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Type-2 Fuzzy Logic Sensor Fusion for Fire Detection Robots

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Abstract- In this paper is presented an approach for fire detection and estimation robots. The approach is based on type-2 fuzzy logic system that utilizes measured temperature and light intensity to detect fires of various intensities at different distances. Type-2 fuzzy logic system (T2 FLS) is known for not needing exact mathematic model and for its capability to handle more complicated uncertain situations compared with Type-1 fuzzy logic system (T1 FLS). Due to lack of expertise for new facilities, a new approach for training experts' expertise and setting up T2 FLS parameters from pure data is discussed and simulated in this paper.

***Keywords*:** fire-detection robots, type-2 fuzzy sets, fuzzy logic system

1. Introduction

Fuzzy sets were first introduced by Zadeh [1] in 1975. Since then, lots of research works have been done on type-1 and type-2 sets and fuzzy logic system. In [2] an introduction of type-2 fuzzy logic was presented by Dongrui Wu. In [3], Mendel provided a comprehensive and detailed review of type-2 fuzzy sets and systems. All significant issues with respect to type-2 fuzzy logic system have been discussed in this article. Other key elements related to type-2 fuzzy logic, such as general and interval fuzzy logic system, footprint of uncertainty (FOU) about type-2 membership function, inference engine, type reduction and defuzzification is discussed in [4]. The concept of the centroid of a type-2 fuzzy set and Karnik-Mendel (KM) algorithms were introduced in [5]. KM algorithms consist of two iteration algorithms which are used to calculate the centroid of a type-2 fuzzy set. To achieve a better performance in real situation, more efficient algorithms about computing the centroid of a type-2 fuzzy set are discussed in [6]. Since the type-2 concept has been introduced, a lot of research works have been done based on comparison between the performances of type-1 and type-2 fuzzy logic systems. [7] In this paper, instead of formulated the type-2 fuzzy logic system direct by prior knowledge of experts available for known facilities, a new approach for training experts' expertise and setting up type-2 fuzzy logic system with its related parameters from data is discussed for the case of new facilities. The performance of the type-2 fuzzy system is modeled and tested in MATLAB Simulation. The performance of type-2 fuzzy logic when compared to type-1 fuzzy logic for a fire detection robot is also discussed in this paper.

2. Setting Up Type-2 Fuzzy Logic Parameters

A. Building Type-1 Membership Function

Membership functions are one of the most important parts of fuzzy logic system. They refer to the way input variables are converting into fuzzy sets. Without prior expertise in the case of new facilities and new floor plans, boundaries and endpoints of each membership functions have to be chosen based on simulations of the direct problem: cause (fire) to effects (temperature and light). In our proposed approach, in order to get a reliable fuzzy logic system, all experts developed type-1 membership function for each fuzzy set based on its own membership function model. The process of how to build membership function model is discussed in this section.

A sample of temperature date and how an expert interpreted it are shown in Table 1 and Table 2.

Table 1. Temperature-distance relationship data

dis(m)\ temp	Large Fire°C	Medium Fire°C	Small Fire°C	No Fire°C
	LT1	MT1	ST1	NT1
Close	LT2	MT2	ST2	NT2
	LT3	MT3	ST3	NT3

Where LT1-LT3 represents the temperature value measured for a large fire, MT1, ST1 and NT1 represent the lowest temperature value measured for a medium fire, a small fire and no fire respectively.

Different model of membership functions with different endpoint and overlaps were generated from data depended on different input temperature values.

Table 2: Temperature data after expert interpreting

dis(m)\ temp	Large Fire°C	Medium Fire°C	Small Fire°C	No Fire°C
	high	medium	low	very low
Close	temperature	temperature	temperature	temp.

As shown in Figure 1(a) - Figure 1(c), three different model of membership functions , A, B and C, could be generated from data depended on different input temperature value produced by various intensities of fire. Model C is generated if there's no overlap between input temperature value LT1-LT3, MT1-MT3 and/or ST1-ST3, whereas Model A is generated if there is overlap between LT1-LT3, MT1-MT3 and/or ST1-ST3.

In fact, membership function models for fuzzy logic system require appropriate overlap. Fortunately, it's easy and reasonable for experts to modify the original membership functions in order to satisfy the requirement of fuzzy logic system.

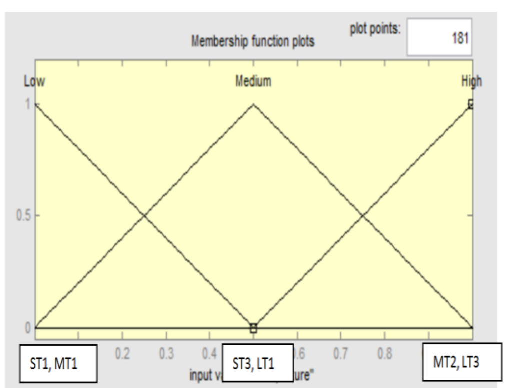


Fig. 1(a). Membership function model A

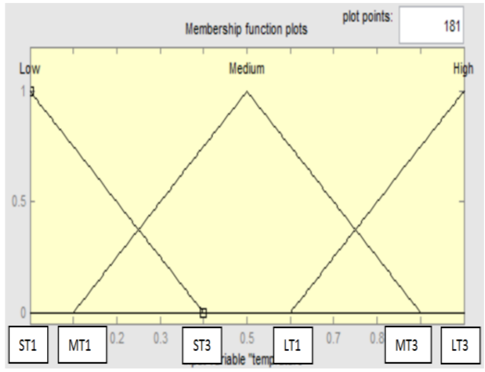


Fig. 1(b). Membership function model B

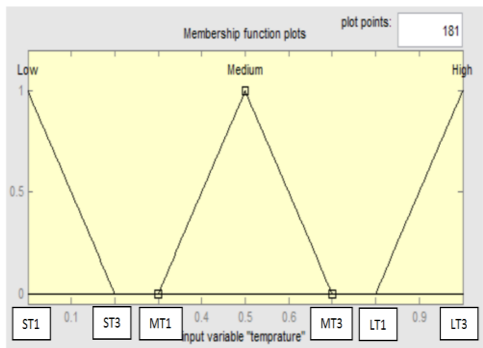


Fig. 1(c). Membership function model C

B. Converting Type-1 to Type-2 Membership Functions

It's common to have several experts working on same problem. In this case, different type-1 fuzzy logic system would be built by different expert using their specific expertise. It's not how to choose from one expert rather from another. A better method is to combine different type-1 fuzzy logic membership functions to a new type-2 membership function.

In our proposed approach, three different type-1 membership functions were built for single fuzzy set by three different experts based on type-1 membership function model as shown in Figure 4. These type-1 membership functions which have both similarity and differences were then used to structure a new type-2 membership function which is illustrated in Figure 2(a) and 2(b).

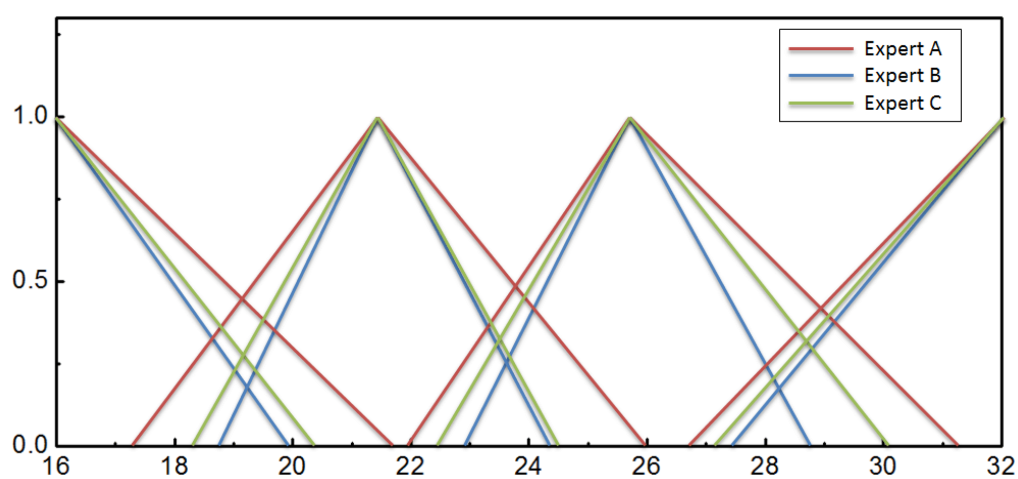


Fig. 2(a). Type-1 membership function built from three experts

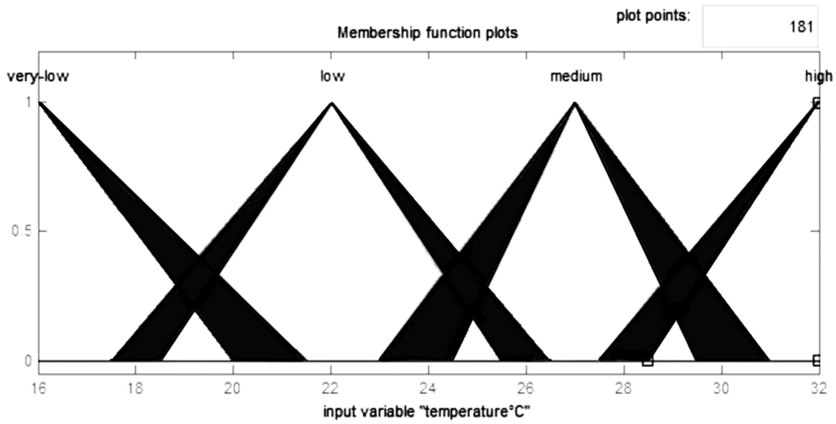


Fig. 2(b). Mixed Type-2 Membership function

C. Fuzzy Logic Module Based on Distance

In order to achieve more precise results, three different sub-modules were developed and embedded in our proposed type-2 fuzzy logic system. As shown in Figure 3, different modules are activated based on different distance values between fire and robot.

Far-distance module will be activated at first when the distance between robot and fire is relatively far. The output from the fuzzy module will give a rough estimation for fire intensity which is occurred. Medium-distance module will then be activated when the distance between fire and robot is getting shorter. Close-fire module will be activated at last and give a precise estimation about the detected fire intensity.

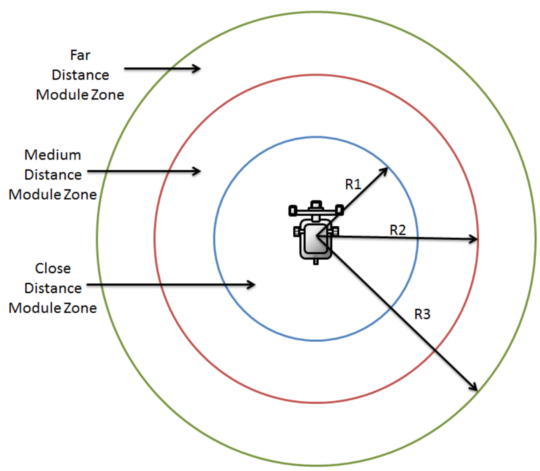


Fig. 3. Three different distance zones for the fire detection robot

3. Simulation Results

The simulation work is achieved by using MATLAB Simulation based on the proposed type-2 fuzzy logic sensor fusion approach. Figure 4(a) – 4(f) shows the results of the robot approaching fire with the following symbols:

The red diamond represents the large fire.
The circle represents the center area of fire.
The arrow represents the current direction of robot.
The circle with radials represents the detection range
The red line represents the trajectory of robot.

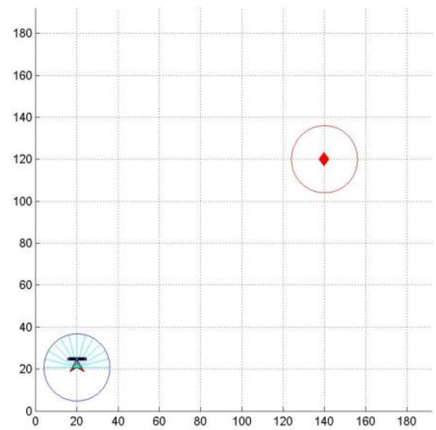


Fig. 4(a)

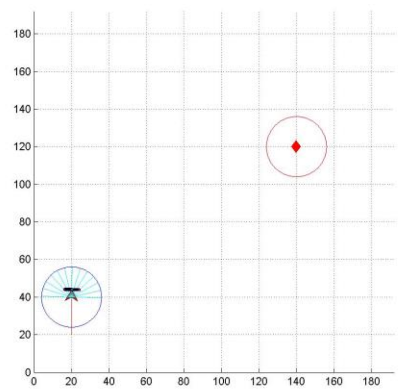


Fig. 4(b)

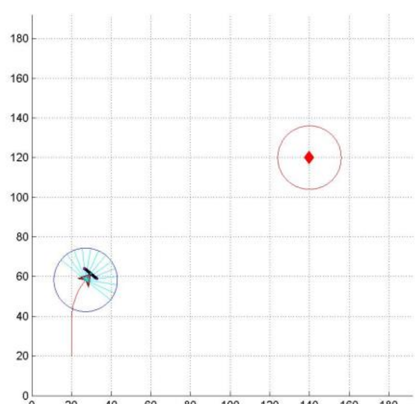


Fig. 4(c)

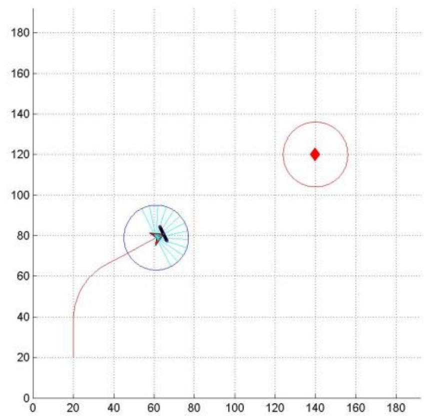


Fig. 4(d)

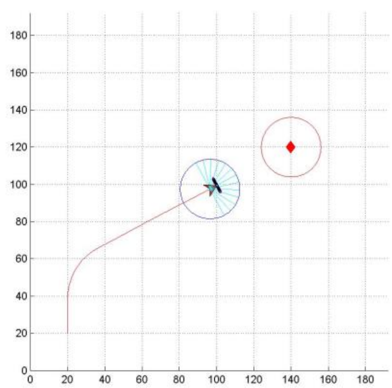


Fig. 4(e)

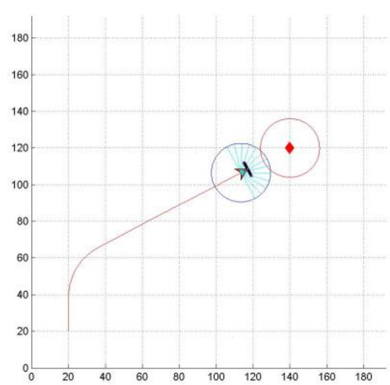


Fig. 4(f)

The simulation results of real time measured temperature and light measurements from robot are shown in Figure 5(a) and 5(b), which include Gaussian white noise for both cases.

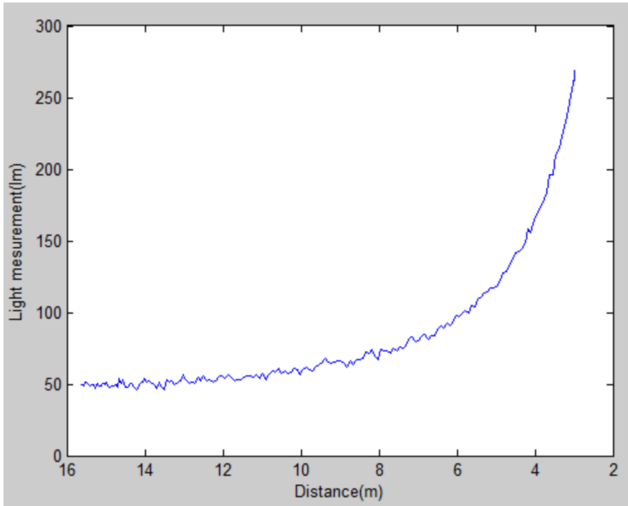


Fig. 5(a). Real time light measurements

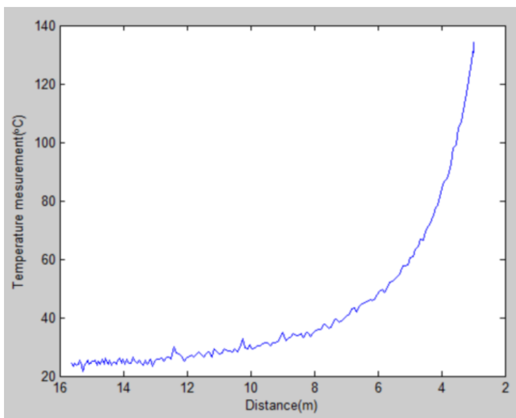


Fig. 5(b). Real time temperature measurements

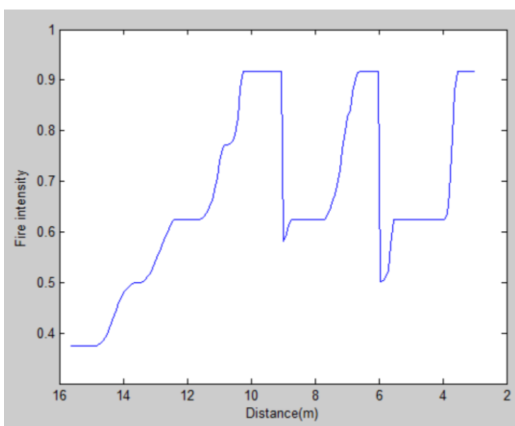


Fig. 6. Estimated fire intensity from fuzzy logic system

Figure 6 shows the changing of estimated fire intensity when robot approached the fire source. Fire intensity is re-estimated at 6m and 9m because different fuzzy logic module is activated. In this case, a large fire at far distance was estimated at beginning because abnormal temperature value had been detected. With robot approached the source, a final decision was made by close model that there's a large fire at close distance.

4. Comparison of Type-1 and Type-2 Fuzzy Logic

A. Analysis of the confidence in the rsults of ype-1 and type-2 Fuzzy Logic

A Comparison of Type-1 fuzzy logic system (T1 FLS) and Type-2 fuzzy logic system (T2 FLS) are discussed in this section. One type-2 fuzzy logic system and three type-1 fuzzy logic systems are simulated and compared with same simulation environment. Three T1 FLSs, namely Fuzzy Logic System A, Fuzzy Logic System B and Fuzzy Logic System C are developed individually by expert A, expert B and expert C. T2 Fuzzy Logic system is consisted of all three T1 FLSs that is developed by three experts together. In order to focus on the difference of the performance between T1 FLS and T2 FLS, exactly the same rule bases are implemented for all four Fuzzy Logic Systems.

The goal of the proposed fuzzy logic system is to output estimated fire intensities when robot approaches the fire source. In this section, the performance of all four different fuzzy logic systems are tested and compared through nine different simulation scenarios. They are: a large fire setting up at far distance, a large fire at medium distance, a large fire at close distance, a medium fire at far distance, a medium fire at medium distance, a medium fire at close distance, a small fire at far distance, a small fire at medium distance and a small fire at close distance. Table3 below shows the results of the simulation.

Table 3: Results of the fuzzy logic system simulation

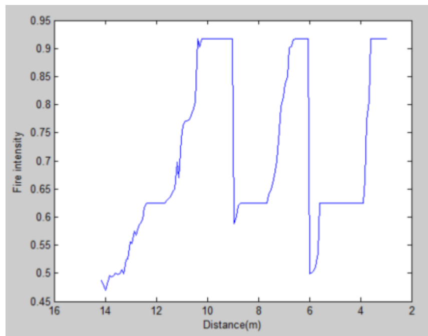
	Large Fire			Medium Fire		Small Fire	
	Distance	Result		Distance	Result	Distance	Result
Type2 Fuzzy Logic System	Far	Correct		Far	Correct	Far	Correct
	Medium	Correct		Medium	Correct	Medium	Correct
	Close	Correct		Close	Correct	Close	Correct
Type1 Fuzzy Logic System A	Far	Correct		Far	Wrong	Far	Correct
	Medium	Correct		Medium	Wrong	Medium	Correct
	Close	Correct		Close	Wrong	Close	Correct
Type1 Fuzzy Logic System B	Far	Correct		Far	Correct	Far	Correct
	Medium	Correct		Medium	Correct	Medium	Correct
	Close	Correct		Close	Correct	Close	Correct
Type1 Fuzzy Logic System C	Far	Wrong		Far	Wrong	Far	Correct
	Medium	Correct		Medium	Correct	Medium	Correct
	Close	Correct		Close	Correct	Close	Correct

As shown in table above, the results from Type-2 Fuzzy Logic System are relevant. The system was able to generate correct fire intensity in all nine simulation scenarios. Also, the output curves are smooth which is ideal for developing robot's navigation system. Although type-1 FLS B results in all 9 correct answers, there are some wrong results in both FLS A and FLS C. These two FLSs failed in some circumstances because of inefficient membership function choice by expert A and expert C. These inefficient membership functions have full weight in its corresponding system. Using the same membership function as MF component, Type-2 fuzzy logic system is able to handle these inefficient choices and detect the correct fire intensity by reducing the weight of each membership function. Opinions from multiple experts were considered when building the membership functions. Results in table above illustrate that type-2 fuzzy logic system has more reliability than type1 fuzzy logic system.

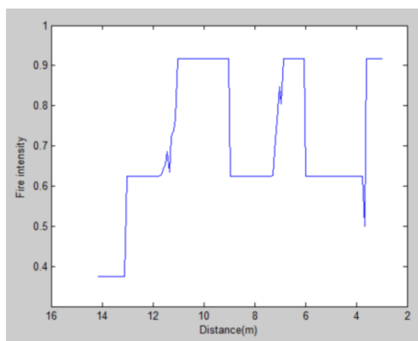
B. Comparison of type-1 and type-2 under different noise level

Sensors can obtain inaccuracy results due to numerous reasons. Significant disturbances can exist in robot's working environment which can result in large noise for sensors. Also inexpensive sensor itself can lead to inaccurte results. A good sensor fusion algorithm should have good features to handle input noise. The goal of the simulation work presented in this section is to test how type-1 fuzzy logic system and type-2 fuzzy logic system handle the input noise. Gaussian white noise is simulated and used as basic noise for inputs in these simulation. The two sensor fusion algorithms which are chosen to compare are Type-2 FLS and Fuzzy Logic System B were presented in the last section.

With regular noise level, both T1 FLS and T2 FLS are able to produce the correct answer and their output curves are smooth. Results are shown in Figure below 7(a) and 7(b).

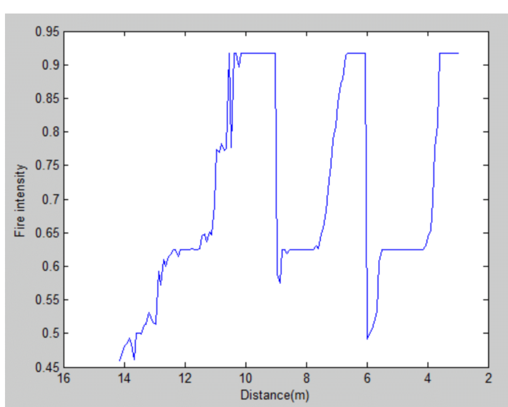


7(a) Type-2 result for robot searching large fire

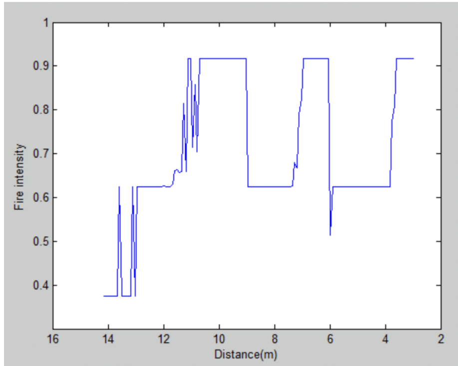


7(b) Type-1 result for robot searching large fire

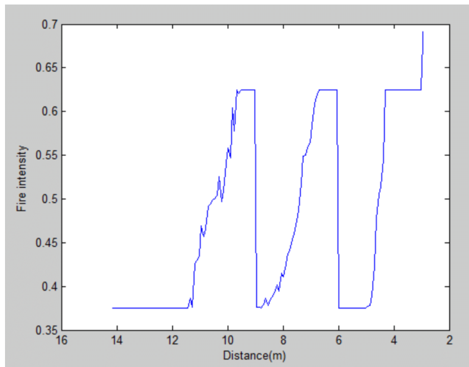
Figure (a)-(f) below shows how T1 FLS and T2 FLS respond when the noise intensity increases. By amplifying the Gaussian noise for amplitude, although T1 FLS is still capable to produce correct result, the system starts to become unstable. There has been significant oscillations in the results generated by T1 FLS, whereas T2 FLS is still able to produce relative stable and clear results for fire intensity estimation.



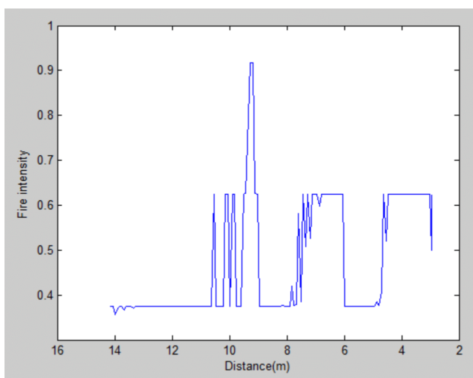
8(a) Type-2 result for robot searching large fire



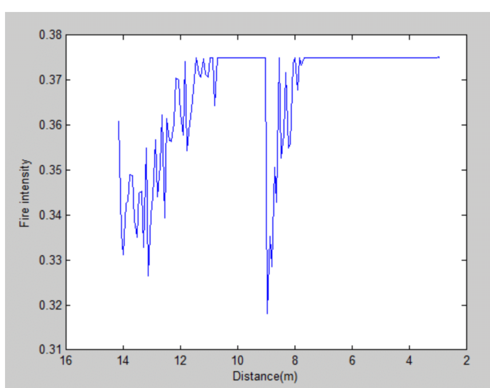
8(b) Type-1 result for robot searching large fire



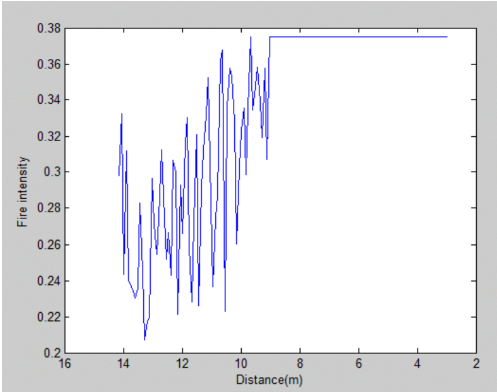
8(c) Type-2 result: searching medium fire



8(d) Type-1 result for robot searching medium fire



8(e) Type-2 result for robot searching small fire



8(f) Type-2 result for robot searching small fire

5. Conclusion

The results presented in this paper illustrate that the type-2 fuzzy logic approach could be used simply and reliably for a robot to detect and estimate fire with various intensities which occurred at different distances.

The proposed approach, which used the proposed type-2 fuzzy logic system, avoids the need for prior expertise to build a fuzzy logic system by direct problem simulation. This helps the experts to design a more reliable fuzzy logic system to solve problems in unknown areas. By comparing the performance with type-1 fuzzy system, it has been found that type-2 fuzzy gives better results when large amount of uncertainty has to be concerned.

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