IoT-Based Monitoring and Control of Smoke Concentration in Fish Smoking Warehouses Using Fuzzy Logic and ESP32

Urifah Nur Rohmah, Faridatun Nadziroh*, Budi Aswoyo, Anang Budikarso, Ida Anisah
Politeknik Elektronika Negeri Surabaya, Indonesia
**Corresponding author: Faridatun Nadziroh; email: faridatun@pens.ac.id*

Manuscript received April 09, 2026, revised April 17, 2026, accepted April 20, 2026

Abstract – *Fish smoking is a common practice for preserving and flavoring fish; unfortunately, traditional methods of smoking can produce dangerous air pollutants, including carbon monoxide (CO) and nitrogen oxides (NO_2), which have severe implications for workers' health and environmental performance. In this context, we propose an Internet of Things (IoT)- based intelligent system for real-time monitoring and control of smoke levels in fish smoking warehouses. The MICS-6814 gas sensor, combined with the ESP32 microcontroller, measures CO and NO_2 levels, while a fuzzy-logic algorithm classifies air quality using the CO_2-N_2 Air Pollution Standard Index (ISPU) from the reference. The proposed approach automatically controls ventilation via a fan actuator, which is triggered when pollutant levels exceed specific thresholds. The results of the experiment show that at a distance of 40 cm, as soon as it falls, this system is determined to be an unhealthy air condition if it starts automatic ventilation. Still, at a distance of 1 m, air quality remains moderate and therefore requires no action. The system enabled real-time monitoring, classification, and control, while data visualization was handled via a web-based interface and an LCD. Power, investigations repeatedly reported that indoor air quality management in fish smoking places demonstrated its practicality in reducing health risks from smoke exposure.*

***Keywords**: smoke, MICS-6814, NodeMCU ESP32, fuzzy logic*

I. Introduction

Indonesia is an island country surrounded by vast seas and oceans. Indonesia is an archipelago surrounded by vast seas and oceans. Indonesia's marine products are very abundant, such as Fish caught by fishermen [1]. Fish caught by fishermen are often not sold immediately. The rest of the sale by fishermen is preserved so that it can still be sold again later. One processed product from fish catches is smoked fish [2]. Smoking Fish in Indonesia was initially done traditionally using simple equipment and paying less attention to sanitary and hygienic aspects [3]. Factors that affect smoking include smoking temperature, air humidity, wood type, and pre-smoking treatment [4]. The use of fuels in Fish smoking, such as coconut shells or wood, produces smoke that contains harmful pollutants, including NO_2 and CO [5]. This can harm the environment and public health around the location of the fish-smoking warehouse [6]. The environmental impact is air pollution because the smoke will interfere with community activities and comfort.

The health impact is caused by various respiratory diseases, including the risk of Acute Respiratory Infection (ARI) [7]. In 2019, Derby Gabriele Tulandi1 and Rachmanu Eko Handriyono conducted research. They concluded that the absence of exhaust gas control equipment in the smoking industry results in high CO emissions discharged directly into the air, thereby decreasing air quality [8]. In 2019, Febian Mahendra Dito1 and Rachmanu Eko Handriyono conducted research. They found that fish-smoking places are not equipped with chimneys so that workers and the surrounding community can inhale the smoke generated from the smoking process. One of the air pollutants proven to cause health problems is nitrogen dioxide (NO_2). Research conducted by Mc. Granahan stated that the effects of NO_2 depend on the length of exposure. Exposure to NO_2 at 50 ppm can cause coughing, hemoptysis, dyspnea, and chest pain. Exposure to more than 100 ppm of NO_2 can cause pulmonary edema, chronic bronchitis, and chronic obstructive pulmonary disease [9].

Based on the existing problems and background, a study was conducted to monitor and control smoke density in a fish-smoking warehouse, determining whether smoke pollution is in good condition or harmful to the surrounding community's health. The smoke concentration monitoring and control system design is implemented as a small-scale prototype. Prototypes in IoT product development are essential for meeting user needs and ensuring reliability and safety when used [10]. In this study, using fuzzy-logic artificial intelligence, the fan will turn on automatically if the air quality is in a dangerous condition, characterized by dense smoke. This system uses the MICS-6814 sensor to detect Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2) [11]. Data from the sensor will be processed using the NodeMCU ESP32 with the Arduino IDE.

Furthermore, the data will be processed using Fuzzy Logic to determine the air quality. The CO and NO_2 measurement results will be compared with the Air Pollution Standard Index (ISPU) to determine whether the gas levels are in the sound, moderate, unhealthy, very unhealthy, or dangerous categories. The division of these categories is based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.14/MENLHK/SETJEN/KUM. 1/7/2020 concerning the Air Pollution Standards Index [12]. The output of Fuzzy logic is used to give the fan an on or off command. The relay activates the fan when the concentration of gas exposure received by the sensor exceeds the predetermined standard limit and stops when the concentration of gas exposure returns to normal [13]. The fan is used to refresh the room's air, reducing exposure to gas pollutants [14]. The processed data results will be sent and stored in the MySQL database using an internet connection (WiFi). The output data will be displayed on the LCD and on the website, which users can access.

II. Research Method

Here is the block diagram of the system design

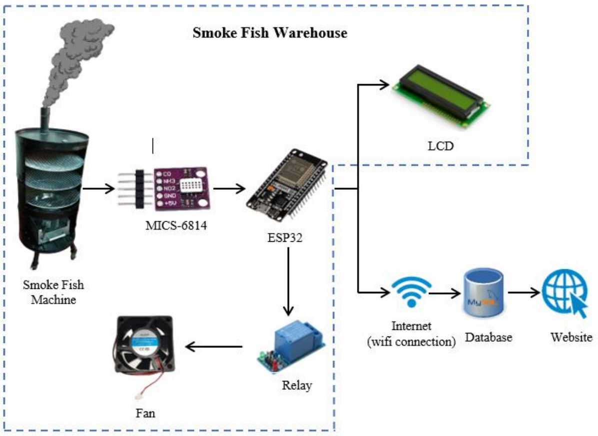

Fig.1 Block Diagram System

Based on the illustration of the system design above, smoke from smoking fish will be detected by the MICS-6814 sensor to determine the levels of Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2). The MICS-6814 sensor is connected to the NodeMCU ESP32 microcontroller, which will process the sensor readings. ESP32 also plays a role in sending measurement data to the database storage [15]. Sensor reading data will be sent and stored in the MySQL database via the internet (WiFi). For this reason, it is necessary to enter the WiFi name and password in the Arduino IDE [16]. The data results are then classified according to the Decree of the Minister of Environment Number P.14 / MENLHK / SETJEN / KUM.1 / 7/2020 concerning the Air Pollutant Standard Index using fuzzy logic. If the results obtained include the range 0-50, then the air condition is good; if the results obtained have the range 51-100, then the air condition is moderate; if the results obtained include the range 101-200, then the air condition is unhealthy, if the results obtained have the range 201-300 then the air condition is very harmful. If the results include a range > 301, air conditioning is dangerous [17]. Suppose the air quality is hazardous, unhealthy, or unsafe. In that case, the fan will turn on automatically to restore the air in a room polluted by gas through the air circulation system. Data will be sent and stored in the MySQL database because the database can store a set of information that is easily accessible [18]. The output will be displayed on the LCD, a liquid-crystal display that uses liquid crystals to produce visible images [19]. The results will also be displayed on the website using the open-source PHP programming language [20]. The website is created using Visual Studio Code, a lightweight, cross-platform code editor that can be used by anyone [21]. A website accessible to users to monitor and control smoke density in fish-smoking warehouses would be needed.

III. Fuzzy Logic Method

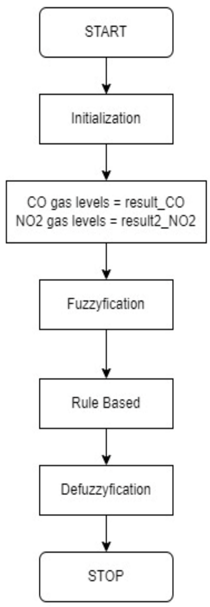

Fig. 2 Fuzzy Logic Flowchart

Fuzzy logic algorithms are used to make decisions about air quality based on the Air Pollution Standard Index (ISPU) derived from CO and NO_2 gas measurements. The fuzzy logic method used is Sugeno fuzzy. The fuzzy Sugeno algorithm is one of the approaches in fuzzy logic used to make decisions based on fuzzy rules and linear function models for predicting or controlling systems [22]. The following are the stages of the Sugeno fuzzy method applied as outputs to the system designed.

The fuzzy set is formed at this stage with the input and output variable criterion fuzzy logic design [23].

TABLE I
Input and output variables

Name	Description	Function
NND	Nitrogen Dioxide (NO_2) Value	Input Variable
NKM	Carbon Monoxide (CO)	Input Variable
ISPU	Air Quality	Output Variable

Next is to determine the universe of speech of each variable that has been selected, as follows:

TABLE 2
The universe of speech.

Function	Variable	Notation	The Universe of Speech
	NND	A	0 - 3000
Input	NKM	B	0 - 45000
Output	ISPU	Z	0 – 301

Then, determine the set of input and output as follows:

TABLE 3
Fuzzy input and output sets.

Variable		Fuzzy Set		
Name	Notation	Name	Notation	Domain
NND	A	Low	R	[0 – 1500]
		Moderate	S	[750 – 2250]
		High	T	[1500 – 3000]
NKM	B	Low	R	[0 – 22500]
		Moderate	S	[11250 – 33750]
		High	T	[22500 – 45000]
ISPU	Z	Good	B	[0 – 50]
		Moderate	SD	[51 – 100]
		Unhealthy	TS	[101 – 200]
		Very Unhealthy	STS	[201 – 300]
		Dangerous	BR	[≥ 301]

3.1 Fuzzification

In the fuzzification stage, we will explain the degree membership function of each input variable presented in the form of a curve, as follows:

1) Membership degree function of NO2 value (NND)

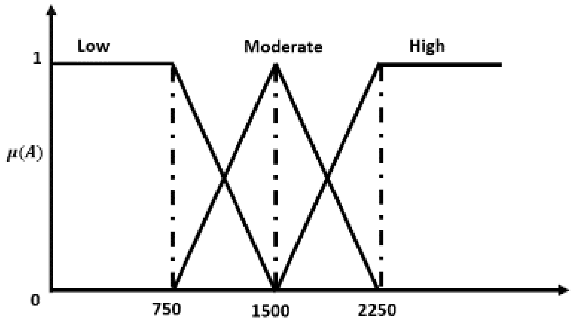

Fig 3. Membership degree function of NO2

Membership function:

$$(Low)\mu\, R = \begin{cases} 0; & A \geq 1500 \\ \frac{1500-A}{1500-750}; & 750 \leq A \leq 1500 \\ 1; & A \leq 750 \end{cases} \quad (1)$$

$$(Moderate)\mu\, S = \begin{cases} 0; & A \leq 750 \\ \frac{A-750}{1500-750}; & 750 \leq A \leq 1500 \\ \frac{2250-A}{2250-1500}; & 1500 \leq A \leq 2250 \\ 0; & A \geq 2250 \end{cases} \quad (2)$$

$$(High)\mu\, T = \begin{cases} 0; & A \leq 1500 \\ \frac{A-1500}{2250-1500}; & 1500 \leq A \leq 2250 \\ 1; & A \geq 2250 \end{cases} \quad (3)$$

2) Membership degree function of CO value (NKM)

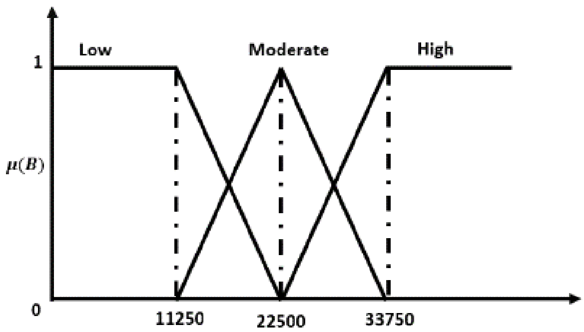

Fig 4. Membership degree function of CO

Membership function:

$$(Low)\mu\, R = \begin{cases} 0; & B \geq 22500 \\ \frac{22500-B}{22500-11250}; & 11250 \leq B \leq 22500 \\ 1; & B \leq 11250 \end{cases} \quad (4)$$

$$(Moderate)\mu\, S = \begin{cases} 0\,; & B \leq 11250 \\ \frac{B-11250}{22500-11250}\,; & 11250 \leq B \leq 22500 \\ \frac{33750-B}{33750-22500}\,; & 22500 \leq B \leq 33750 \\ 0\,; & B \geq 33750 \end{cases} \quad (5)$$

$$(High)\mu\, T = \begin{cases} 0\,; & B \leq 22500 \\ \frac{B-22500}{33750-22500}\,; & 22500 \leq B \leq 33750 \\ 1\,; & B \geq 33750 \end{cases} \quad (6)$$

3.2 Determination of Inference (Rule Base)

The base rule is determined based on the specified variable at this stage. At this stage, fuzzy rules are formed in the form of if-then as follows [24]:

TABLE 4
Rule-based.

Rule	IF		ISPU
	NO_2	CO	
R1	Low	Low	Good
R2	Low	Moderate	Moderate
R3	Low	High	Unhealthy
R4	Moderate	Low	Moderate
R5	Moderate	Moderate	Moderate
R6	Moderate	High	Very Unhealthy
R7	High	Low	Unhealthy
R8	High	Moderate	Very Unhealthy
R9	High	High	Dangerous

3.3 Defuzzification

The defuzzification process with the Sugeno method is done by finding the average value or weighted average with the following formula [25]:

$$WA = \frac{x_1 z_1 + x_2 z_2 + x_3 z_3 + \cdots + x_n z_n}{x_1 + x_2 + x_3 + \cdots + x_n} \quad (7)$$

The input of the defuzzification process is the Fuzzy set generated from the composition process, and the output is a value. X is the α-predicate while Z is the output value index (constant). The value of the rules evaluation results will be processed by multiplying each minimal value, which is the result of the rules evaluation, by the value of the rules in the form of a predetermined value.

- If the rule in the rule base is "Good", then the Zn value is 0.
- If the rule in the rule base is "Moderate", then the Zn value is 1.
- If the rule in the rule base is "Unhealthy", then the Zn value is 2.
- If the rule in the rule base is "Very Unhealthy", then the Zn value is 3.
- If the rule in the rule base is "Dangerous", then the Zn value is 4.

Therefore, the formula can be written as (8)

$$WA = \frac{(R1*0)+(R2*1)+ \ldots +(R9*4)}{R1+R2+ \ldots + R9} \quad (8)$$

The multiplier variable is the minimum value of the rules evaluation process results multiplied by the predetermined value. The divider variable is the minimum value of the rules evaluation process that is summed. The output value can indicate air quality based on smoke density in the fish smoking warehouse. The defuzzification output determines whether the fan is on or off based on air quality.

IV. Website Design

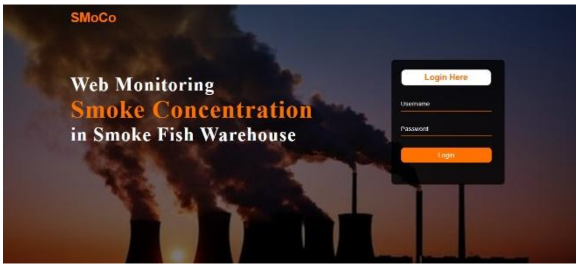

Fig 5. Website Login Page

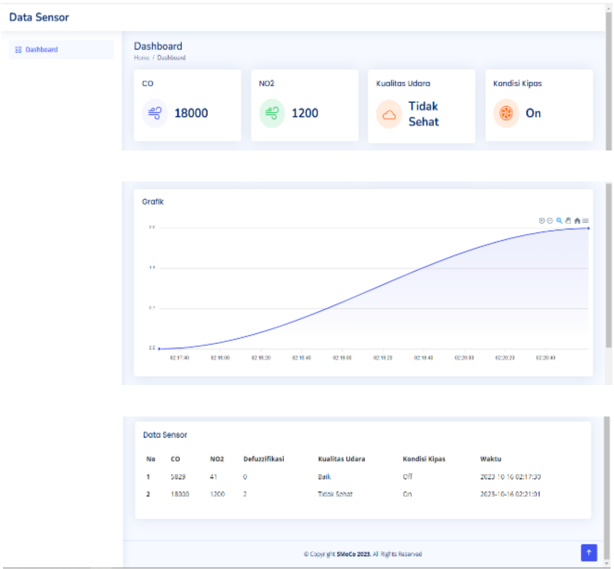

Fig 6. Website Dashboard Page

Website design displays sensor readings, making it easier for users to monitor air quality in fish-smoking warehouses.

Figure 5 is the Design of the login page of the smoke density monitoring website in the fish smoking warehouse. On the login page, the user enters their username and password to proceed to the next page. The username and password used have been registered as an admin to access the next page or the website's dashboard.

In Figure 6, is it the dashboard page or the main page of the smoke density monitoring website at the fish smoking warehouse? The dashboard page displays results for CO and NO_2 gas readings, air quality, fan conditions, graphs, and tables.

V. Results and Discussion

A. Sensor testing on fish smoking equipment at a distance of 40 cm.

This test is carried out to determine the levels of Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2). The fish smoking equipment is placed in the room so it appears to be in a fish smoking warehouse, with a 5-second delay. In this test, the sensor is placed 40 cm from the fish smoker. The results of the measured Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2) gas levels will be converted to a range of categories according to the Air Pollution Standards Index (ISPU). These results will be processed using a fuzzy logic algorithm, and the output will be air condition classifications based on ISPU. From these air conditions, we will determine the fan's status. The fan will turn on if the air conditioner exceeds predetermined normal limits, such as unhealthy levels.

TABLE V.
Sensor testing on fish smoking equipment at a distance of 40 cm

Number	Time	CO (μg/m³)	NO_2 (μg/m³)	Air Quality	Fan
1.	12:40:34	7182	328	Moderate	Off
2.	12:40:40	7340	362	Moderate	Off
3.	12:40:45	7483	368	Moderate	Off
4.	12:40:47	7258	360	Moderate	Off
5.	12:40:53	8636	482	Unhealthy	On
6.	12:40:58	9712	404	Unhealthy	On
7.	12:41:03	8739	486	Unhealthy	On
8.	12:41:08	8658	733	Unhealthy	On
9.	12:41:13	8795	809	Unhealthy	On
10.	12:41:18	8828	890	Unhealthy	On

The data obtained above show that the average values of sensor testing on fish smoking equipment at close range are 7723 μg/m³ for CO and 522 μg/m³ for NO_2. From the data above, it can also be seen that the room's air quality is unhealthy, so the fan is on.

This condition confirms that the air in the room does not meet the recommended ISPU standards. The smoke detected from gas-fueled fish smoking, with gas concentrations above the threshold, indicates the need for immediate action to improve air quality and maintain a healthier environment. Therefore, the presence of fans will restore the air's freshness.

B. Sensor testing on fish smoking equipment with a distance of 1 m

This test is carried out to determine the levels of Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2) gas on the fish smoking equipment, which is placed in the room to simulate a fish smoking warehouse, with a 5-second delay. In this test, the sensor is placed 1 m from the fish smoking equipment. The results of the measured Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2) gas levels will be converted to a range of categories according to the Air Pollution Standards Index (ISPU). These results will be processed using a fuzzy logic algorithm, and the output will be air condition classifications based on ISPU. From these air conditions, we will determine the fan's status. The fan will turn on if the air conditioner exceeds the predetermined normal limits, such as when it becomes unhealthy.

TABLE VI.
Sensor testing on fish smoking equipment at a distance of 1 m

Number	Time	CO (μg/m³)	NO_2 (μg/m³)	Air Quality	Fan
1.	13:23:11	3795	66	Good	Off
2.	13:23:17	3911	68	Good	Off
3.	13:23:23	5396	94	Moderate	Off
4.	13:23:28	6597	101	Moderate	Off
5.	13:23:33	6239	124	Moderate	Off
6.	13:23:38	7007	130	Moderate	Off
7.	13:23:44	7558	121	Moderate	Off
8.	13:23:50	7415	165	Moderate	Off
9.	13:23:55	7528	147	Moderate	Off
10.	13:24:00	7294	183	Moderate	Off

The data obtained above show that the average values of sensor testing on fish smoking equipment at a distance of 1m for CO are 6274 μg/m³ and for NO_2 are 119 μg/m³. From the data above, it can also be seen that the air conditioning in the room is in moderate need of health, so the fan is off. This condition confirms that the air in the room still meets the recommended ISPU standards. The data show that the results are smaller than the 40 cm distance. This is because the gas detected is not as much as would be expected at a distance of 40 cm.

VI. Conclusion

From the observations during the design, implementation, and testing stages of the system that have been carried out, the following conclusions can be drawn:

1. When testing the sensor against a fish-smoking device at 40 cm, the air quality results are unhealthy because the detected smoke exceeds the threshold. Hence, the fan is on to restore fresh air.
2. In sensor testing of fish smoking equipment at a distance of 1 m, getting moderate air quality for health, so that the fan is off, and the results of CO and NO_2 values are smaller than 40 cm.
3. The use of Sugeno fuzzy logic to determine air quality based on smoke density during fish smoking.
4. Presentation of monitoring data on the website works well and can be updated in real time.
5. The system can work well, as evidenced by its ability to test the overall integration.

References

[1] M. Pieper, A. Michalke, and T. Gaugler, "Calculation of external climate costs for food highlights inadequate pricing of animal products," *Nature Communications*, vol. 11, no. 1, Art. no. 6117, Dec. 2020.

[2] E. K. Asamoah et al., "Comparison of the efficiency of improved and traditional fish smoking kilns and their effects on smoked fish quality in Ghana," *J. Sci. Food Agric.*, vol. 105, no. 5, pp. 2923–2930, 2025. doi: 10.1002/jsfa.14060.

[3] H. P. d. B. Y. Hidayatus Shoimah, "Pengelolaan Lingkungan di Sentra Pengasapan Ikan Desa Wonosari," *Prosiding Seminar Nasional Pengelolaan Sumberdaya Alam dan Lingkungan,* 2013.

[4] J. S. d. S. HS, "Teknologi Alat Pengasapan Ikan Dan Mutu Ikan Asap," *Jurnal Riset Teknologi Industri, Balai Riset dan Standarisasi Industri Samarinda,* vol. 14, p. no. 2, December 2020.

[5] K. Bomfeh et al., "Reducing polycyclic aromatic hydrocarbon contamination in smoked fish in the Global South: a case study of an improved kiln in Ghana," *J. Sci. Food Agric.*, vol. 99, no. 12, pp. 5417–5423, Sep. 2019. doi: 10.1002/jsfa.9802.

[6] J. M. C. Santos et al., "Systems and methods for real-time adaptive air quality and pollution control in food processing and other thermal processing environments," *US Patent* 12,050,014, Jul. 30, 2024.

[7] D. S. N. d. C. I. Prasasti, "Konsentrasi Pm2,5 Dan Analisis Karakteristik Pekerja Terhadap Keluhan Kesehatan Pekerja Pengasapan Ikan Di Kelurahan Tambak Wedi Surabaya," *Jurnal Kesehatan Lingkungan,* vol. 8, p. no. 1, January 2015.

[8] F. Rokhmalia, "Pengaruh Paparan Asap Pembakaran Kayu Terhadap Peningkatan Aktivitas Enzim Sod, Gpx Serum Dan Keluhan Pernafasan Pada Pekerja Di Home Industry Petis Desa Sekardangan Kabupaten Sidoarjo," *Skripsi Fakultas Kesehatan Masyarakat Universitas Airlangga,* 2015.

[9] D. G. T. d. R. E. Handriyono, "Analisis Konsentrasi CO Pada Kegiatan Industri Pengasapan Ikan Di Tambak Wedi Surabaya," *Seminar Nasional Sains dan Teknologi Terapan VII, Institut Teknologi Adhi Tama Surabaya,* 2019.

[10] K. Bomfeh et al., "Reducing polycyclic aromatic hydrocarbon contamination in smoked fish in the Global South: a case study of an improved kiln in Ghana," *J. Sci. Food Agric.*, vol. 99, no. 12, pp. 5417–5423, Sep. 2019. doi: 10.1002/jsfa.9802.

[11] S. sensortech, "Datasheet MiCS-6814," [Online]. Available: https://www.sgxsensortech.com/content/uploads/2015/02/1143_ Datasheet-MiCS-6814-rev-8.pdf.

[12] K. M. N. L. Hidup, "Keputusan Menteri Negara Lingkungan Hidup Nomor:P.14/MENLHK/SETJEN /KUM.1/7/2020 Tentang Indeks Standar Pencemaran Udara (ISPU),".

[13] Z. A. Ahmad et al., "Durio Zibethinus L plantation intelligent web-based irrigation system using fuzzy logic (DuWIMS) based on IoT," *J. Adv. Res. Appl. Sci. Eng. Technol.*, vol. 49, no. 1, pp. 161–182, 2025.

[14] I. D. Rahayu and M. Basri, "Automatic fan design based on microcontroller with combination of DHT11 sensor and motion sensor," *Hanif J. Inf. Syst.*, pp. 30–37, 2024.

[15] M. D. Gurmu and X. Qian, "Automatic room temperature control system using Arduino UNO R3 and DHT11 sensor," *in Proc. 17th Int. Comput. Conf. Wavelet Active Media Technol. Inf. Process*. (ICCWAMTIP), 2020, pp. 428–432.

[16] L. Gao, F. Jiang, and S. Wang, "Paper counting display device based on STM32F103 single chip computer," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 914, no. 1, art. no. 012043, Aug. 2020. doi: 10.1088/1757-899X/914/1/012043.

[17] F. Pradityo and N. Surantha, "Indoor air quality monitoring and controlling system based on IoT and fuzzy logic," *in Proc. 7th Int. Conf. Inf. Commun. Technol. (ICoICT),* 2019, pp. 1–6.

[18] A. Rista and L. Q. Zdrali, "Design and implementation of an alumni management system," *in Proc. Int. Conf. Inf. Syst. Technol*., Tirana, Albania, 2023, pp. 1–6

[19] S. A. Hossain, "Internet of Things-driven precision in fish farming: A deep dive into automated temperature, oxygen, and pH regulation," *Computers*, 2024.

[20] H. F. W. d. X. N. Astria Firman, "Sistem Informasi Perpustakaan Online Berbasis Web," *E-journal Teknik Elektro dan Komputer, Jurusan Teknik Elektro Fakultas Teknik UNSRAT,* vol. 5, p. no. 2, Maret 2016.

[21] Z. Ariyandi, T. Taufiq, and N. Nunsina, "Design of an Internet of Things (IoT)-based fish feeder system using an Android application," *J. Appl. Inf. Commun.*, vol. 9, no. 4, pp. 1593–1601, Aug. 2025. doi: 10.30871/jaic.v9i4.10072.

[22] Z. Gacovski, *Fuzzy Systems and Applications*, 1st ed. Burlington, ON, Canada: Arcler Education Inc, 2024.

[23] T. J. Ross, *Fuzzy Logic with Engineering Applications*, 4th ed. New York, NY, USA: Wiley, 2016.

[24] H.-J. Zimmermann, *Fuzzy Set Theory—and Its Applications*, 4th ed. Boston, MA, USA: Springer, 2001

[25] T. H. Siregar, M. Zarlis, D. Abdullah, and R. W. Sembiring, "Performance comparison of membership functions in fuzzy logic control for milk pasteurization process," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1122, pp. 112–120, 2021.