: Fifth International Conference on Computational Intelligence, pp. 83–87 (2013)
12. Bradstock, R.A., Hammill, K.A., Collins, L., Price, O.: Effects of weather, fuel and terrain on fire severity in topographically diverse landscapes of south-eastern Australia. Landscape Ecology 25, 607–619 (2010)
13. Bhowmik, S., Giri, C.: Energy Efficient Fuzzy Clustering in Wireless Sensor Network. In: Proceedings of Ninth International Conference on Wireless Communication & Sensor Networks (2013)
14. Bhowmik, S., Mitra, D., Giri, C.: K-Fault Tolerant Topology Control in Wireless Sensor Network. In: Proceedings of International Symposium on Intelligent Informatics (2013)