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DESIGN OF PROTOTYPE GAS DETECTION SYSTEM BASED ON FUZZY LOGIC IN CHEMICAL WAREHOUSE

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Abstract

In the work regulations in the industry, minimizing the risk of work accidents is the main thing. Work accidents arise as a result of dangerous conditions. One of the dangerous conditions is the emergence of toxic and combustible gases that enter the chemical warehouse area. A basic prototype of a gas detection system in a chemical warehouse was created to solve this issue and was provided with an action at the output to dispose of the gas. The process at the output includes condition indicators, alarms, and gas handling with exhaust fans and water sprayers. This system is made by utilizing communication between Arduino and Delphi. The system uses fuzzy logic computing with the Mamdani inference model. Based on the data from the comparison between Matlab and Delphi, the smallest average accuracy value is 99.714%. The use of serial communication produces a delay in the output response of 2.4 seconds.

Keywords: Arduino, Detection, Fuzzy logic, Gas detection, Safety.

1. Introduction

Automation industries such as petrochemical are one industry that works continuously or continuously. In its work to run a continuous industry, an inventory is needed to support the supply of the entire work system. In this case, a storage room (warehouse) is needed as a support building to lay supplies of supporting components for system work. This warehouse is very efficient; in addition to storing manufacturing materials, the structure can also be utilized to layout production outcomes. Storage warehouses need to be protected from various dangerous conditions. This is because the center of the system's work support is in this room. Refinery plants can stop working if things happen that are not desirable. Moreover, if storage such as a chemical warehouse contains chemicals [1], it will be possible for an enormous explosion to affect the surrounding area. Among the dangers that this warehouse may face is the entrance of gases such as methane (CH_4) and carbon monoxide (CO). The gas is combustible [2] and poisonous [3]. Where it may harm employees and the structures utilized. This must be avoided by equipping storage facilities such as chemical warehouses with a gas detection system. Previous research has been conducted regarding the detection of combustible gases. From this research, a method was designed to map the size of the combustible gas. The method used is computational fluid dynamics (CFD) by adjusting the distance between combustible gas detectors [4, 5]. It aims to predict the magnitude of the explosion that may not impact other tools. Reflecting on the research and background above, several studies were conducted to develop gas leak detection tools [2, 6] and gas sensor placement methods [7, 8].

In this study, the author intends to develop a gas detection system in a chemical warehouse using the fuzzy logic method. The fuzzy logic approach is a logical notion with many possible values but may specify temporary characteristics such as true or false, yes or no, open or close, and so on. Fuzzy logic describes a conclusion from data information that is still vague so that it still looks ambiguous. Several simulations for gas detection using the fuzzy method have been carried out, such as low cost multisensor [9] and gas type determination [10, 11]. Over the years, many studies have begun to develop related to the use of fuzzy logic. One of them is the research conducted by Mamdani in 1974 regarding the application of fuzzy algorithms for controlling simple refinery plants [12] and flood alert disasters [13]. In this study, Mamdani stated that this fuzzy could be used by humans (operators) to express strategies or protocols for controlling refinery plants by providing a different set of rules. In addition, this fuzzy algorithm can also provide instructions for adding or changing rules in future decision-making. In previous studies, a monitoring tool for clean air conditions and hazardous gases CO, CO_2 CH_4 was developed in the Chemical Laboratory using Microcontroller-Based Fuzzy Logic [14]. The previous study was still a simple scenario and only used a blower as gas control. Applications for smart homes by using gas sensors to detect unhealthy conditions, such as carbon monoxide and carbon dioxide (CO_2) [15].

With the fuzzy capabilities that have been described and with the support of existing journals about the concept of fuzzy logic models for several gas sensor arrays [16], in this study, the authors would like to collaborate on the importance of gas detection systems for chemical warehouses with fuzzy logic as an alternative for decision-makers when they occur gas leak. The gas detector used has the same principle for several sensors such as the MQ-4 and MQ-7, which use micro AL_2O_3 as a ceramic tube and a sensitive layer of Tin Dioxide (SnO_2). This study tested the reliability of this system using 34 scenarios designed for the gas detection system. The scenario uses two gas processes with different types. Where the value of the input is obtained from the four detectors while the output produced will work on 7 existing components, namely buzzer 1, buzzer 2, buzzer 3, buzzer 4, exhaust fan, lamp and water sprayer.

2.Research Method

In this research method, the discussion refers to a prototype in the form of an electronic wiring diagram. The stages of the research to be carried out, from initial preparation to reaching the final result. In this study, the creation of a wiring diagram serves to describe the overall performance of the system created. Based on Fig. 1, it is explained about the performance scheme of the gas detection system, where when a gas release is detected by the gas detector sensor, this component will send a signal to the microcontroller which is connected to each other with the Arduino Uno.

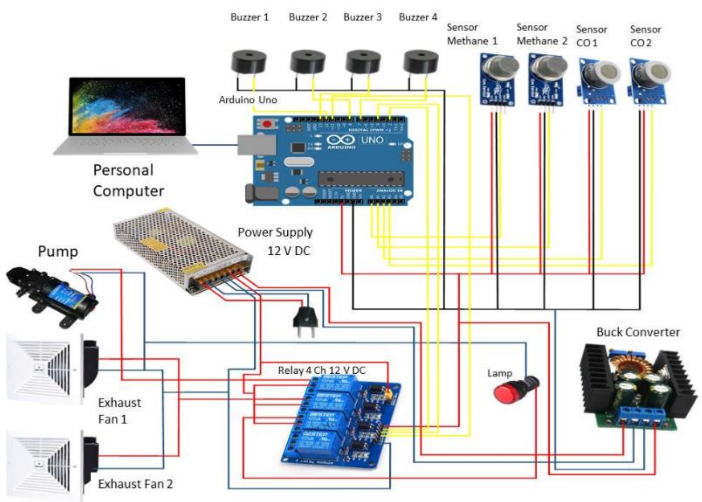


Fig. 1. Wiring diagram design.

Furthermore, the value of each gas content in the chemical warehouse will be read by each sensor. After that the Arduino Uno will send a value signal to the personal computer (PC). On the personal computer there is Delphi software which is used as a monitor as well as for processing analog values from each sensor using fuzzy logic computing programs [17]. After the final result of the fuzzy computational value is obtained, it will then be sent back to Arduino Uno to be used as a work order for output. The outputs in question are exhaust fans, water sprayers, lamps, and piezoelectric buzzers. Each of these outputs will be active (on) and perform its own function when the value of the hazardous gas is in abnormal content. If the detected gas content is in normal conditions, then all outputs will remain in the off state. The design of the gas detection system includes two important stages, namely the design of hardware and software. The first step in this research is making a prototype design. The arrangement of the whole tool is shown in Fig. 2, beginning with the location of the pump, storage tank, and prototype of the room construction.

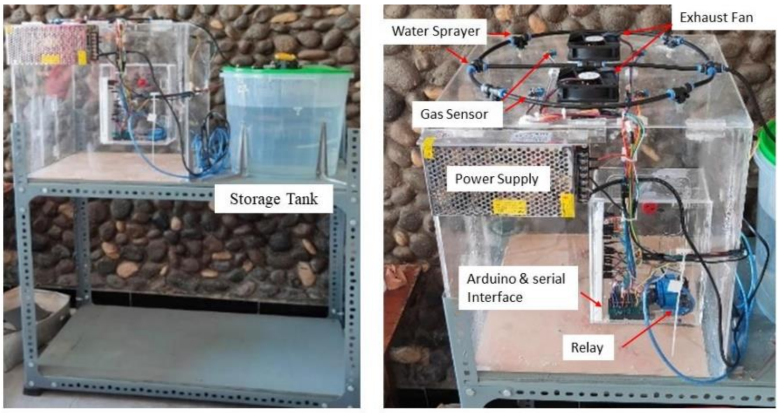


Fig. 2. Overall prototype design

As for the laying of components, where the exhaust fan is in the middle position. This serves so that the exhaust fan can reach all sides of the room to remove gas. The water sprayer system is no exception, which requires five sprayer nozzles so that it can reach all existing areas. While for the four gas detectors, the placement is done near the exhaust fan which is useful for maximizing sensor performance in terms of knowing the last condition of the mitigation results. In this experiment, the gas to be tested is sprayed manually into the room through the hole in the prototype.

Furthermore, the buzzer setting is on the top side which functions to avoid contact with water generated from the water sprayer and can reduce the noise received by the operator's ears. The next step involves creating cause and effect to define actions that work from the output side. Cause and effect are determined based on the best steps taken to deal with a hazardous condition by adjusting the characteristics of the gas. In Tables 1 and 2 it can be seen that the scenario setting uses 4 inputs and uses 7 outputs. The table shows that, there are 34 scenarios designed for the gas detection system. The scenario uses two gas processes with different types. The input value is obtained from the four detectors while the output produced will work on 7 components, namely buzzer 1, buzzer 2, buzzer 3, buzzer 4, exhaust fan, lamp and water sprayer.

In its work, if gas detectors 1 and 2 detect a gas whose value is in the membership field, there are little alarms and many alarms, the buzzer 1 and 2 will be active. This is intended as an alarm marker on the safety system in the chemical warehouse. Buzzers 3 and 4 will remain active when conditions enter the dangerous membership area followed by a water sprayer that will cool the air and spray water vapor to settle on the floor. This is followed by an active exhaust fan to remove the remaining gas in the chemical warehouse. In this dangerous membership area, the light will also be active as a dangerous indicator for those who do not hear the buzzer.

Table 1. Cause and effect 1.

INPUT					OUTPUT							
No.	**Gas Detector 1**	**Gas Detector 2**	**Gas Detector 3**	**Gas Detector 4**	**Buzzer 1**	**Buzzer 2**	**Buzzer 3**	**Buzzer 4**	**Exhaust Fan**	**Lamp**	**Water Sprayer**
1	Little Safe	Little Safe	None	None	Off	Off	None	None	Off	Off	Off
2	Little Safe	Little Alarm	None	None	Off	On	None	None	Off	Off	Off
3	Little Safe	Danger	None	None	On	On	None	None	On	On	On
4	Little Safe	Many Alarm	None	None	Off	On	None	None	On	Off	On
5	Little Safe	Many Safe	None	None	Off	Off	None	None	On	Off	On
6	Little Alarm	Little Safe	None	None	On	Off	None	None	Off	Off	Off
7	Little Alarm	Little Alarm	None	None	On	On	None	None	Off	Off	Off
8	Little Alarm	Danger	None	None	On	On	None	None	On	On	On
9	Little Alarm	Many Alarm	None	None	On	On	None	None	On	Off	On
10	Little Alarm	Many Safe	None	None	On	Off	None	None	On	Off	On
11	Danger	Little Safe	None	None	On	On	None	None	On	On	On
12	Danger	Little Alarm	None	None	On	On	None	None	On	On	On
13	Danger	Danger	None	None	On	On	None	None	On	On	On
14	Danger	Many Alarm	None	None	On	On	None	None	On	On	On
15	Danger	Many Alarm	None	None	On	On	None	None	On	On	On

While gas detectors 3 and 4 detect a gas whose value is in the membership field, it detects a little, so as an alarm marker in the safety system, buzzers 3 and 4 will be active. Buzzers 3 and 4 will also remain active when the gas value in the membership field detects a lot as a marker that the gas is entering a dangerous condition. In dangerous conditions other than buzzers 3 and 4 are active, the exhaust fan will also be active to blow the air inside to the outside. In addition, the lamp will also be active as a danger marker for people who do not hear the buzzer sound. Table 2 shows a different input scenario with gas detector 1 with many alarms. The two types of gas processes above have different handling because they have different impacts. For gas detectors 1 and 2 are used to detect gases that have combustible properties (combustible). Meanwhile, gas detectors 3 and 4 are used to detect dangerous toxic gases. For gases that have combustible properties, they will be sprayed using a water sprayer to avoid contact with the exhaust fan engine which causes heat. In addition, a water sprayer is also useful for precipitating the gas to the bottom later.

Meanwhile, the handling of the remaining gas in the air is carried out by the exhaust fan. For toxic gas itself, the settings used are directly focused on exhausting to the outside with an exhaust fan. In designing the system on the software side, the first thing to do is create a source of validation calculations using the fuzzy logic designer Matlab 2017 [18, 19]. The design of the fuzzy set is shown in Fig. 3.

In Table 3 it is explained that the system created using the Mamdani Fuzzy Inference System uses 2 types of input variables, namely combustible and toxic. The use of sensors 1 and 2 are intended for combustible gas types while for 3 and 4 are used for toxic gases. The membership function of combustible gas is 5 while the toxic is only 3. As for the rule base gas, there are 34 obtained from the overall arrangement of the possibilities of 5 membership functions for sensors 1 and 2

(Combustible) totalling 25 plus 3 membership functions for sensors 3 and 4 (Toxic) with an amount of 9. For the results of defuzzification using the Centroid calculation. Then the calculation is done in Microsoft Excel to find out the details of the fuzzy logic computational process flow. The computation of fuzzy logic in Excel utilizes the use of the IF and THEN, MIN and MAX commands as well the use of other functions. We use the excel program as a verification method of mathematical calculations for fuzzy logic. Furthermore, the design of the display design uses Borland Delphi 7 software which is integrated with Arduino uno hardware as an input and output connection line supported by the Comport library as a component for exchanging information on the serial side of the communication [17]. Delphi is programming that is easy to understand and more flexible and can be used for optimization with artificial intelligence methods [20].

Table 2. Cause and effect 2.

	INPUT				OUTPUT						
No.	**Gas Detector 1**	**Gas Detector 2**	**Gas Detector 3**	**Gas Detector 4**	**Buzzer 1**	**Buzzer 2**	**Buzzer 3**	**Buzzer 4**	**Exhaust Fan**	**Lamp**	**Water Sprayer**
1	Many Alarm	Little Safe	None	None	On	Off	None	None	On	Off	On
2	Many Alarm	Little Alarm	None	None	On	On	None	None	On	Off	On
3	Many Alarm	Danger	None	None	On	On	None	None	On	On	On
4	Many Alarm	Many Alarm	None	None	On	On	None	None	On	Off	On
5	Many Alarm	Many Safe	None	None	On	Off	None	None	On	Off	On
6	Many Safe	Little Safe	None	None	Off	Off	None	None	On	Off	On
7	Many Safe	Little Alarm	None	None	Off	On	None	None	On	Off	On
8	Many Safe	Danger	None	None	On	On	None	None	On	On	On
9	Many Safe	Many Alarm	None	None	Off	On	None	None	On	Off	On
10	Many Safe	Many Safe	None	None	Off	Off	None	None	On	Off	On
11	None	None	Not Detected	Not Detected	None	None	Off	Off	Off	Off	None
12	None	None	Not Detected	Little Detected	None	None	Off	On	Off	Off	None
13	None	None	Not Detected	Many Detected	None	None	Off	On	On	On	None
14	None	None	Little Detected	Not Detected	None	None	On	Off	Off	Off	None
15	None	None	Little Detected	Little Detected	None	None	On	On	Off	Off	None
16	None	None	Little Detected	Many Detected	None	None	On	On	On	On	None
17	None	None	Many Detected	Not Detected	None	None	On	On	On	On	None
18	None	None	Many Detected	Little Detected	None	None	On	On	On	On	None
19	None	None	Many Detected	Many Detected	None	None	On	On	On	On	None

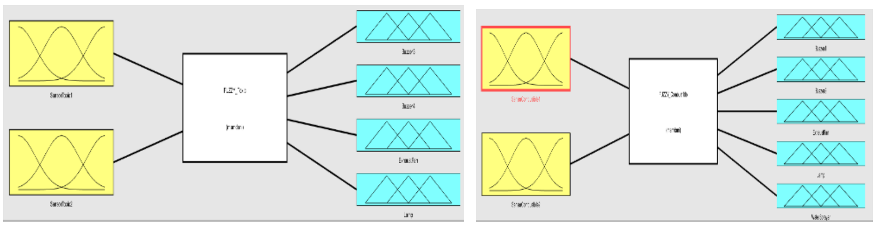


Fig. 3. Matlab validation fuzzy design.

Table 3. Fuzzy computing specification.

Definition	Specification
Fuzzy Inference System	Fuzzy-Mamdani
Input Variable Combustible	Sensor 1 dan Sensor 2
Input Variable Toxic	Sensor 3 dan Sensor 4
Output Variable Combustible	Buzzer 1, Buzzer 2, Exhaust Fan, Lamp, Water Sprayer
Output Variable Toxic	Buzzer 3, Buzzer 4, Exhaust Fan, Lamp
Membership Function Input Combustible	Little Safe = 0;0;10;44 (Trapezium) Little Alarm = 44;65;88 (Triangle) Danger = 88;215;340 (Triangle) Many Alarm = 340;380;420 (Triangle) Many Safe = 420;490;500;500 (Trapezium)
Membership Function Input Toxic	Not Detected = 0;0;15 30 (Trapezium) Little Detected = 30;115;200 (Triangle) Many Detected = 200;235;250;250 (Trapezium)
Membership Function Output Combustible	Buzzer 1: Off1 = 0;50 dan On1 = 50;100 (Trapezium) Buzzer 2: Off2 = 100;150 dan On2 = 150;200 (Trapezium) Exhaust Fan: Off5 = 400;450 dan On5 = 450;500 (Trapezium) Lamp: Off6 = 500;550 dan On6 = 550;600 (Trapezium) Water Sprayer: Off7 = 600;650 dan On7 = 650;700 (Trapezium)
Membership Function Output Toxic	Buzzer 3: Off1 = 200;250 dan On1 = 250;300 (Trapezium) Buzzer 4: Off2 = 300;350 dan On2 = 350;400 (Trapezium) Exhaust Fan: Off5 = 400;450 dan On5 = 450;500 (Trapezium) Lamp: Off6 = 500;550 dan On6 = 550;600 (Trapezium)
Operator	AND, Implication (MIN), Aggregation (MAX)
Rule Base	34 Rules

3.Results and Discussion

This research produces a prototype scenario of a hazardous gas detection system in a chemical warehouse based on fuzzy logic equipped with Borland Delphi Interface. As for the results of the implementation that has been made, it contains a prototype from the software and hardware side that forms a gas detection system based on fuzzy logic rules as can be seen in Fig. 4.

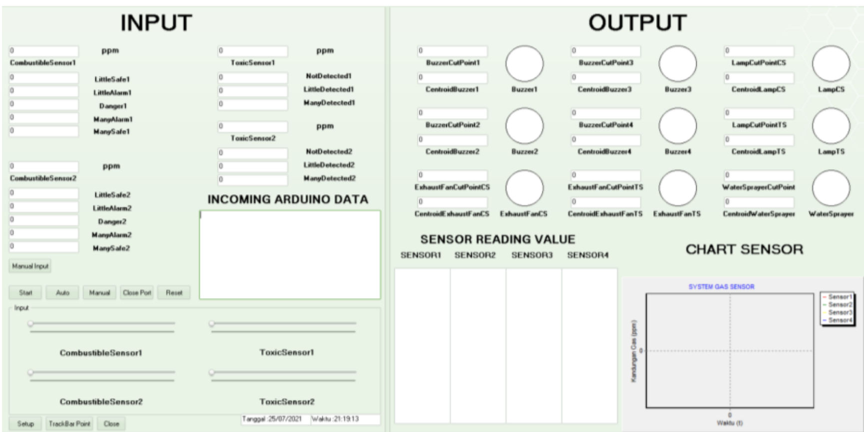
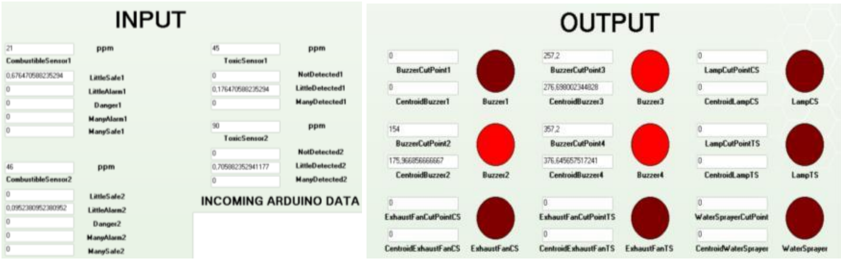


Fig. 4. System prototype results.

At the time of testing, this system produces some useful data as material for the author's analysis so that it is possible to conclude. The system data contains the results of 10 experiments that have been carried out. One of the experimental results can be seen in Fig. 5(a) which is the result of data from experiment 1 related to the fuzzification setting.



(a) (b)

Fig. 5. Experimental (a). Fuzzification results 1 and (b). Interface results.

At the time of testing for the value of defuzzification, this system will display a number using the Centroid calculation. The Delphi interface will also show an indication of the output component. The data for 10 trials are loaded into Table 4, while the results for the display of experiment 1 can be seen in Fig. 5(b).

In Table 4, it can be seen that when the value 0 then each component will be in an active condition. This can be seen when the centroid value for each output is at a value of 50, 150, 250, 350, 450, 550 and 650 then the condition of the hardware components will be active (On) by changing the display colour which was originally maroon to red. On the other hand, when the value that appears in each output = 0, the indication display will remain maroon, and the hardware output will also remain off (Off).

In Table 5, it can be seen that there are differences from the results of the calculations that have been carried out. The cause is the difference in the computational model, where Matlab tends to round the value on the calculation results. As for the Delphi software, the calculation will involve more decimal numbers. The comparison results above show a small difference, where the largest average error deviation is at buzzer 1 of 0.284 % in the combustible gas test. So it can be concluded that fuzzy logic computing using Mamdani inference has been proven in this study to have an accuracy of 99.716%, as shown in Table 6. While the average for the highest accuracy is obtained by the output lamp in the combustible gas test with an accuracy of 99.99939%.

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Table 4. Defuzzification test results and output indications.

Test	Parameter	Condition Indication
1	**Value PPM Sensor**	21 46 45 90
	Centroid Buzzer (1), (2), (3), (4)	(0 ; Off), (175.96 ; On), (276.698 ; On), (376.645 ; On) (0 ;
	Exhaust fan (ME), (CO)	Off), (0 ; Off)
	Lamp (ME), (CO)	(0 ; Off), (0 ; Off)
	Water sprayer	0 ; Off
2	**Value PPM Sensor**	210 33 28 5
	Centroid Buzzer (1), (2), (3), (4)	(78.04 ; On), (178.02 ; On), (0 ; Off), (0 ; Off)
	Exhaust Fan (CS), (TS)	(477.852 ; On), (0 ; Off) (577.759 ; On), (0 ;
	Lamp (CS), (TS)	Off)
	Water Sprayer	677.648 ; On
3	**Value PPM Sensor**	37 80 65 230
	Centroid Buzzer (1), (2), (3), (4)	(0 ; Off), (177.015 ; On), (278.768 ; On), (378.709 ; On) (0 ;
	Exhaust Fan (CS), (TS)	Off), (478.63 ; On)
	Lamp (CS), (TS)	(0 ; Off), (578.533 ; On)
	Water Sprayer	0 ; Off
4	**Value PPM Sensor**	341 425 220 35
	Centroid Buzzer (1), (2), (3), (4)	(75.296 ; On), (0 ; Off), (275.543 ; On), (375.493 ; On) (0 ;
	Exhaust Fan (CS), (TS)	Off), (475.134 ; On)
	Lamp (CS), (TS)	(0 ; Off), (575.346 ; On)
	Water Sprayer	674.956 ; On
5	**Value PPM Sensor**	115 360 95 20
	Centroid Buzzer (1), (2), (3), (4)	(77.033 ; On), (177.015 ; On), (280.806 ; On), (0 ; Off)
	Exhaust Fan (CS), (TS)	(476.855 ; On), (0 ; Off)
	Lamp (CS), (TS)	(576.767 ; On), (0 ; Off)
	Water Sprayer	676.662 ; On
6	**Value PPM Sensor**	421 48 116 20 (0 ;
	Centroid Buzzer (1), (2), (3), (4)	Off), (175.081 ; On), (280.806 ; On), (0 ; Off) (474.937 ;
	Exhaust Fan (CS), (TS)	On), (0 ; Off)
	Lamp (CS), (TS)	(0 ; Off), (0 ; Off)
	Water Sprayer	674.76 ; On
7	**Value PPM Sensor**	239 54 29 219 (79.416 ;
	Centroid Buzzer (1), (2), (3), (4)	On), (179.394 ; On), (275.641 ; On), (375.591 ; On) (479.21 ;
	Exhaust Fan (CS), (TS)	On), (475.525 ; On)
	Lamp (CS), (TS)	(579.109 ; On), (575.44 ; On)
	Water Sprayer	687.989 ; On
8	**Value PPM Sensor**	345 62 87 230 (76.273 ;
	Centroid Buzzer (1), (2), (3), (4)	On), (176.256 ; On), (280.806 ; On), (380.737 ; On) (476.103 ;
	Exhaust Fan (CS), (TS)	On), (480.647 ; On)
	Lamp (CS), (TS)	(0 ; Off), (580.535 ; On)
	Water Sprayer	675.916 ; On
9	**Value PPM Sensor**	27 298 95 82 (78.218 ;
	Centroid Buzzer (1), (2), (3), (4)	On), (178.198 ; On), (280.37 ; On), (380.304 ; On) (478.028 ;
	Exhaust Fan (CS), (TS)	On), (0 ; Off)
	Lamp (CS), (TS)	(577.934 ; On), (0 ; Off)
	Water Sprayer	677.822 ; On
10	**Value PPM Sensor**	54 98 42 123 (75.788 ;
	Centroid Buzzer (1), (2), (3), (4)	On), (175.772 ; On), (276.318 ; On), (376.266 ; On)
	Exhaust Fan (CS), (TS)	(475.622 ; On), (0 ; Off)
	Lamp (CS), (TS)	(575.539 ; On), (0 ; Off)
	Water Sprayer	675.44 ; On

Table 5. Comparison of value output software.

Output	**Matlab**			**Delphi**	
	Nilai Input	**Combustible**	**Toxic**	**Combustible**	**Toxic**
Buzzer (1), (2)	Sensor 1 = 21	(0), (176)	(None), (None)	(0), (175.96)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 46	(None), (None)	(277), (377)	(None), (None)	(276.6), (376.6)
Exhaust Fan, Lamp	Sensor 3 = 45	(0), (0)	(0), (0)	(0), (0)	(0), (0)
Water Sprayer	Sensor 4 = 90	0	None	0	None
Buzzer (1), (2)	Sensor 1 = 210	(78.3), (178)	(None), (None)	(78.04), (178.02)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 33	(None), (None)	(0), (0)	(None), (None)	(0), (0)
Exhaust Fan, Lamp	Sensor 3 = 28	(478), (578)	(0), (0)	(477.852), (577.759)	0
Water Sprayer	Sensor 4 = 5	678	None	677.648	None

Buzzer (1), (2)	Sensor 1 = 37	(0), (176)	(None), (None)	(0), (175.96)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 80	(None), (None)	(277), (377)	(None), (None)	(276.698), (376.645)
Exhaust Fan, Lamp	Sensor 3 = 65	(0), (0)	(0), (0)	(0), (0)	(0), (0)
Water Sprayer	Sensor 4 = 230	0	None	0	None
Buzzer (1), (2)	Sensor 1 = 341	(75.5), (0)	(None), (None)	(75.296), (0)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 425	(None), (None)	(276), (376)	(None), (None)	(275.543), (375.493)
Exhaust Fan, Lamp	Sensor 3 = 220	(476), (0)	(476), (576)	(475.134), (0)	(475.428), (575.346)
Water Sprayer	Sensor 4 = 35	676	None	674.956	None
Buzzer (1), (2)	Sensor 1 = 115	(77.3), (177)	(None), (None)	(77.033), (177.015)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 360	(None), (None)	(281), (0)	(None), (None)	(280.806), (0)
Exhaust Fan, Lamp	Sensor 3 = 95	(477), (577)	(0), (0)	(476.855), (576.767)	(0), (0)
Water Sprayer	Sensor 4 = 20	677	None	676.662	None
Buzzer (1), (2)	Sensor 1 = 421	(0), (176)	(None), (None)	(0), (175.081)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 48	(None), (None)	(281), (0)	(None), (None)	(280.806), (0)
Exhaust Fan, Lamp	Sensor 3 = 116	(476), (0)	(0), (0)	(474.937), (0)	(0), (0)
Water Sprayer	Sensor 4 = 20	676	None	674.76	None
Buzzer (1), (2)	Sensor 1 = 239	(79.6), (180)	(None), (None)	(79.416), (179.394)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 54	(None), (None)	(276), (376)	(None), (None)	(275.641), (375.591)
Exhaust Fan, Lamp	Sensor 3 = 29	(480), (580)	(476), (576)	(479.21), (579.109)	(475.525), (575.44)
Water Sprayer	Sensor 4 = 219	680	None	678.989	None
Buzzer (1), (2)	Sensor 1 = 239	(76.5), (176)	(None), (None)	(76.273), (176.256)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 54	(None), (None)	(281), (381)	(None), (None)	(280.737), (380.806)
Exhaust Fan, Lamp	Sensor 3 = 29	(476), (0)	(481), (581)	(476.103), (0)	(480.647), (580.535)
Water Sprayer	Sensor 4 = 219	676	None	675.916	None
Buzzer (1), (2)	Sensor 1 = 27	(78.4), (178)	(None), (None)	(78.218), (178.198)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 298	(None), (None)	(281), (381)	(None), (None)	(280.37), (380.304)
Exhaust Fan, Lamp	Sensor 3 = 95	(478), (578)	(0), (0)	(478.028), (577.934)	(0), (0)
Water Sprayer	Sensor 4 = 82	678	None	677.822	None
Buzzer (1), (2)	Sensor 1 = 54	(76), (176)	(None), (None)	(75.788), (175.772)	(None), (None)
Buzzer (3), (4)	Sensor 2 = 98	(None), (None)	(277), (377)	(None), (None)	(276.318), (376.266)
Exhaust Fan, Lamp	Sensor 3 = 42	(476), (576)	(0), (0)	(475.622), (575.539)	(0), (0)
Water Sprayer	Sensor 4 = 123	676	None	675.44	None

Table 6. The average error of the experimental results.

Type	Combustible	Toxic
Buzzer (1), (2)	(0.997161942), (0.998544567)	(None), (None)
Buzzer (3), (4)	(None), (None)	(0.998649129), (0.99877109)
Exhaust Fan, Lamp	(0.999077376), (0.999391376)	(0.999022177), (0.999030672)
Water Sprayer	0.999112613	None

4. Conclusions

The stages in the research on the design of a gas detection system prototype in a chemical warehouse based on fuzzy logic include making cause and effect scenarios, setting reference validation calculations and fuzzy logic algorithms, making fuzzy logic flows into programming forms, making hardware prototypes, and integration between software and hardware.

The flow of making fuzzy logic using the Mamdani Fuzzy Inference System (FIS) model includes 5 critical stages of fuzzification, operator determination, implication, aggregation, and defuzzification.

The results obtained in applying fuzzy logic computing to decision making produce excellent accuracy. This can be seen from 10 times the system trial resulted in the most significant average error value of 0.284% so that the accuracy reached 99.716%. In serial communication, sending data that is too fast can cause reading errors on the Delphi 7 interface.

This is related to the problem of reading data sent from Arduino to Delphi7. The identification of data from the four sensors needs to be classified to find out what gas is detected and the location of the sensor that detects it.

In this study, we use the filter method in the form of character symbols for data clusters from the measurement results from the sensor. The best total delay time used to minimize errors is 2.4 seconds.

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