Formalin Detection Tool Using HCHO and MQ-7 Sensor Series with Fuzzy Logic

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ABSTRACT — Formalin is a hazardous chemical substance that has a pungent odor, is colorless or clear, and is flammable. It should be used to preserve corpses, but often misused by unscrupulous traders to preserve food. Formalin has harmful effects on the human body if it is ingested. Therefore, a practical tool that can detect the presence of formalin in food is needed. Making a formalin detection tool using the Mamdani fuzzy inference system is very useful for detecting formalin and the level of food safety quickly and economically. This tool used the HCHO and the MQ-7 sensors combined with an expert system, namely fuzzy logic. The HCHO detects formalin in the food, like the sense of smell; meanwhile, the MQ-7 sensor detects carbon monoxide (CO). In the testing process, a heater was utilized to vaporize the food samples. The vapor was then detected by the two gas sensors and was processed using the fuzzy logic of the Mamdani method. To see the test's accuracy using the tool, its results were compared with those of the formalin kit and the Fuzzy Logic Toolbox in MATLAB. The results showed that the lowest level of formalin in the tofu sample, namely sample H, was 0.60 ppm; meanwhile, the highest level was in sample E, with 13.64 ppm. The lowest formalin found in salted fish, namely sample P, was 7.14 ppm, while the highest formalin level was in the salted fish sample, namely sample T, with 193.81 ppm. Compared with the formalin kit results, the accuracy value obtained from the total testing of twenty samples was 95%. The output of the tool was nearly identical to that of MATLAB: 85% with a difference of 0.01 and 15% with a difference of 0.02. The average error between tool output and MATLAB was 0.77%.

KEYWORDS — Fuzzy Logic, Mamdani, Formalin, HCHO Sensor, MQ-7 Sensor.

I. INTRODUCTION

Formalin is a chemical substance that has a pungent odor and is colorless or clear [1]. It is a hazardous chemical and is usually used as a corpse preservative, disinfectant, and wood adhesive. Unfortunately, the use of formalin is often abused by unscrupulous traders to preserve food. The regulation of the Minister of Health of the Republic of Indonesia No. 033 Year 2012 on Food Additives bans the use of formalin as a food additive. Formaldehyde-contaminated foods can harm the body [2]. The short-term effects of formalin when entering the body are stomach pain, nausea, vomiting, and diarrhea. At the same time, the long-term effects include triggering cancer [3]. The fact that some types of food are susceptible to rot is one of the reasons why formalin is often misused.

The use of formalin as a food preservative is invisible to the unaided eye. Tests that are commonly used to detect the formalin in foods are the formalin test kits or laboratory tests. However, these tests kit have several drawbacks, including they can only be used once and are unable to provide additional information about the levels of formalin in food. Whereas, the laboratory tests are quite costly. Therefore, technology must be utilized to resolve these issues.

In recent years, studies related to the identification of formalin levels in foods has been carried out, one of which utilizing gas sensors as electronic smell (e-nose). A study used the MQ-138 sensor to detect formalin and a photodiode sensor to detect rhodamine. The results reveal that formalin is found in several foods, such as noodles, salted fish, meatballs, and tofu. This study yielded a testing error value of 7% – 17% for formalin and 24% – 27% for rhodamine [4].

The subsequent study utilized the TGS2600 gas sensor to detect carbon monoxide (CO) and TGS2611 to detect methane gas, so it did not directly detect formalin gas [5]. Then, a study utilized HCHO sensors as formalin detectors. The HCHO sensor is a semiconductor volatile organic compounds (VOC) gas sensor. The conductivity of the HCHO sensor will change according to the concentration of VOC gas in the air [6].

Based on this, further research is needed to obtain a better formalin detection tool in terms of accuracy. Therefore, this research used the Mamdani fuzzy logic method to create a formalin detection tool using sensor arrays, namely the HCHO and MQ7 sensors. The HCHO detects formalin in the food, like the sense of smell; meanwhile, the MQ-7 sensor detects CO. Both sensors can also be referred to as e-nose. The HCHO sensor is a sensor that can detect formaldehyde (formalin), benzene, toluene, and alcohol. Since the HCHO detects more than just formalin gas, an additional sensor is also required to corroborate that the gas detected is formalin and not other gases. Therefore, the MQ-7 sensor is required to detect CO because formalin decomposes into CO and carbon dioxide at temperatures above 96 °C (its boiling point) [7].

The Arduino Mega 2560 works to control other components. The experiment results were displayed on the I2C LCD and the MIT App Inventor application was used to input data on a system utilizing a Bluetooth connection. The data were then stored on the SD card. The food testing only focused on salted fish and tofu. They were selected as the test materials because they are affordable side dishes that people often consume. Therefore, this study aims to detect the presence of formalin in tofu and salted fish using three food safety indicators: safe, cautious, and hazardous. This tool is designed in a small size to be more portable.

II. METODHOLOGY

The process of making a formalin detector tool was started with reading scientific articles. This process aims to analyze the

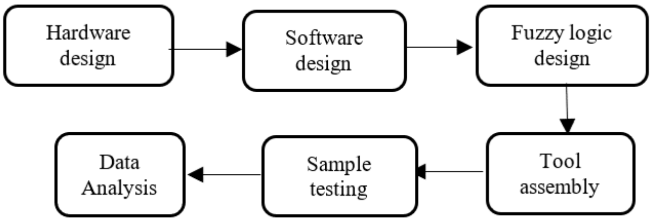


Figure 1. Research flow.

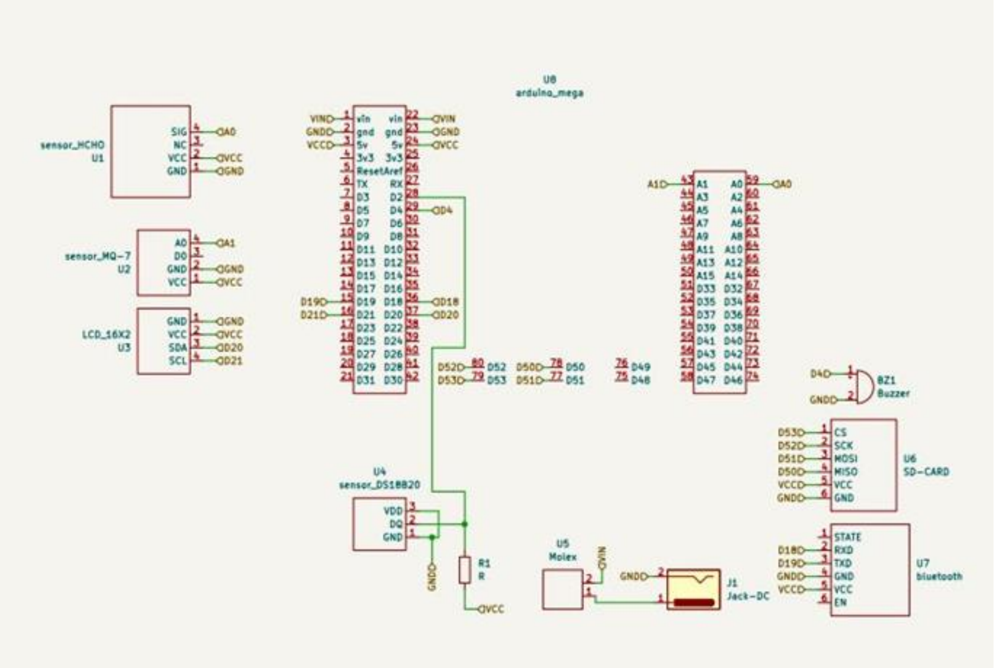


Figure 2. Circuit schematic.

advantages and disadvantages of previous studies. In order to be able to design a formalin detection tool, several stages are required. The flow of this research can be seen in Figure 1.

A. HARDWARE DESIGN

At the hardware design stage, a circuit schematic was made between the Arduino Mega 2560 and the HCHO sensor, MQ-7 sensor, DS18B20 temperature sensor, 16×2 I2C LCD, HC-05 Bluetooth module, microSD module, and buzzer. The connection of each component to the Arduino Mega 2560 is shown in Figure 2.

The Arduino Mega 2560 served as the brain of the formalin detection tool and the fuzzy logic processing site. The HCHO sensor functioned to detect formalin, while the MQ-7 sensor detected CO. The DS18B20 sensor detected the temperature during the testing process. The LCD was used to display the processed characters from the Arduino. In this study, besides being displayed on the LCD screen, data were also stored on the SD card. The means used for communication between the SD card and Arduino was the microSD module [8].

B. SOFTWARE DESIGN

Applications on Android were created using the MIT App Inventor application. The MIT App Inventor is a system for creating website-based Android applications [9]. It is a platform that facilitates the creation process of simple applications using code blocks. This application can also be used to design Android applications as desired by using a variety of available layouts and components.

The MIT App Inventor has two main pages: the designer page and the blocks page. The Android application design in the MIT App Inventor is shown in Figure 3. After the application design process on the designer page was complete, code blocks were created by dragging and dropping on the blocks page. The code blocks that were created are shown in Figure 4. Applications created in the MIT App Inventor can be installed by building an Android App (.apk) using six-character codes or scanning a QR code in the previously-installed MIT AI2 Companion on the handphone.

Figure 4 shows the code blocks used in creating applications via the MIT App Inventor website. The meaning of the code blocks is as follows. First, check the Bluetooth connection and select the appropriate Bluetooth. If it is connected, enter the characters into TextBox1, TextBox2, and TextBox3, which are the identities of the sample test. Press the Button1 or the send button afterwards. The process of sending sample data from applications on Android to Arduino initiates the sample testing process.

C. FUZZY LOGIC DESIGN

The method used in this study was the Mamdani method utilizing min-max operations [10], [11]. The advantage of fuzzy logic is that it can tolerate inaccurate data and generally can be used for actions in a system [12], while the advantages of the Mamdani method over other fuzzy inference system methods are that it is intuitive, covers a broad field, and is in accordance with the human information input process [13], [14].

The term fuzzy itself is defined as a condition that is not only true or false but also based on the degree of membership that ranges from zero to one [15]. In addition, fuzzy logic is

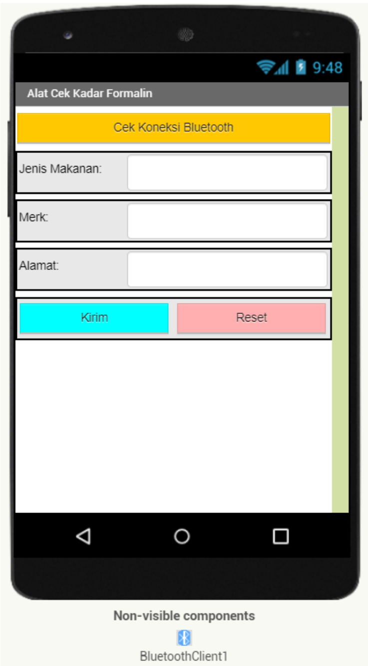


Figure 3. Application Design on the MIT App Inventor.

regarded as the right way to map the input space into the output space. Input and output spaces can be in the form of linguistic variables in lieu of numerical calculations [16]. In this study, there were two input variables, namely formalin and CO levels, in which both are in part per million (ppm). At the same time, the output variables were food safety indicators. The stages in each fuzzy process included fuzzification, inference, and defuzzification. In this study, fuzzy logic was used as knowledge to determine the presence of formalin and CO in tofu and salted fish. The inference system used in this study was the Mamdani method. The fuzzy logic design of the formalin detection tool is depicted in Figure 5.

Figure 5 was created using MATLAB software. MATLAB was used to visualize fuzzy logic designs. There are only two types of methods in the fuzzy toolbox in MATLAB, namely Mamdani and Sugeno.

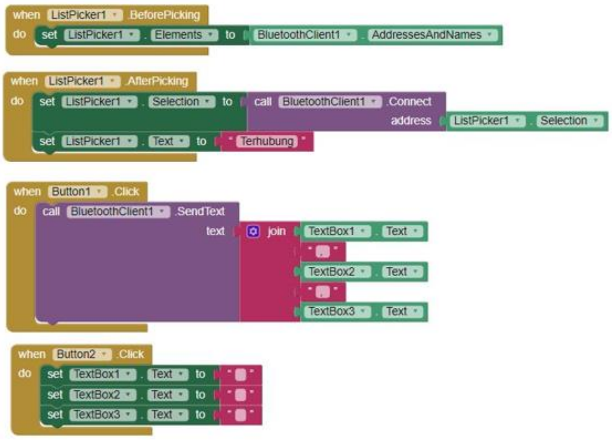
1) FUZZIFICATION

Fuzzification is the stage of converting crisp system inputs into linguistic variables by utilizing membership functions stored in the knowledge base [17]. It is the initial stage in fuzzy logic for all types of methods. The crisp input indicates that the value is not vague or can be said to be high and low.

According to the International Program on Chemical Safety (IPCS), in general, the threshold of formaldehyde in the body is 1 ppm [18]. The National Institute of Safety and Health (NIOSH) states that formaldehyde is harmful to health at levels of 20 ppm [19]. Meanwhile, the acceptable threshold for formalin ranges from 1.5 ppm to 14 ppm [20]. The membership functions $(\mu(x))$ for formalin are shown in (1), (2), and (3).

$$\mu_{low}(x) = \begin{cases} 0, & x \geq 14 \\ \frac{14-x}{14-1}, & 1 \leq x \leq 14 \\ 1, & x \leq 1 \end{cases} \tag{1}$$

$$\mu_{medium}(x) = \begin{cases} 0, & x \leq 1 \; or \; x \geq 20 \\ \frac{x-1}{14-1}, & 1 \leq x \leq 350 \\ \frac{20-x}{20-14}, & 14 \leq x \leq 20 \end{cases} \tag{2}$$



```
when ListPicker1 .BeforePicking
do  set ListPicker1 . Elements to BluetoothClient1 . AddressesAndNames

when ListPicker1 .AfterPicking
do  set ListPicker1 . Selection to call BluetoothClient1 .Connect
                                        address ListPicker1 . Selection
    set ListPicker1 . Text to " Terhubung "

when Button1 .Click
do  call BluetoothClient1 .SendText
                     text join TextBox1 . Text
                               " , "
                               TextBox2 . Text
                               " , "
                               TextBox3 . Text

when Button2 .Click
do  set TextBox1 . Text to " "
    set TextBox2 . Text to " "
    set TextBox3 . Text to " "
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Figure 4. Code blocks that were created on the MIT App Inventor.

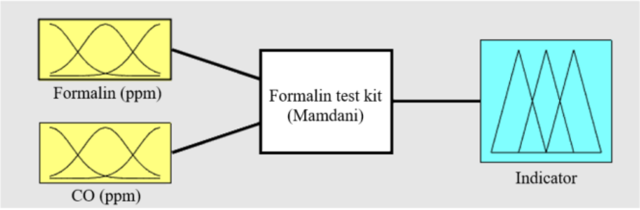


Figure 5. Fuzzy logic design.

$$\mu_{high}(x) = \begin{cases} 0, & x \leq 14 \\ \frac{x-14}{20-14}, & 14 \leq x \leq 20. \\ 1, & x \geq 20 \end{cases} \tag{3}$$

The membership functions of formalin comprise low, medium, and high, with predetermined thresholds in each function. CO concentrations are expressed between 0 – 1000 ppm, with 0 – 70 being low, 350 ppm being adequate, and 600 – 1000 ppm being high [21]. The membership functions for the CO are shown in (4), (5), and (6).

$$\mu_{low}(x) = \begin{cases} 0, & x \geq 350 \\ \frac{350-x}{350-70}, & 70 \leq x \leq 350 \\ 1, & x \leq 70 \end{cases} \tag{4}$$

$$\mu_{medium}(x) = \begin{cases} 0, & x \leq 70 \; or \; x \geq 600 \\ \frac{x-70}{350-70} & ,70 \leq x \leq 350 \\ \frac{600-x}{600-350}, & 350 \leq x \leq 600 \end{cases} \tag{5}$$

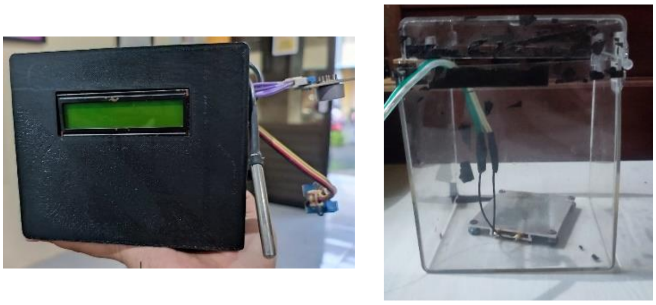
$$\mu_{high}(x) = \begin{cases} 0, & x \leq 350 \\ \frac{x-350}{600-350}, & 350 \leq x \leq 600. \\ 1, & x \geq 600 \end{cases} \tag{6}$$

There are three types of membership functions of CO, namely low, medium, and high, with predetermined thresholds in each function.

As with the two inputs, the output also has a membership function based on the knowledge base. The membership functions of food safety indicators are indicated in (7) until (9).

$$\mu_{safe}(z) = \begin{cases} 0, & z \geq 14 \\ \frac{2-z}{2-1.5}, & 1.5 \leq x \leq 2 \\ 1, & z \leq 1.5 \end{cases} \tag{7}$$

$$\mu_{cautious}(z) = \begin{cases} 0, & z \leq 1.5 \; or \; x \geq 2.5 \\ \frac{z-1.5}{2-1.5}, & 1.5 \leq x \leq 2 \\ \frac{2.5-z}{2.5-2}, & 2 \leq z \leq 2.5 \end{cases} \tag{8}$$



(a) (b)

Figure 6. Formalin testing tools, (a) main tool and (b) evaporation chamber of the test sample.

$$\mu_{hazardous}(z)a = \begin{cases} 0, & z \le 2 \\ \frac{z-2}{2.5-2}, & 2 \le z \le 2.5. \\ 1, & z \ge 2.5 \end{cases} \qquad (9)$$

There are three types of membership function indicators, namely safe, cautious, and hazardous, with predetermined thresholds in each function.

2) INFERENCE

At this stage, a rule base was designed to determine the formalin indicators found in salted fish and tofu using the Mamdani max-min inference. This logic rule was obtained from a combination of the HCHO and MQ-7 inputs as well as the food indicator output. The number of membership functions of each input and output variable was three, so the rule base obtained was nine.

3) DEFUZZICATION

The defuzzification stage is the stage of calculating the fuzzy output into a crisp output value. The inference system used in this study was the Mamdani inference system, using the center of area (CoA) or centroid method. Mathematically, CoA is shown in (10).

$$z^* = \frac{\int \mu(z)\, z\, dz}{\int \mu(z)\, dz} = \frac{Moment}{Area} \qquad (10)$$

where z^* is the CoA, $\mu(z)$ is the membership function of output, and z is variables value of output.

D. TOOL DESIGN

The research stage after designing the tool (schematic) was assembling the tool, including making the footprint and designing the printed circuit board (PCB) through the KiCad. After the design process was complete, it was continued with the PCB printing. Apart from making PCBs, three-dimensional casings were also made. The casing for PCBs was made using a three-dimensional (3D) printer with polylactic acid (PLA) plastic material, which is a type of bioplastic material or organic plastic made from vegetable oil, corn starch, pea starch, and microbiota. At the same time, the casing for the heater was made of acrylic. This material has a melting point of around 105 °C [22]. Acrylic was chosen because its attributes fit the testing needs. The maximum testing temperature is only up to 100 °C, therefore, it does not reach the melting point of acrylic. Since acrylic is transparent, the sample testing process can be seen clearly. The finished tool is depicted in Figure 6.

E. SAMPLE TESTING

After the tools were assembled, salted fish and tofu samples were tested. The first test employed a formalin detection tool using the Mamdani fuzzy inference system. Following the initial test was testing using a formalin kit to see the presence of formalin in foods. The results of the formalin kit test were used as a reference to see the accuracy of the results obtained through the tool that was made. In addition, the safety indicator values were compared with the indicator values from the MATLAB's Fuzzy Logic Toolbox.

TABLE I
TOFU SAMPLE TESTING

Tofu	Formalin (ppm)	CO (ppm)	Output	Indicator	Kit Formalin
A	11.97	54.50	1.58	Cautious	Positive
B	5.75	108.37	1.09	Safe	Negative
C	0.63	39.27	0.88	Safe	Negative
D	10.97	99.58	1.47	Safe	Negative
E	13.64	128.97	1.88	Cautious	Negative
F	1.34	74.60	0.91	Safe	Negative
G	2.14	79.39	0.93	Safe	Negative
H	0.60	60.11	0.88	Safe	Negative
I	4.32	71.85	1.02	Safe	Negative
J	5.89	65.76	1.10	Safe	Negative

TABLE II
SALTED FISH SAMPLE TESTING

Salted Fish	Formalin (ppm)	CO (ppm)	Output	Indicator	Formalin Kit
K	27.59	41.26	3.12	Hazardous	Positive
L	177.91	55.23	3.12	Hazardous	Positive
M	8.93	12.08	1.29	Safe	Negative
N	30.68	53.44	3.12	Hazardous	Positive
O	21.18	58.19	3.12	Hazardous	Positive
P	7.14	32.49	1.18	Safe	Negative
Q	18.93	164.80	2.99	Hazardous	Positive
R	19.18	83.93	3.04	Hazardous	Positive
S	15.85	62.48	2.63	Hazardous	Positive
T	193.81	60.11	3.12	Hazardous	Positive

F. DATA ANALYSIS

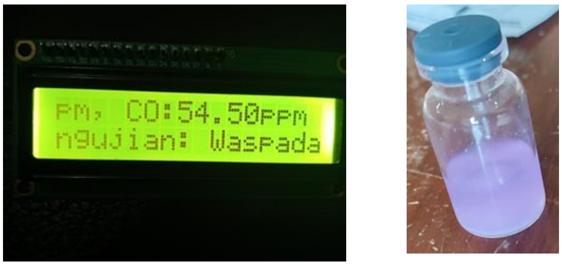
This stage involved the process of analyzing the data obtained from sample testing as the output of the fuzzy inference system process. The output values were compared to the results of the formalin and MATLAB kits. A comparison between output values of the tool and the reference could determine the accuracy values obtained from the tool that was made. The performance of the tool that was made could be seen from the accuracy percentage obtained using (11) [23].

$$Accuracy(\%) = \frac{\Sigma correct\ data}{N} \times 100\% \qquad (11)$$

where N denotes the total sample tested. In addition to the accuracy value, the discrepancy (measurement error) must also be known. Calculating the percentage error value derived from a comparison of sensor readings and testing instruments is crucial for determining the viability of a created tool. The discrepancy percentage (Z) is shown in (12).

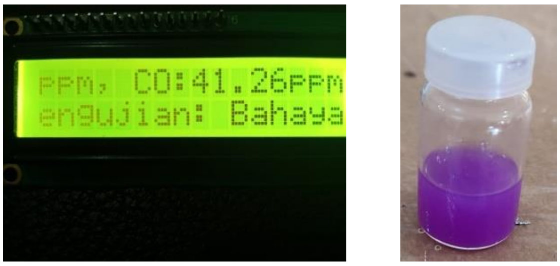
$$Z = \frac{|X - X_i|}{X} \times 100\% \qquad (12)$$

where X is the reference or standard value and X_i is the measured value of the created tool.



(a) (b)

Figure 7. Results of cautious sample testing, (a) LCD and (b) formalin kit.



(a) (b)

Figure 8. Results of hazardous sample testing, (a) LCD and (b) formalin kit.

III. RESULT AND DISCUSSION

The role of fuzzy logic in this study was to determine the results when taking sample data. Fuzzy logic decided the test indicator values for safe, cautious, and hazardous scales on the test samples. The output of this research, namely safety indicators, was determined after going through a series of processes in fuzzy logic, namely fuzzification, inference, and defuzzification, according to the knowledge base or based on experts.

After the formalin detection tool was made, ten samples of tofu and ten samples of salted fish were tested using that tool, and the results were compared with those from the formalin kit as comparison data. In the testing process using the tool, samples must be evaporated using a heater, and the DS18B20 temperature sensor would detect the temperature. Vapor from the sample was detected by the HCHO sensor and the MQ-7 sensor. The presence of formalin and CO was tested when the temperature was above 96 °C [7]. Table I and Table II, respectively, display the findings from the testing of the tofu and salted fish samples. According to Table I, only one data from the tofu sample differs between the results of the formalin test tool and the formalin kit test, namely on the tofu sample E. In testing the tofu sample E, the result from the formalin kit was negative, but the results using the tool was cautious, with the tool indicator value (as output) being 1.88. Nonetheless, this cautious indicator falls between safe and hazardous results, so it can be concluded that the value is close to the results of the formalin kit test. These different results likely stem from inaccurate gas sensor readings. The accuracy value of testing ten samples of tofu was 90%.

Following the testing of ten tofu samples, ten salted fish samples were tested. Based on Table II, all data from the results of testing salted fish using the tool are in accordance with the test data using the formalin kit, indicating that it is 100% accurate. When viewed from the total of all tests, there were a total of twenty samples, namely ten tofu samples and ten salted fish samples, so the accuracy of the entire test was 95%. This accuracy value is very high, so the performance of the tool that has been made is adequate and satisfactory.

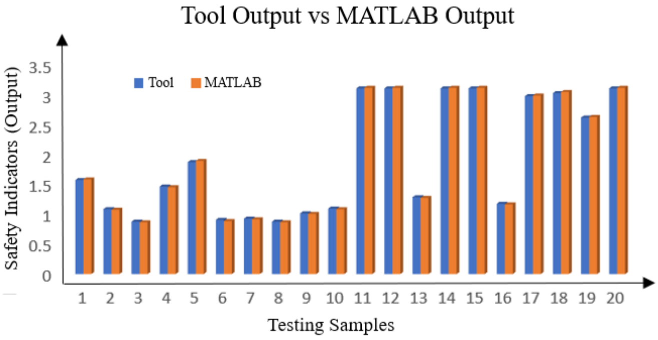


Figure 9. Comparison of the tool and MATLAB outputs.

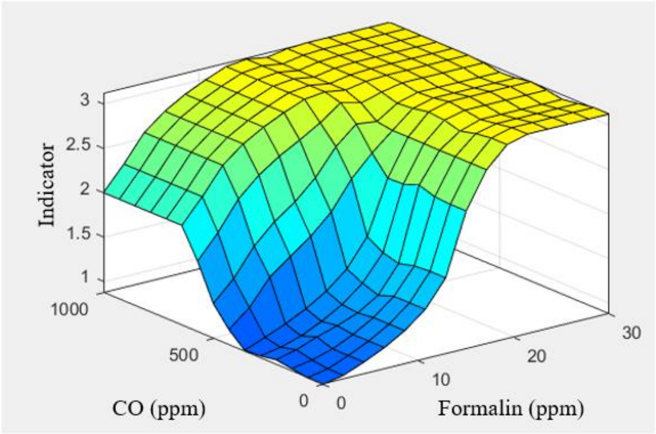


Figure 10. Graphic of three-dimensional output in MATLAB.

Table I and Table II demonstrate that when the formalin test results are negative, there are two possible conditions on the tool: cautious and hazardous conditions. It is due to the rules made in the Mamdani fuzzy inference system based on the values of formalin and CO levels detected on the tool. Tests using the formalin kit only show two conditions, namely positive with the original color of the sample and negative with the color indicator changing to purple. As shown in Figure 7 and Figure 8, when the results show negative, the dark level of the purple varies, ranging from light purple to dark purple. The purple color level indicates the level of formalin contained in the sample. However, the formalin kit cannot directly show the level of formalin in ppm, so the results only show positive or negative formalin content by looking at the color change. It is different from the created tool, which can show formalin levels, CO levels, and safety indicators from samples according to the Mamdani fuzzy inference process. Therefore, if the reference is to use a formalin kit, the only thing that can be compared is the presence of formalin in food samples without comparing the levels of formalin in ppm.

Based on Figure 7 and Figure 8, it can be concluded that the higher the safety indicator value of the test sample from the created tool, the darker the purple color obtained from the results of the formalin kit. The level of purple color concentration generated by the formalin kit shows the higher concentration of formalin in the test sample. However, this concentration level is not indicated by a value in ppm, only by a change in color to purple. It is one of the drawbacks of using formalin kits because they are typically used for rapid testing. The indicators that appear from the tool during the testing corresponds to the rule base of the membership function of the input variables (formalin and CO) and output variables (indicators).

In addition to the comparison of the results of the two tests, it is also possible to compare the output values, namely safety indicators, of the tool with the results of the Mamdani fuzzy simulation method using MATLAB, as shown in Figure 9.

The graph shown in Figure 9 is a comparison between the output generated by the tool (blue bar graph) and the output obtained from MATLAB (orange bar graph). The output produced by the tool was nearly the same as that of MATLAB, differing only in the decimal; that is, 85% of the test samples had a difference of 0.01, while the rest, that is 15%, had a difference of 0.02. One of the differences in these values is due to rounding, while the average error between the tool output and MATLAB was 1.15% or 0.0115. This error value remains relatively small. The smaller the error, the better the measurement results, indicating that the tool that has been made has good measurement accuracy.

In this study, formalin levels in ppm could not be compared to the reference because the reference was only the formalin kit. The laboratory test must be conducted if one wishes to confirm the formalin level.

However, the output of the tool can be compared with the results obtained from MATLAB. The output comparison with MATLAB was only used to validate that the coding made and uploaded to the tool was correct since the output value obtained from the tool was very close to the output of MATLAB. This study used the Fuzzy Logic Toolbox by providing the same input data as the tool.

From the Fuzzy Logic Toolbox in MATLAB, it can be seen the three-dimensional surface of the input and output. A three-dimensional graph depicting the two inputs and one output from MATLAB is shown in Figure 10. In this graph, the darker the blue, the safer the food is. On the other hand, the darker the yellow in the graph, the more hazardous the food is. If the color is between blue and yellow, it indicates a cautious condition.

IV. CONCLUSION

Implementing the Mamdani method of fuzzy logic, this study has successfully produced a tool for detecting the presence of formalin in food. In other words, the tool developed in this study has successfully detected the presence of formalin. The amount of formalin was not measured, as the reference tool was only a formalin kit. However, the resulting output was very close to the results obtained in MATLAB. The lowest formalin found in the tofu sample, namely sample H, was 0.60 ppm; in contrast, the highest content of formalin was found in sample E, with 13.64 ppm. In salted fish, the lowest formalin content was found in sample P, with 7.14 ppm; meanwhile, the highest level was found in the salted fish sample, namely sample T, with 193.81 ppm. The overall accuracy of the testing of twenty samples was 95%. The average error between the tool and MATLAB outputs was 1.15%.

Based on the study that has been done, there are several suggestions for better results obtained. First, the comparison tool for measuring formalin levels should be conducted by testing formalin in the laboratory. Thus, not only can indicate positive and negative, but the formalin levels in ppm yielded from the tool can also be compared. Second, the formalin detection gas sensor should use a single gas sensor, which is specifically used to only detect formalin. By doing so, no other gases will be detected.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTION

Conceptualization, Indri Yanti; methodology, Indri Yanti; system design, Cyntiya Laxmi Haura, Indri Yanti, and Muh Pauzan; software, Cyntiya Laxmi Haura, Indri Yanti, and Muh Pauzan; anlysis, Cyntiya Laxmi Haura, Indri Yanti; writing—original draft preparation, Cyntiya Laxmi Haura; writing—review and editing, Indri Yanti and Muh Pauzan.

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