Research Article

International Journal of Advanced Computer Research, Vol 9(43)
ISSN (Print): 2249-7277 ISSN (Online): 2277-7970
http://dx.doi.org/10.19101/IJACR.PID30

Early detection of fire hazard using fuzzy logic approach

Nesi Syafitri[1*], Ause Labellapansa[1], Evizal Abdul Kadir[1], Rizauddin Saian[2], Nur Nabila Afini Zahari[3], Nur Hadirah Khairul Anwar[3], and Nurul Ezzatul Mawaddah Shaharuddin[3]
Senior Lecturer, Department of Informatics Technology, Universitas Islam Riau, Indonesia[1]
Senior Lecturer, Faculty of Computer & Mathematical Sciences, Universiti Teknologi MARA, Malaysia[2]
Faculty of Computer & Mathematical Sciences, Universiti Teknologi MARA, Malaysia[3]

Received: 9-September-2018; Revised: 16-January-2019; Accepted: 30-January-2019

Abstract
A fire alarm system has numerous devices that work together to detect and give warning to the people through visual and audio appliances when there are smoke, fire and gas. The system is very sensitive to the fire, smoke and gas; hence the system sensitivity must be advanced enough so that it does not trigger any false alarm. The aim of this study is to reduce false alarm within the fire alarm system that diverts emergency responders away from legitimate emergencies that could result in loss of life and properties. The method used to conduct the research is a fuzzy logic approach (FLA). The method is tested using MATLAB and it has 125 rules since it has three variables which are fire, smoke and gas with five linguistic variables. The number of false alarms can be reduced if the fuzzy logic approach is put into practice in the alarm system since the probability of occurrence shows only 3% of error which is considered to be small. From these findings, we found that the number of false alarms can be minimized to the minimal by implementing fuzzy rules into the alarm system.

Keywords
Fuzzy logic approach, Fire, Gas, Smoke, False alarm.

1.Introduction
Fire alarm system, embedded with technology, has been widely used worldwide. The existence of smart alarm technology that can spot early warning signs of fire provide more security to life. The fire alarm system is capable of saving lives and even properties. Fire alarm systems have been created to respond to the presence of fire, smoke and gas. The system is very sensitive and will respond to the fire, smoke or gas in the sensor's surveillance area. However, the level of system sensitivity must not provide false information to the input system. An example of false information received by the alarm system is fired from candles detected by the sensor that does not threaten human life.

Other than the use of fire extinguisher, fire can be avoided before it occurs by detecting the fire at the source. There are various studies conducted using fire sensors such as Arduino UNO, The Grove-Flame sensor and many more. Each sensor has the same purpose or function of detecting the fire at the source that react to heat and flame. There are also some sensors that have the extra function of detecting infrared as well.

Synthesis method of GM (1, 1) gray prediction model and adaptive Neuro fuzzy inference system (ANFIS) is used to detect fire and to make sure it works in the environment [1]. The study can ensure the data processing is more accurate to avoid false alarms. Moreover, study to detect a fire in the tunnel is used as a quality criterion [2]. The biggest challenge in designing a fuzzy system is the original identification and calibration of such a system. The results of the process are then evaluated in a real-world case study from Lochkov tunnel near the city of Prague.

This paper studied some related work based on smart fire and home security by using fuzzy method. The objective is to present a monitoring device that is able to detect the presence of a gas leak and take action before the actual fire happens [3].

Furthermore, the sensitivity of the alarm, due to the use of fuzzy logic approach also needs to be investigated in terms of accuracy level. Fuzzy systems use rules as a guide in producing outputs

*Author for correspondence

based on expert inputs and logical thinking only. The objectives of this study are to reduce false alarm in the fire alarm system, to identify the accuracy of alarm and to recognize the differences of alarm's output between actual data and MATLAB output.

This study focuses on the relevant factors that influence fire incident. The factors come from the existence of flame, smoke and gas. The inputs from every factor are collected using sensor namely as Arduino flame sensor and MQ2 smoke and gas sensor. Input about flame are collected in terms of the wavelength of flame with unit nanometer (nm) meanwhile both smoke and gas are measured in terms of density by using a unit of part per million (ppm).

The limitation of this study is the placement of a fire alarm system in rooms of different sizes. Fire alarm system sensors will only detect fire warning in its surveillance area. If the room is bigger than the size of the sensor's surveillance area, the sensor cannot track the fire warning to notify the user by then the fire will be too big when it reaches the surveillance area.

This study will give benefit to the household. It will increase the level of awareness among the households. The household will be more aware the benefit of installing the fire alarm system at their house. By installing the alarm system, they will be more alert when something unpleasant happens such as burning fire, gas leakage and so on. The fire alarm system will give early warning to the household, so that they can save their life and their property.

Second benefit goes to firefighters. If the building has the fire alarm system, then the firefighter can have access to the early warning of fire. A warning alarm will be triggered when it senses the presence of fire, smoke or gas. It will alert people nearby to call the firefighter. It will reduce the case where the fire fighter coming late to the place of incidence when they receive the call and thus preventing fire from being uncontrollable.

2.Fire, smoke and gas

Most dictionaries state that fire is a process of burning that produces flames that send out heat and light, and might produce smoke. Fire can either burn rapidly or slowly. Slow burning or combustion, known as oxidation, includes no fiery processes in the form of rusting and digestion [4].

A fire sensor is a sensor capable of impressing and converting it into its analogue representation quantity [5]. He also stated that the fire sensor is different from the heat sensor. The heat sensor parameter measured is the temperature, while the fire sensor measures the wavelength of flame. This sensor works based on infrared light and can detect between 760nm – 1100nm wavelength range.

Smoke is a suspension of the small element within the air (aerosols) that come from unfinished combustion of a fuel. Besides that, smoke can also cause harm for the human being. The primary cause of death caused by fire is due to smoke poisoning. Smoke can kill a human being with the combination of thermal harm, poisoning, and lung inflammation due to carbon monoxide, hydrogen, cyanide and other combustion sources [6]. There are several things that can lead to the existence of fire such as short circuit on the electricity network, leaking of liquefied petroleum gas (LPG), cigarette and others [7].

Smoke can easily be detected using simple technology due to the advancement in technology [6]. Easy and powerful smoke warnings can lessen the effect caused by fire. The fire sensor will continuously monitor the state of the room. When this tool senses the presence of heat or smoke or both, then it will react. The action done by fire sensor is in the form of sending notification to fire fighter or security officer or authorized party, spurting water and smoke suctioning [8].

LPG is a highly inflammable gas, which is the result of combination of propane and butane, while butylene, propylene and other hydrocarbons may exist in small quantities. The gas can be used as fuel for domestic, automobile and industrial purposes, including several heating applications. LPG is a well-known gas that is used as a cooking gas. The characteristic of LPG gas is it is odourless but with the addition of Ethanethiol that act as a powerful odorant, it will produce a smell and thus gas leakage will be easily detected [9].

LPG can be obtained from two sources. It is either through refining of crude oil or extract from natural gas or crude oil streams from underground reservoirs. Today 60% of LPG is obtained from underground reservoir while another 40% is from extraction of refining crude oil. The price of LPG is low compared to petrol and diesel. LPG is environmentally friendly compared to petrol and diesel since it burns cleaner and free of the particulates from the latter [10].

Smoke detector might not go off or provide early warning in as many as 35% of all fires, according to the study conducted by the Federal Emergency Management Agency (an agency of the United States government). Fire alarm system is designed to give warning against fire, but at the same time they do not guarantee warning or defence against fire.

In general, smoke detectors on one level of a structure cannot be expected to detect fires developing on another level. The amount of "smoke" maybe not enough to notify smoke detectors to produce alarm. Smoke detectors are designed to alarm at different levels of smoke density. If such density levels are not created by a developing fire at the position of detectors, the detectors will not go into alarm [11].

3.Methodology

3.1Method of data collection

Arduino flame sensor and MQ2 smoke and gas sensor were used in order to obtain the dataset for each of the input variables. There are several parameters included in the study of the alarm system. The parameters that represent the study are made up of fire, smoke and gas. Thirty datasets were collected based on the experiment conducted.

3.2Method of data analysis

In order to solve some diagnosis issues, classification or fuzzy logic approach is used. The fuzzy logic approach (FLA) is oriented towards numerical processing, unlike conventional expert system which focused on symbolic engines. FLA is built on fuzzy set, fuzzy membership and fuzzy variable, which is the three-basic concept of fuzzy logic. A collection of fuzzy membership functions and rules were used in fuzzy expert system (FES) for knowledge representation and reasoning with observed system state data. Fuzzifier, knowledge base (rule base), fuzzy inference engine and defuzzifier are the components consist of the FLA. Rule base of FLA is a collection of IF-THEN rules. IF-THEN rules are used to describe the functional dependencies of the input and output of the variables and there are operators AND, OR, or NOT to support the reasoning. The framework of fuzzy logic is shown in *Figure 1*.

The parameters and the corresponding linguistic degrees in the rule base are presented in *Table 1*.

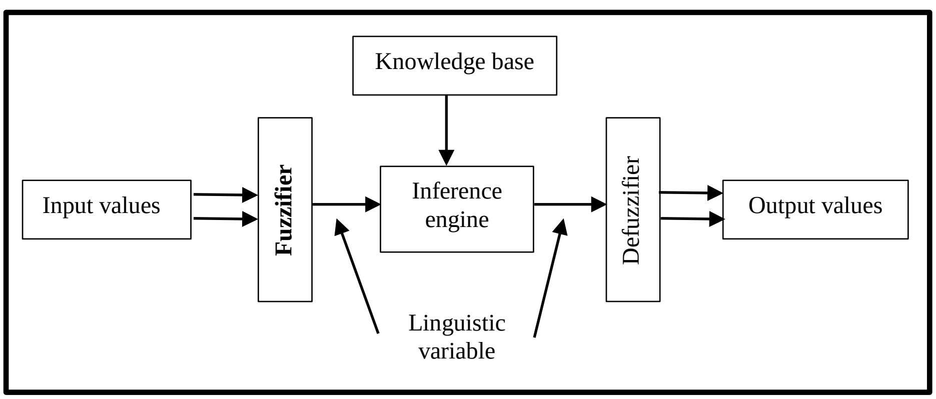

Figure 1 Fuzzy logic framework

Table 1 Parameters and the corresponding linguistic degrees

Parameter	Interval	Linguistic Variables
Fire	[0, 1100]	Very Small [0, 251], Small [100, 251, 521], Normal [251, 521, 762], Large [521, 762, 991], Very Large [762, 1100]
Smoke	[0, 10000]	Very Little [0, 400], Little [299, 400, 750], Medium [400, 750, 3250], Compact [750, 3250, 7750], Very Compact [3250, 10000]
Gas	[0, 2000]	Very low [0, 43], Low [35, 43, 225], Medium [43, 225, 1000], High [225, 1000, 1600], Very High [1000, 2000]

In fuzzification, the FLA structure is illustrated as shown in *Figure 2* and the membership functions are defined for the input variables. The membership functions defined on the input variables are applied to the actual values of the input variables to determine the degree of truth for each rule's premise.

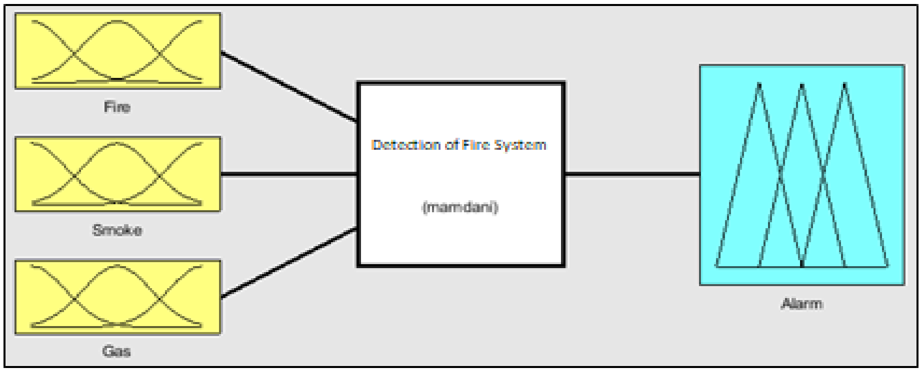

Figure 2 FLA – fuzzy logic approach

In order to form a fuzzy set, the membership value for each variable must be assigned in the interval of [0, 1]. The triangle and trapezoidal functions affiliation define the membership function. Let X denotes the universe of discourse, where x represents an element of the universe and A denotes a fuzzy set that characterized by its membership function, $\mu_A(x)$.

The Mamdani model approach is used in this study, as the output obtained will be in the fuzzy set. The composition-based inference is when all fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. IF-THEN rule is the structure of the fuzzy rule base.

125 rules are generated by using Mamdani IF-THEN Rules. *Table 2* shows the way to set up the linguistic variable in each of the variables in order to create the Mamdani IF-THEN Rules. From the *Table 2*, the fire, smoke and gas were labelled with 0 to 4. Meanwhile, for the grade, it was labelled from 0 to 12.

Table 2 The arrangement of the linguistic variable for each variable

Input variables			**Output variable**
Fire	**Smoke**	**Gas**	**Alarm**
Very Large (0)	Very Little (0)	Very Low (0)	Not Dangerous (0 – 2)
Large (1)	Little (1)	Low (1)	Potential Danger (3 – 7)
Normal (2)	Medium (2)	Medium (2)	Dangerous (8 – 12)
Small (3)	Compact (3)	High (3)	-
Very Small (4)	Very Compact (4)	Very High (4)	

The following some rules define the logic behind the operation of the fire alarm system for the fuzzy interference process.

1. If fire is "very large" and smoke is "very little" and gas is "very low" then the alarm is "not dangerous".
2. If fire is "very large" and smoke is "very little" and gas is "low" then the alarm is "not dangerous".
3. If fire is "very large" and smoke is "very little" and gas is "medium" then the alarm is "not dangerous".
4. If fire is "very large" and smoke is "very little" and gas is "high" then the alarm is "potential danger".
5. If fire is "very large" and smoke is "very little" and gas is "very high" then the alarm is "potential danger", etc.

In defuzzification, the crisp value is essentially the centre of the area under the curve of the new fuzzy subset derived from the composition stage. Defuzzification maps a fuzzy set, which is the output of a fuzzy inference engine with a crisp output. Fuzzy

centroid method is the most common technique used in defuzzification. There are few methods of defuzzification, which are weighted average method, centroid method, height method and middle of maxima method [12].
The function of the centroid method relies on using the centre of gravity (COG) of the membership function to calculate the crisp value of the output variable. Defuzzification is an essential process when there are multiple rules that conclude the same diagnosis. The crisp output can be obtained from the centroid method formula where y^* refer to centroid value (middle of area) obtained.

$$y^* = \frac{\int y \bullet \mu(y)\, dy}{\int \mu(y)\, dy} \tag{1}$$

The output of alarm in *Figure 3* explains that if the fire = 739 nm, the smoke = 4277 ppm and the gas = 1024 ppm, then the predicted value for the alarm = 6.51. The value 6.51 of the alarm means that it falls under potential danger. Based on Figure 3, membership function of the grade for potential danger is used to find out the centroid value of the grade manually, as the value of MATLAB output falls under that alarm.

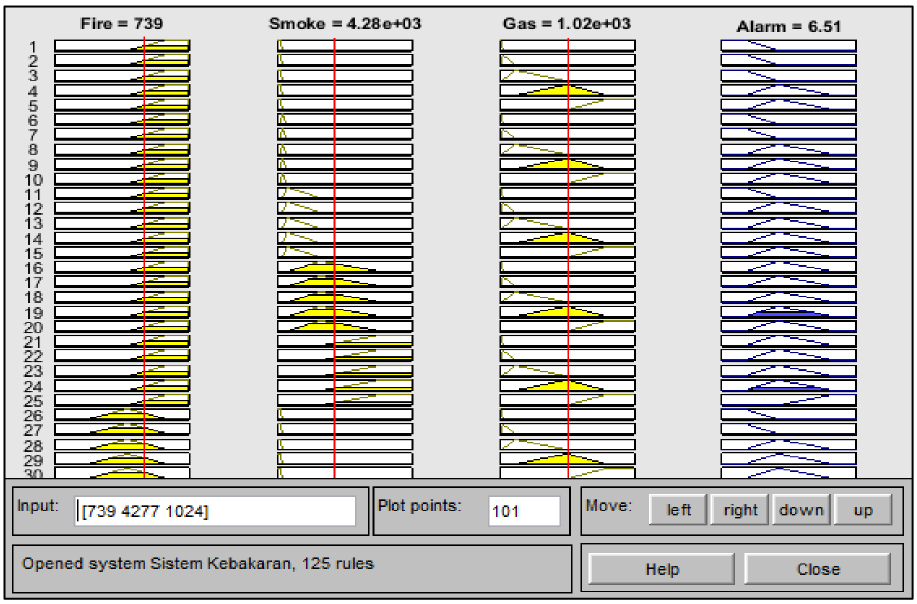

Figure 3 Output of the Alarm from MATLAB

4.Result

Table 3 shows the result of alarm output predicted by the MATLAB software and the alarm output from the actual data.

Based on the result of MATLAB output and the actual data, there are minor differences in the output. Out of 30 data, only one data of MATLAB outputs is not parallel to the actual data as list out in *Table 4.*

Table 3 Output of alarm from MATLAB

	Actual data				**MATLAB Output**	
No.	**Fire (NM)**	**Smoke (PPM)**	**Gas (PPM)**	**Alarm**	**Alarm**	**Alarm**
1	10	3098	1536	Dangerous	9.47	Dangerous
2	941	306	177	Potential danger	2.54	Potential danger
3	338	844	433	Potential danger	5.82	Potential danger
4	28	519	1374	Dangerous	9.24	Dangerous
5	734	4745	38	Potential danger	5.74	Potential danger
6	410	1211	71	Potential danger	5.75	Potential danger
7	713	4625	571	Potential danger	6.79	Potential danger
8	383	2643	1858	Dangerous	8.30	Dangerous
9	523	9558	16	Potential danger	5.70	Potential danger

	Actual data				MATLAB Output	
No.	**Fire (NM)**	**Smoke (PPM)**	**Gas (PPM)**	**Alarm**	**Alarm**	**Alarm**
10	634	6966	37	Potential danger	5.70	Potential danger
11	10	7831	264	Dangerous	9.52	Dangerous
12	403	9136	1127	Dangerous	9.21	Dangerous
13	619	7593	1612	Dangerous	9.38	Dangerous
14	569	329	50	Potential danger	3.62	Potential danger
15	60	139	32	Potential danger	5.74	Potential danger
16	19	917	1644	Dangerous	9.51	Dangerous
17	641	5220	367	Potential danger	6.38	Potential danger
18	729	387	213	Potential danger	5.37	Potential danger
19	182	315	29	Potential danger	4.20	Potential danger
20	43	8186	1606	Dangerous	9.55	Dangerous
21	828	1762	197	Potential danger	5.74	Potential danger
22	891	6320	348	Potential danger	6.14	Potential danger
23	313	299	35	Not dangerous	1.90	Not dangerous
24	245	483	1141	Potential danger	6.32	Potential danger
25	686	671	491	Potential danger	5.73	Potential danger
26	121	225	30	Not dangerous	5.11	Potential danger
27	878	8698	27	Potential danger	5.68	Potential danger
28	335	2532	41	Potential danger	5.71	Potential danger
29	1074	3870	171	Potential danger	5.71	Potential danger
30	812	9102	679	Potential danger	6.95	Potential danger

Table 4 Different case in MATLAB output

		Actual data			MATLAB Output	
No.	**Fire**	**Smoke**	**Gas**	**Alarm**	**Alarm**	**Alarm**
1	121	225	30	Not dangerous	5.11	Potential danger

Based on *Table 3*, it can be concluded that the number of false alarms can be reduced if FLA by using MATLAB were practiced in the alarm system. The error for the different case in the MATLAB output with actual data can be calculated as below:

$$\frac{1}{30} \times 100 = 3\%$$

The results obtained from the prediction using fuzzy expert system indicates there is only 3% of error, which is considered as very small. Therefore, it shows that this method is suitable to be used in determining the alarm as the output shows 97% accuracy of the results.

5.Conclusion

Implementing fuzzy logic approach into the alarm system will ensure that the system will work more effectively and efficiently. The fuzzy logic approach will reduce the possibility of false alarm which may cause unnecessary panic and/or bringing resources (such as fire fighter) to a place where they are not needed. Besides that, false alarms have the potential to divert emergency responders away from legitimate emergency which could ultimately lead to loss of life and properties.

The fuzzy logic approach applied in the fire alarm system reduced the false alarm based on the result shown in *Table 4*. The percentage of error obtained in the comparison between actual data and MATLAB output is only 3% and it is considered as insignificant value. There are 30 actual data that will be compared with the MATLAB output. Alarm is divided into three types which is not dangerous, potential danger and dangerous. These three types will be determined based on the value of fire, smoke and gas. From the 30 data, only 1 data from MATLAB output is not accurate in comparison with the actual data. The final result obtained is 97% accurate to the actual data and this proved the suitability in using this method.

For the recommendation part, this paper suggests the improvement of fire alarm system. Before this, fire alarm system is equipped with Arduino flame sensors and MQ2 sensor that are specifically designed for detection of smoke and gas. The improvement that this paper suggest is to add another sensor which is MQ6. MQ6 sensor is specifically designed to detect the presence of gas and the sensor is highly sensitive to LPG, isobutane and propane. Since this paper focuses more on LPG, therefore this sensor will be the best choice. MQ2 sensor can sense both smoke and gas presence, but there might be a possibility of sensor making mistakes such as the existence of smoke but the sensor read it as gas. That is why the fire alarm system needs a sensor that is specially designed to be able to distinguish and detect fire, smoke and gas.

Acknowledgment

This research is partially supported by Universitas Islam Riau-Indonesia and Universiti Teknologi MARA, Malaysia.

Conflicts of interest

The authors have no conflicts of interest to declare.

References

[1] Wang Y, Yu C, Tu R, Zhang Y. Fire detection model in Tibet based on grey-fuzzy neural network algorithm. Expert Systems with Applications. 2011; 38(8):9580-6.
[2] Přibyl P, Přibyl O. Calibration of a fuzzy model estimating fire response time in a tunnel. Tunnelling and Underground Space Technology. 2017; 69:28-36.
[3] Kumar K, Sen N, Azid S, Mehta U. A fuzzy decision in smart fire and home security system. Procedia Computer Science. 2017; 105:93-8.
[4] Adams, C. http://www.straightdope.com/columns/read/2425/what-exactly-is-fire/ , Accessed 22 November 2018.
[5] http://saptaji.com/2016/08/11/menangani-sensor-api-flame-detector-dengan-arduino/
[6] Himawan FP, Sunarya U, Nurmantris DA. Design of microcontoller based smoke detectors, GSM modules, smoke sensors, and temperature sensors. eProceedings of Applied Science. 2017; 3(3):1963-8.
[7] Faishal A, Budiyanto M. Fire detection using the Lm35D temperature sensor and smoke sensor. In the National Information Science 2015.
[8] http://digilib.polban.ac.id/files/disk1/83/jbptppolban-gdl-didinsaefu-4119-1-implemen-s.pdf. Accessed 20 November 2018.
[9] Enalume KO, Obianke SK. Design and implementation of an efficient LPG leakage detector.2017; 2(6):20-6.
[10] Seyhan N, Jasharllari L, Kayapınar M, Savacı N. An unusual cause of cold injury: 258iquefied petroleum gas leakage. Ulus Travma Acil Cerrahi Derg. 2011; 17(6):561-2.
[11] http://www.systemsensor.com/en-us/Documents/Limitations-of-fire-alarm-systems_techbulletin.pdf. Accessed 20 November 2018.
[12] Ross TJ. Fuzzy logic with engineering applications. New York: Wiley; 2004.

Nesi Syafitri received her Bachelor degree in Information System from Universitas Putra Indonesia "YPTK", Padang-Indonesia in 2003 and the Master degree in Computer Science from Universitas Gadjah Mada in 2009. Her current position is Lecturer at the Faculty of Engineering, department of Informatics in Universitas Islam Riau (UIR), Indonesia. Her research interests are based on Fuzzy Logic, Data Mining and Machine Learning.
Email: nesisyafitri@eng.uir.ac.id

Ause Labellapansa earned her Master degrees in Universitas Gadjah Mada (Artificial Intelligence) and Universitas Islam Indonesia (Medical informatics - focused on Medical Imaging), Yogyakarta - Indonesia simultaneously from 2011 to early 2014. She is currently the head department of Informatics in Universitas Islam Riau (UIR) Indonesia. She has experienced several projects related to Artificial Intelligence especially on Rule-Based Reasoning & Case-Based Reasoning.
Email: ause.labella@eng.uir.ac.id

Evizal Abdul Kadir received his Master of Engineering and PhD in Wireless Communication at Faculty of Electrical Engineering, Universiti Teknologi Malaysia in 2008 and 2014 respectively. He is currently as Lecturer and Researcher in Islamic University of Riau (UIR) Indonesia as well as Director of research institute and community services and get promoted to Associate Professor. He has experience and worked in several companies that provide a system solution in Wireless Communication and Radio Frequency (RF) as well as Radio Frequency Identification (RFID), currently is continuing his research activities related to the Wireless Communication System, Antenna, Remote Sensing, Radio Frequency Identification (RFID), Wireless Sensor Network (WSN), Wireless and Mobile Monitoring System and IoT.
Email: evizal@eng.uir.ac.id

Rizauddin Saian received his degree of Bachelor of Science in Mathematics from Universiti Malaya, Malaysia in 1998 and the degree of Doctor of Philosophy from Universiti Utara Malaysia in 2013. His current position is Senior Lecturer at the Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, Malaysia. His research interests are Data Mining and Machine Learning.
Email: rizauddin@uitm.edu.my

Hadirah Khairul Anwar received her Diploma in Mathematical Sciences at Universiti Teknologi MARA Arau Perlis. After successfully getting her diploma, she continues her study of Bachelor Degree in Mathematics Management at the same university. Currently, she's planning to further her studies doing a Master in Mathematical Sciences. She is interested in research involving implementation of Fuzzy.
Email: hadirah1995@gmail.com

Nabila Afini Zahari received Diploma in Mathematical Science from University Technology MARA Segamat Branch, Johor at 2016 and Bachelor Dergee in Management Mathematics at University Technology MARA Arau Branch, Perlis at 2018. She currently works as Finance Clerk at Logistic Company. Her research interest is in how Fuzzy works to decide non-error result.
Email: nabilaafinyzahari@gmail.com

Nurul Ezzatul Mawaddah Shaharuddin received her Diploma in Mathematical Science from Universiti Teknologi MARA, Segamat Branch in 2016 and Bachelor Degree in Management Mathematics at Universiti Teknologi MARA, Perlis Branch in 2018. She is currently an Assistant Branch Manager at 99Speedmart Sdn Bhd, one of the market leaders in grocery markets of Malaysia. Her research interests include Fuzzy Logic Approach and Fuzzy Expert Systems.
Email: nurulezzatulmawaddah@gmail.com