Formalin Detection System in Fish with HCHO Sensor and pH Sensor Using Fuzzy Logic Method

Rainhart Sitohang[1], Illa Aryeni[1], Hana Mutialif Maulidiah[2], Ririn Humaera[1], Handri Toar[3*], and Jum Malindo Siregar[1]

[1]Electronics Engineering Technology Study Program, Electrical Engineering Department, Politeknik Negeri Batam, Batam, Indonesia
[2]Manufacturing Electronics Engineering Study Program, Electrical Engineering Department, Politeknik Negeri Batam, Batam, Indonesia
[3]Power Plant Engineering Technology Study Program, Electrical Engineering Department, Politeknik Negeri Batam, Batam, Indonesia

*Email: toar@polibatam.ac.id

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***Abstract*—This study aims to design a system for detecting formalin and pH levels in fish using the Mamdani Fuzzy Logic method. The system consists of an HCHO sensor and a pH sensor as the system input, and an Arduino Mega 2560 microcontroller as a data processor. The data is processed in real-time and classified into three categories. Testing was carried out on snapper samples with a duration of 1–60 minutes and 10 repeats of the experiment. The results of the study showed that the accuracy rate of the system was 91%. The system can identify formalin levels and classify them into safe (0 ppm formalin, pH 6,5), alert (12,42 ppm, pH 6,64), and danger (19,29 ppm, pH 5,42). The implementation of this system can facilitate the direct detection of formalin in fish and can help increase public awareness of the dangers of formalin.**

Keywords: Arduino Mega 2560, Fish, Formalin, HCHO Sensor, Mamdani Fuzzy Logic, pH Sensor.

I. INTRODUCTION

The Riau Islands Province has a very strategic geographical position, stretching from the Malacca Strait to the South China Sea adjacent to the Natuna Islands with an area of 251,810 km². The province is dominated by waters, with 96% of its total area being ocean, while only 4% is land. This geographical advantage not only makes the Riau Islands a major gateway for maritime activities and trade, but also as a region that has great potential for the development of a marine-based economy and produces a very significant diversity of fish [2].

Fish is a very important food source for humans because it is rich in protein, omega-3 fatty acids, vitamin D, and various other essential micronutrients [3]. One type of sea fish that has high nutritional value and is in great demand by the public is snapper, this fish is famous for its delicious and savory meat and high protein content.

To maintain the quality of fresh fish and prevent spoilage, sellers usually carry out preservation [4]. The commonly used preservation method is cooling by utilizing ice blocks, this method functions to maintain the temperature of the fish and slow down the growth of microbes that cause decay. However, this method has several drawbacks, including uneven cooling and the potential for physical damage to fish that causes a decline in fish quality. In addition, this method requires a large storage space, quite complicated handling and operations, and a lack of supply of ice blocks.

This encourages some sellers to carry out fraudulent practices using formalin as a fish preservative. Formalin is a chemical compound that is shaped like a gas or liquid with the chemical formula H2CO. Formalin is one of the chemicals that is prohibited from being used in food as a preservative [5], because it can cause health problems for humans such as poisoning, respiratory disorders, skin irritation, and cancer.

Several previous studies have proposed a tool to detect formalin content in fish and other types of foodstuffs. In the study [6], one sensor was used, but the system was already integrated with the Internet of Things (IoT). Furthermore, in the study [7], the K-Nearest Neighbor method was used with an accuracy rate of 90%. Research [8] resulted in an accuracy rate of 92% using three sensors. Then in the study [9] using the image processing method but it is susceptible to light interference, and in the study [10] using two sensors, namely HCHO and MQ7 with an accuracy rate of 95%.

Based on the problems and results of previous research, in this study a formalin detection system in fish was designed using the Mamdani Fuzzy Logic method which can classify formalin levels in snapper with safe conditions (fish do not contain formalin), alert (fish with moderate formalin levels), and danger (fish with high formalin levels). This research is designed using several components, such as HCHO sensors which are useful for detecting formalin gas, pH sensors as a measure of acidity in fish and then processed by an Arduino Mega 2560 microcontroller, and the detection results will be displayed on the LCD. LED as an indicator of the classification of three categories of formalin content in fish, and the buzzer will emit a sound according to the condition of the detected fish.

II. METHOD

A. Research Flow

This research is carried out in stages to ensure that each process runs systematically and according to the goals that have been set. The research begins with problem identification and literature study, then the design and creation of the system is carried out. The final stage is to test and analyze the system. The research flow can be seen in Figure 1.

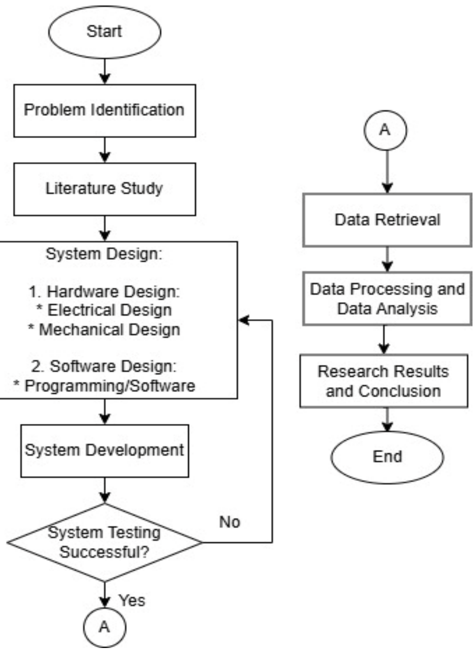


Figure 1. Stages of Research

B. System Block Diagram

A block diagram of the formalin detection system in fish can be seen in Figure 2. The system is designed with three main components, namely inputs, processes, and outputs that are integrated with each other to form an effective and responsive system. At the input stage, data was obtained from the test object in the form of snapper which was observed using the Grove HCHO sensor to detect formalin content and the pH sensor to measure the level of acidity or alkalinity (Potential of Hydrogen). The data from the reading of these two sensors is sent to the Arduino Mega 2560 microcontroller which acts as a processing center. The Mamdani Fuzzy Logic algorithm is run to process and classify test results into safe, alert, and danger categories.

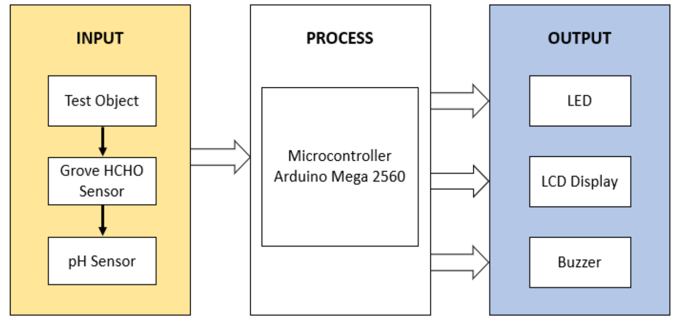


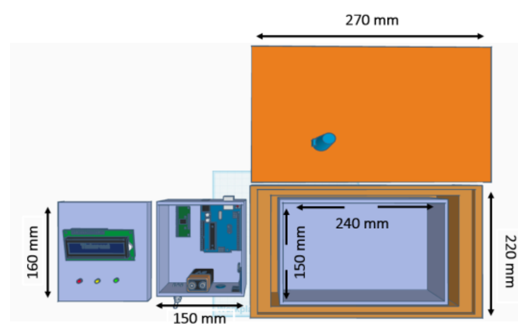
Figure 2. System Block Diagram

The information from the processing results is displayed through an output block consisting of an LCD that functions to display informative data including formalin content, pH value, and the results of the classification of fish safety levels. LEDs are used as visual indicators that will illuminate (ON) according to the classification results and provide an easily recognizable sign by the user. Meanwhile, the buzzer serves as a sound alarm that will sound with a certain pattern or tone based on the level of danger detected.

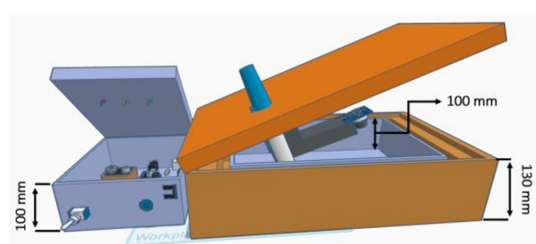
C. Mechanical Design

The system is designed to easily detect formalin and pH levels in fish, then classify them. The system is designed to be portable, which makes it easy to use and test. The mechanical design in this study can be seen in Figure 3.

The mechanical design is made using PVC (Polyvinyl Chloride) material with a 2-box design, consisting of a control box and an object testing box. The control box is 150 mm x 160 mm, while the Test box is 270 mm x 220 mm. Then inside the object box there is a test container measuring 240 mm x 150 mm which functions as a container to place the test sample object.



(a)



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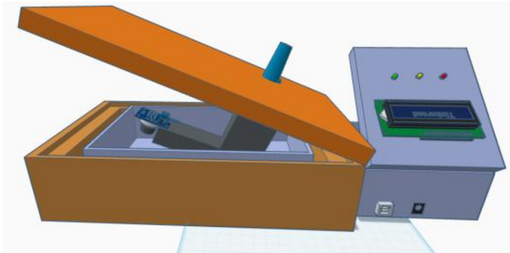

(c)

Figure 3. Mechanical Design, (a) Top View (b) Side 1, (c) Side 2

D. Electrical Design

In this study, electrical design is carried out through the process of integrating several key electronic components that are designed synergistically to form a complete work system. The electrical network on this system can be seen in Figure 4.

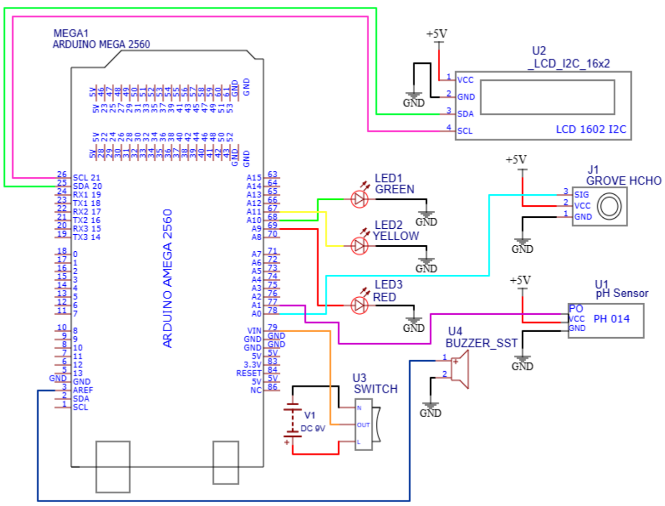

Figure 4. Electrical Design

The Arduino Mega 2560 microcontroller is used as the main controller unit in this system. The microcontroller functions to read the analog signal generated by the HCHO sensor which is useful for detecting formalin levels and the pH sensor to measure the acidity or alkalinity of the solution in the fish. The analog signal received by the microcontroller will be further processed and classified using a fuzzy logic algorithm, resulting in outputs in the form of fish condition status, namely safe, alert, and danger based on the combination of detected formalin and pH values. For the power source, this system uses a 9V battery as the main power supply, the use of this battery allows the tool to operate portable, thus facilitating the testing process and direct use in the field without relying on an external power source. The electrical design features the array of circuits and the relationships between the sensor pins and the Arduino Mega 2560. Details of the connections between the pins can be seen in Table 1.

TABLE I
CONFIGURATION OF EACH PIN

HCHO Pin Sensor	Arduino Mega 2650 Pin
VCC	5V
GND	GND
SIG	A0
Sensor pH Pin	Arduino Mega 2560 Pin
VCC	5V
GND	GND
PO	A1
DO	2
TO	A2
LCD I2C Pin	Arduino Mega 2560 Pin
VCC	5V
GND	GND
SCL	SCL
SDA	SDA
Pin LED	Arduino Mega 2560 Pin
LED Green	10
LED Yellow	11
LED Red	9
Push Buzzer	Arduino Mega 2560 Pin
Positive Pin	3
Negative Pin	GND

E. Software Design

The software on the system for detecting formalin and pH levels in fish is designed using the Mamdani Fuzzy Logic method to classify the measurement results into three categories: safe, alert, and danger. The system operates automatically with control by an Arduino Mega 2560 microcontroller using the C programming language via the Arduino IDE platform. A system flowchart or system flowchart is shown in Figure 5.

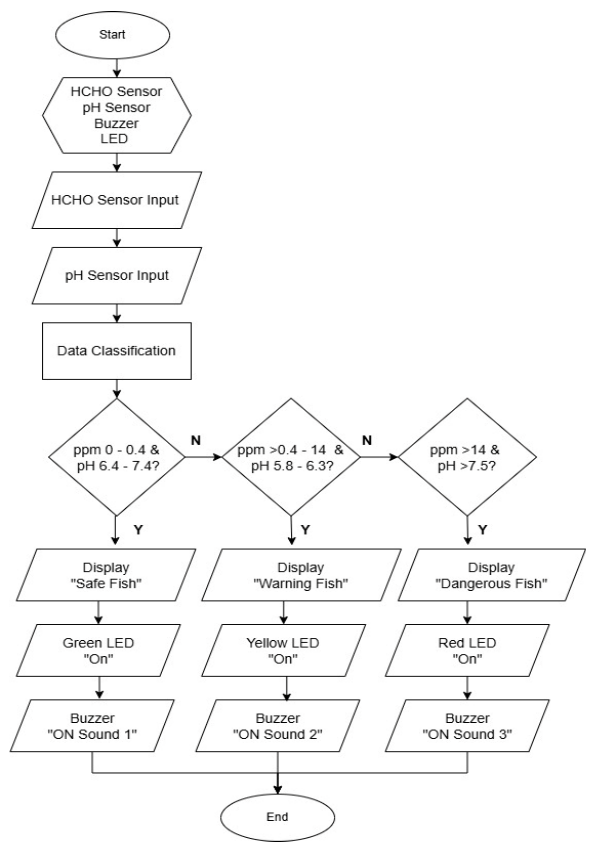

Figure 5. System Flowchart

F. Fuzzy Logic Algorithm Implementation

The classification of the level of safety in fish is carried out using the fuzzy logic method, by determining the formalin level and pH value as the membership function. In this method, the range of values of each sensor is used as a fuzzy domain, which is then classified into three sets of safe, alert, and danger. The entire process is carried out automatically by a microcontroller that has been programmed to handle all input and output activities. The sensor values that are read are then processed through the stages of fuzzification, inference, and defuzzification to produce an output that represents the status and safety condition of the fish based on the detected samples.

1) Membership Function of Formalin

Formalin is a dangerous chemical compound that can have a serious impact on human health. Its use in processed fish is very risky, both in the short and long term. The level of this danger depends on the dose and length of exposure in the body. If the amount of formalin entering exceeds the threshold, damage can occur to various organs and systems of the body. In the short term, exposure to formalin can trigger irritation of the respiratory and digestive tracts, accompanied by symptoms such as nausea, vomiting, and dizziness. Meanwhile, prolonged exposure has the potential to cause permanent damage to the liver, kidneys, heart, spleen, and trigger cancer in the body and accelerate the aging process [11].

The determination of formalin levels in food is carried out based on regulatory and scientific references to group formalin values into three fuzzy sets. The "Few/Low" membership degree is determined by referring to the Regulation of the Minister of Health of the Republic of Indonesia Number 722/Menkes/Per/IX/1988 which emphasizes that there is no tolerance for the presence of formalin in foodstuffs, so the membership value is at zero. The "Medium" membership degree is based on information from the IPCS, an agency under the WHO, ILO, and UNEP, which sets a daily intake limit of formalin in food between 1.5–14 mg per day or a maximum of 0.2 mg/liter [12]. Meanwhile, the "Many/High" membership degree is set at 20 ppm as per the threshold declared to be a risk to human health by NIOSH and is used as the highest limit in the fuzzy model applied. These three references are used as the basis for compiling the fuzzy membership function to classify formalin levels.

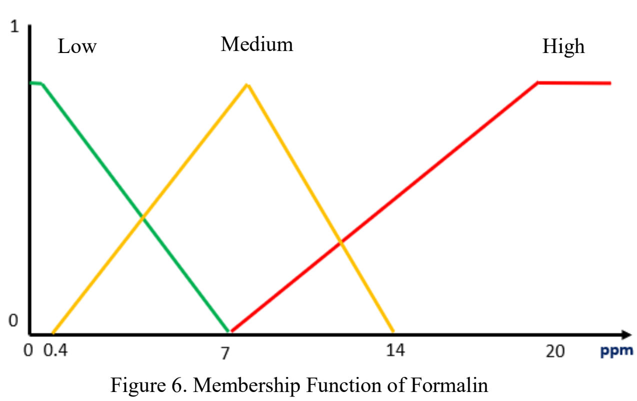

Figure 6. Membership Function of Formalin

A graph of formalin membership function can be seen in Figure 6, which explains that in the "Low" category with a value in the formalin concentration range (0 – 0,4 ppm) low formalin levels are declared. Meanwhile, in the "Medium" category with a value range (0,4 - 14 ppm) it is a medium formalin level, but in the "High" category with a concentration value (14 - 20 ppm) it shows a high formalin level.

2) Membership Function of pH

The freshness level of fish can be identified through pH value analysis, which serves as an important physiological indicator after harvest or fishing. The change in pH in fish tissue reflects an ongoing biochemical phase [13]. The three main phases that are the reference for classification are pre-rigor, rigor mortis, and post-rigor. The pre-rigor phase has a pH range between 6,9 to 7,2; the rigor mortis phase is in the range of 6,2 – 6,6; and the post-rigor phase is in the range of 7,5 – 8,0 [14].

The pH condition of fish undergoes a gradual change that affects the quality and feasibility of consumption. The initial phase of pre-rigor maintains a pH of 6.9–7.2 with the physical characteristics of fresh, elastic meat, brilliant red gills, protruding eyeballs, and clear corneas, this condition indicates high-grade fish. The transition to the rigor mortis phase lowers the pH to 6,2 – 6,6 through lactic acid accumulation, which results in a stiff fish texture, slightly slimy and less bright red in color, this condition indicates that the fish is reduced in quality but is still safe to consume. In the post rigor phase, proteolytic activity triggers a pH increase of 7,5 – 8,0 accompanied by the formation of alkaline compounds that degrade organoleptic qualities and increase safety risks. The physical condition of the fish towards decay is sunken eyeballs, blurred corneas, grayish gills, soft flesh, and leaves permanent marks if pressed and emits an unpleasant odor, so consuming fish at this stage should be avoided [15]. Fish in the pre rigor and rigor mortis phases generally still have good quality, while fish in the post rigor phase tend to decay which triggers the formation of harmful compounds such as histamine. Histamine is formed from the amino acid histidine through a decarboxylation reaction by the enzyme histidine decarboxylase produced by decay microorganisms. Consumption of fish with high histamine levels can cause scombroid poisoning, characterized by symptoms such as flushed face, headache, nausea, and heart palpitations. If left untreated, this condition has the potential to pose a chronic health risk [16].

The information from the previous study was used as a reference in compiling the fuzzy membership function on the pH variable, which was then used in the fish freshness level classification system in this study. Figure 7 is a graph of the function membership of pH with three fuzzy sets, namely rigor mortis, pre rigor, and post rigor with a pH value range from 0 to 14.

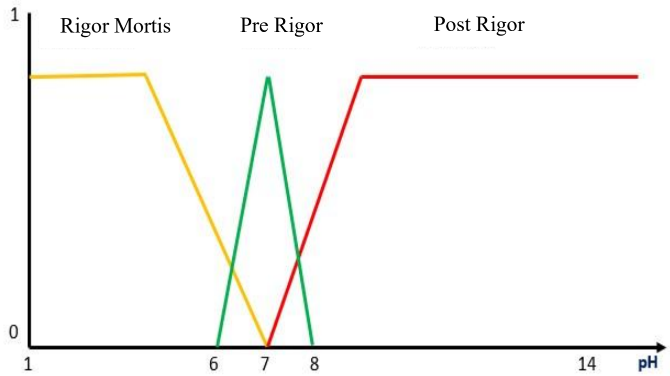

Figure 7. Membership Function of pH

Figure 7 shows that on the yellow line in the rigor mortis phase with a pH range value (5,8 – 6,3), the physical condition of the fish is rigid and has decreased fish freshness. Meanwhile, the green line with the pre-rigor phase with a pH range value (6,4 – 7,4) shows that the physical condition of the fish is still fresh. However, the red line in the post rigor phase with a pH range value of around (7,5 - 14) indicates that the fish is starting to rot and has an unpleasant smell.

3) *Fuzzy Rule Base*

In a fuzzy logic system, the rule base serves as the core of decision-making. These rules are written in an "IF–THEN" form and are designed to relate the combination of input values from the sensor to the desired output result [17]. Fuzzy rules are created based on the reading values of the HCHO sensor (formalin level) and the pH sensor, which are then classified into safe, alert, or danger categories. Fuzzy Rule Base can be seen in Table II.

TABLE II
FUZZY RULE BASE

Fuzzy Rule Base		pH		
		Rigor Mortis	Pre Rigor	Post Rigor
Formalin	Low	Safe	Safe	Danger
	Medium	Alert	Alert	Danger
	High	Danger	Danger	Danger

Based on Table II, the determination of the level of safety of fish consumption is carried out through a combination of formalin level parameters and pH conditions that represent the physiological phase of fish. Safe conditions are generally at very low formalin levels or close to zero ppm, with pH values still in the neutral range, so the risk to health can be said to be minimal or suitable for consumption. Under alert conditions, formalin levels begin to increase, and pH tends to change to abnormal limits, indicating a higher potential danger. If left unchecked, this condition can cause health problems such as irritation, headaches, nausea, and organ damage in the long term. Meanwhile, the danger conditions show high formalin levels with a pH that is far from normal, which has the potential to pose chronic risks such as respiratory problems, liver and kidney damage, and even cancer risk if exposure continues to occur. Therefore, this classification is important as an early detection guide, so that preventive measures can be taken immediately before serious health impacts occur.

4) *Defuzzification*

At the defuzzification stage, the system converts the fuzzy result into a firm numerical value. The method used is generally to find the center point (centroid) of the area of the active output membership curve. This value is the final representation of the results of the fuzzy process that will be used for system decision-making [18]. The fuzzy output indicator can be seen in Figure 8.

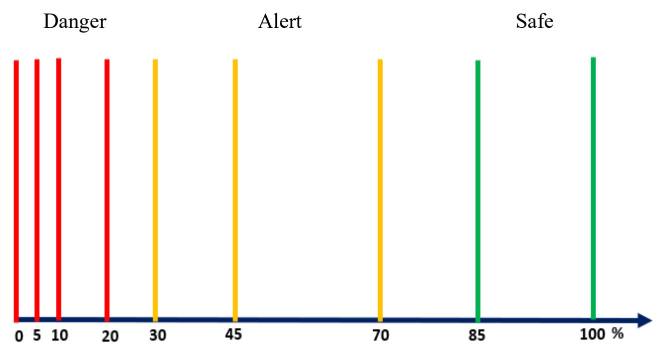

Figure 8. *Fuzzy* Output Indicator

The category indicator of the defuzzification results from Figure 8 explains that on the horizontal axis it states the level of safety of formalin content, while the vertical line is the limit of the category, namely danger (0 - 20%) marked with a red line indicating that the detected formalin level is not safe for consumption. For the alert category (20 - 70%), it is marked with a yellow line indicating that formalin levels are at medium level that is still potentially harmful if consumed, while in the safe category (70 - 100%) it is marked with a green line indicating that formalin levels are not detected and safe for consumption.

III. RESULTS AND DISCUSSION

A. *Results of a Formalin Detection System in Fish*

This tool is designed to detect formalin content in fish quickly and accurately, and can be used portably, allowing direct field use. The mechanical design uses lightweight, moisture-resistant PVC, which supports mobility and makes the testing process easier for users. The sample chamber is made in a closed condition to minimize the influence of outside air contamination and maintain the stability of gas concentrations during the detection process. The control suite is designed in a separate compartment from the sample chamber to minimize exposure to formaldehyde vapor and to reduce fluctuations in high humidity, thereby reducing the risk of damage to electronic components and maintaining the system's performance and durability in long-term use. This system uses a 9V battery as its power source, so the tools operation does not depend on an external power source and can still function independently under various environmental conditions. The results of making formalin detection devices and their descriptions are shown in Figure 9.

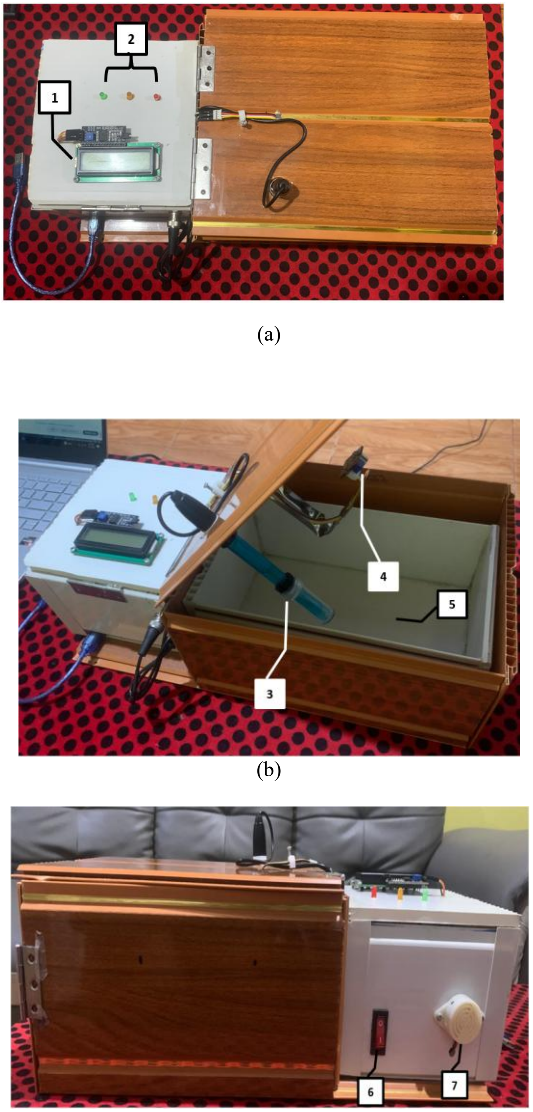

Figure 9. Formalin Detection Devices (a) Top View, (b) Front View, (c) Rear View

Figure description as follows: 1. LCD; 2. LED; 3. pH sensor; 4. HCHO sensor; 5. Box Sample; 6. Switch Button; and 7. Buzzer.

B. Sensor Testing

This test was carried out using a pH sensor as a measure of acidity and a Grove HCHO sensor to measure formalin levels in snappers. Before taking measurements, both sensors are first calibrated to ensure that the appliance is operating in optimal condition and providing accurate results. The pH level measurement was carried out by weighing 10 grams of snapper samples, then homogenized with 10 ml of aquadest. After the homogeneous solution, the pH meter electrode is inserted into the solution and left for approximately 1–2 minutes until the displayed pH value is stable or unchanged [19]. Meanwhile, formalin levels were measured using the Grove HCHO sensor by placing fish samples in a closed test chamber (test box). The sample is left in the test chamber so that formaldehyde gas can accumulate optimally in an enclosed space, so that the sensor can detect the gas concentration optimally and stably. The test was carried out on five samples of snapper that had been mixed with 15% formalin and tested at a time range of 1 minute, 5 minutes, 10 minutes, 30 minutes, and 60 minutes. Each sample was tested, then repeated five times to ensure consistency and accuracy of the data. From the test, a total of 15 measurement data were obtained which were then analyzed to assess the accuracy and stability of the readings from the two sensors.

1) HCHO Sensor Testing

In HCHO sensor testing, calibration is carried out to obtain a value from the sensor reading, calculating the resistance of the sensor during measurement with the following formula:

$$R_s = \frac{Vref}{Vout} - 1 \,.\, R_L \quad (1)$$

In the program:

$$R_s = \frac{1023}{ADC} - 1 \,.\, R_o \quad (2)$$

Formula description as follows, R_s for Resistance during measurement; R_o for Resistance when the air is clean; ADC for Analog read values; V_{ref} for Voltage (V); and R_L for Load resistor.

The sensor generates an analog signal that is converted into a resistance value R_s. After that, compared to the resistance R_o taken at 0 ppm clean air condition. Based on the logarithmic relationship between $log_{10}(R_s/R_o)$ and log_{10}(ppm), with the following regression equation.

$$\text{Ppm} = 10^{\frac{log_{10}.R_s/R_o - a}{b}} \quad (3)$$

Formula description as follows, Ppm for Concentration value; R_s for Resistance during measurement; R_o for Resistance when the air is clean; a for Intercept value; and b for Results of linear regression.

After calibration, HCHO sensor testing was then carried out using a fish sample that had been mixed with formalin as much as 100 ml with a concentration of 15% in the mixing time variation, namely 1 minute, 5 minutes, 10 minutes, 30 minutes, and 60 minutes.

TABLE III
HCHO SENSOR TESTING

No	Mass (gr)	Time (minutes)	Ppm	Formalin Level
1.	0.72	1	2,52	Medium
2	0,185	5	4,30	Medium
3	0,80	10	10,09	Medium
4	0,67	30	12,14	Medium
5	0,76	60	19,31	High

Table III shows the results of the HCHO sensor test with the variation in the length of the time of soaking in formalin solution under closed conditions. The test results showed that fish that were left for 1 minute had a formalin level of 2,52 ppm, so it was categorized as "medium". Meanwhile, fish that were left for 60 minutes showed a formalin level of 19,31 ppm and were categorized as "high". This pattern of increasing formalin levels with increased soaking time is in line with the findings of the study [6], which also showed that the longer the contact time with the formalin solution, the higher the formalin levels detected. Thus, the data obtained in this test can be declared valid and consistent with the results of previous research, so that it can be used as a basis for determining the category of formalin in fish.

2) pH Sensor Testing

pH sensor testing is carried out through the calibration stage to obtain accurate measurement results that are in accordance with pH standards. The linear regression method is a statistical analysis technique used to model the relationship between one independent variable and one dependent variable using a straight line equation [20]. The formula used in the pH sensor calibration process is as follows:

$$pH = mV + C \quad (4)$$

Formula description:
pH : the measured pH value of the solution
m : calibration line tilt
V : the output voltage of the pH sensor measured from the solution
C : value of calibration line shift

The pH sensor calibration process is carried out using two standard buffer solution points, namely pH 4,01; pH 6,86; and pH 9,18 to ensure the accuracy of sensor readings in different pH ranges. The test was carried out on the three buffer solutions and repeated five times to test the accuracy of the sensor readings, as well as determine the sensor's response to different pH conditions.

TABLE IV
PH SENSOR CALIBRATION

No	Buffer Solution	pH	Sensor Output Voltage (V)	ADC Value
1.	Acid	3,96	4,02	822
		3,95	4,02	822
		3,97	4,02	822
		4,00	4,02	822
		4,01	4,02	822
2.	Neutral	6,97	3,62	740
		6,98	3,62	740
		6,98	3,62	740
		7,00	3,62	740
		7,00	3,63	740
3.	Base	9,18	3,32	678
		9,18	3,32	678
		9,17	3,32	678
		9,16	3,32	678
		9,18	3,32	678

The reading of the ADC value to the actual value is obtained from the calibration equation of the pH sensor as follows:

$$pH = - 0,03594\ ADC + 33,81 \quad (5)$$

The formula used in converting the ADC value to the actual pH, in order to get the ADC value from the actual pH, the inversion of the equation is carried out as follows:

$$ADC = \frac{33,81-pH}{0,03594} \quad (6)$$

Based on Table IV, the calibration of the pH sensor can be included, that an acid solution with a pH value (3,96 – 4,01) produces an ADC value of 822 with a sensor output voltage of about 4.02V. Meanwhile, a neutral solution with a pH value of 6,97 – 7,00 shows an ADC value of around 740 with a sensor output voltage of around 3,62V. However, alkaline solutions with pH values of 9,16 – 9,18 produce an ADC value of around 678 with an output voltage of 3,32V. From the five repetitions of each solution, the ADC value obtained showed full consistency (no change in the ADC value), so that the standard deviation of the ADC reading was close to 0. In the acid solution, an average pH of 3,98 with a maximum deviation of ±0,03 was obtained, so that the relative variation of the measurement was:

$$\frac{0,03}{3,98} \times 100\% \approx 0,75\%$$

In a neutral solution, the average pH obtained is 6,98 with a maximum deviation of ±0,02, resulting in relative variations:

$$\frac{0,02}{6,98} \times 100\% \approx 0,29\%$$

Meanwhile, in the alkaline solution, an average pH of 9,17 with a maximum deviation of ±0,01 was obtained, so that the relative variation became:

$$\frac{0,01}{9,17} \times 100\% \approx 0,11\%$$

All variations were relatively below 1%, indicating that the measurement deviations were very small and were still within acceptable tolerance limits for food quality monitoring applications.

C. System Testing with Snapper Samples

The system test was carried out on ten snapper samples, namely two formaldehyde-free snapper tested for 10 and 20 minutes, with 10 repetitions. Then, testing was conducted on eight samples of snapper that had been mixed with formalin as much as 100 ml with a concentration of 15% at the variation of mixing time, namely 1 minute, 5 minutes, 10 minutes, 20 minutes, 30 minutes, 40 minutes, 50 minutes, and 60 minutes, then repeated 10 times. The results of the system tests are shown in Table V.

The test results showed that the formalin concentration value (ppm) tended to increase as the formalin mass increased and the length of exposure time to the fish, while the pH value decreased as the acidity of the solution increased. These changes reflect the degradation of freshness and physiological modification of fish tissue due to chemical reactions between formalin and protein components. Based on the testing of ten snapper samples consisting of two samples without formalin and eight samples with variations in formalin mixing time (1, 5, 10, 20, 30, 50, 50 and 60 minutes), a pattern was observed that the longer the mixing duration, the formalin level increased from 0 ppm to ±19 ppm, accompanied by a change in pH from the pre rigor phase to rigor mortis.

TABLE V
SNAPPER SAMPLE TESTING

No	Mass (gr)	Formalin Usage (minutes)	Ppm	pH	Condition	Percentage
1	0,94	No Formalin (10)	0	6,14	Safe	74 %
			0	6,14	Safe	74 %
			0	6,14	Safe	74 %
			0	6,14	Safe	74 %
			0	6,14	Safe	74 %
			0	6,14	Safe	74 %
			0	6,14	Safe	74 %
			0	6,14	Safe	74 %
			0	6,14	Safe	74 %
			0	6,14	Safe	74 %
2	0,85	No Formalin (20)	0	6,12	Safe	73 %
			0	6,12	Safe	73 %
			0	6,12	Safe	73 %
			0	6,12	Safe	73 %
			0	6,12	Safe	73 %
			0	6,12	Safe	73 %
			0	6,12	Safe	73 %
			0	6,12	Safe	73 %
			0	6,12	Safe	73 %
			0	6,12	Safe	73 %
3	0,107	1	2,54	6,14	Alert	45 %
			2,58	6,14	Alert	45 %
			2,54	6,14	Alert	45 %
			2,54	6,14	Alert	45 %
			2,54	6,14	Alert	45 %
			2,54	6,14	Alert	45 %
			2,54	6,14	Alert	45 %
			2,54	6,14	Alert	45 %
			2,54	6,14	Alert	45 %
			2,54	6,14	Alert	45 %
4	0,94	5	4,84	6,50	Alert	45 %
			4,90	6,50	Alert	45 %
			4,84	6,50	Alert	45 %
			4,84	6,50	Alert	45 %
			4,84	6,50	Alert	45 %
			4,84	6,50	Alert	45 %
			4,84	6,50	Alert	45 %
			4,84	6,50	Alert	45 %
			4,84	6,50	Alert	45 %
			4,84	6,50	Alert	45 %
5	0,62	10	10,13	6,75	Alert	40 %
			10,18	6,75	Alert	40 %
			10,13	6,75	Alert	40 %
			10,13	6,75	Alert	40 %
			10,13	6,75	Alert	40 %
			10,13	6,75	Alert	40 %
			10,13	6,75	Alert	40 %
			10,13	6,75	Alert	50 %
			10,13	7,00	Alert	50 %
			10,13	7,00	Alert	40 %
6	0,51	20	11,85	6,68	Alert	40 %
			11,85	6,68	Alert	40 %
			11,85	6,68	Alert	40 %
			11,85	6,68	Alert	40 %
			11,85	6,68	Alert	40 %
			11,85	6,68	Alert	40 %
			11,85	6,68	Alert	40 %
			11,85	6,68	Alert	40 %
			11,85	6,68	Alert	40 %
			11,85	6,68	Alert	40 %
7	0,51	30	12,42	6,64	Alert	40 %
			12,50	6,64	Alert	40 %
			12,42	6,64	Alert	40 %
			12,43	6,64	Alert	40 %
			12,42	6,64	Alert	40 %
			12,42	6,64	Alert	40 %
			12,43	6,64	Alert	40 %
			12,42	6,64	Alert	40 %
			12,42	6,64	Alert	40 %
			12,42	6,64	Alert	40 %
8	0,66	40	15,80	6,20	Danger	15 %
			15,80	6,20	Danger	15 %
			15,80	6,20	Danger	15 %
			15,80	6,20	Danger	15 %
			15,80	6,20	Danger	15 %
			15,80	6,20	Danger	15 %
			15,80	6,20	Danger	15 %
			15,80	6,20	Danger	15 %
			15,80	6,20	Danger	15 %
			15,80	6,20	Danger	15 %
9	0,60	50	17,80	6,20	Danger	15 %
			17,83	6,20	Danger	15 %
			17,80	6,20	Danger	15 %
			17,80	6,20	Danger	15 %
			17,80	6,20	Danger	15 %
			17,80	6,20	Danger	15 %
			17,80	6,20	Danger	15 %
			17,80	6,20	Danger	15 %
			17,80	6,20	Danger	15 %
			17,80	6,20	Danger	15 %
10	0,72	60	19,29	5,42	Danger	3 %
			19,36	5,42	Danger	3 %
			19,29	5,42	Danger	3 %
			19,29	5,42	Danger	3 %
			19,29	5,42	Danger	3 %
			19,29	5,42	Danger	3 %
			19,29	5,42	Danger	3 %
			19,29	5,42	Danger	3 %
			19,29	5,42	Danger	3 %
			19,29	5,42	Danger	3 %

The implementation of the fuzzy rule base system used successfully classified the level of fish safety into three categories, namely safe, alert, and danger according to the combination of formalin and pH level parameters. The results of this classification also provide an overview of health risks that may arise, ranging from potential irritation and mild disturbances in the alert category, to serious risks such as organ damage and cancer in the danger category. Thus, the developed tool is proven to be able to effectively detect the level of fish safety, allows for immediately identifying indications of fish consumption danger and take preventive measures before more severe health impacts arise. After that, the safety end-level value uses the centroid defuzzification method with the following formula:

$$\text{Safety} = \frac{\sum \alpha i \,.\, zi}{\sum \alpha i} \quad (7)$$

Based on the description of the formula, safety is αi, the degree of membership obtained from the minimum result between the ppm and pH membership functions for the fuzzy logic rule used. Meanwhile, zi is a representative value of security which is classified into the categories of safe, alert, and danger. Table VI shows the accuracy of the testing of snapper samples that have been carried out.

Based on Table VI, the average calculation is obtained as follows:

Average of Error

$$= \frac{160+170+50+50+100+100+50+50+70}{100} = \frac{900}{100} = 9\ \%$$

Average of Accuracy

$$= \frac{840+830+950+950+900+900+900+950+950+930}{100} = \frac{9100}{100} = 91\ \%$$

TABLE VI
ACCURACY OF SNAPPER SAMPLE TESTING

Mass (gr)	Formalin Usage (minutes)	Error	Accuracy
0,94	No formalin (10)	16 %	84 %
0,85	No Formalin (20)	17 %	83%
0,107	1	5 %	95 %
0,94	5	5 %	95 %
0,62	10	10 %	90 %
0,51	20	10 %	90 %
0,51	30	10 %	90 %
0,66	40	5 %	95 %
0,60	50	5 %	95 %
0,72	60	7 %	93 %
Average		9%	91 %

Based on the results of the snapper test using the Mamdani Fuzzy Logic method of defuzzification of the target value of the safety category, an average accuracy level of 91% was obtained.

IV. CONCLUSION

This study showed that the HCHO sensor detected formalin with a value of 0 – 0.4 ppm and the pH sensor 6,4 – 7,4 showed a "safe" condition with a green LED light indicator and a buzzer that sounded Sound 1. When the HCHO sensor detects formalin with a value of 0,5 – 14 ppm and the pH sensor 5,8 – 6,3 indicates an "alert" condition with a yellow LED indicator and a buzzer that reads Sound 2. Then, when the HCHO sensor detects formalin with a value of >14 ppm and the pH sensor >7.5 indicates a "danger" condition with a red LED indicator and a buzzer that reads Sound 3. Based on tests conducted on snapper samples, the system achieves an accuracy rate of 91%. This system is able to detect formalin content and measure acidity levels (pH) effectively. This study has limitations in the test object, as it uses only snapper samples. However, in principle, the sensor and system can be applied to a wide range of other fish types, as detection is based on the presence of formaldehyde gas (HCHO) and changes in pH rather than on the specific characteristics of a single fish type. For further development, this system can be improved with the integration of Internet of Things (IoT) technology that allows real-time monitoring of sample results through mobile applications and websites, making it easier for users to access data and monitor fish quality more efficiently.

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