Iot Optimization in Marine Weather Monitoring for Maritime Activities with Mamdani Fuzzy Analysis Method

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Abstract **— Fishermen's activities are highly dependent on weather information. Wind speed, temperature and humidity are important to know so that fishermen can prepare their needs when they want to sail. This research focuses on fishermen and coast guards as the main users to know the condition of the beach. This system uses BME280 sensors to determine air temperature and humidity, while wind speed is obtained from an anemometer sensor. The sensor readings are then sent to the IoT server via the MQTT protocol. Optimization of the IoT system is carried out using fuzzy methods so that the performance results based on the Mean absolute deviation (MAD) value of 0.012236364 and Mean Absolute Percentage Error (MAPE) 0.0258583%. The developed system is able to provide information needed by fishermen and coast guards in providing early warning based on environmental parameters so that it can be used to support decision making related to weather conditions.**

Key Words — Anemometer, BME280, fuzzy, ESP, MQTT, IoT

I. Introduction

The Unitary State of the Republic of Indonesia (NKRI) is an archipelago consisting of land and sea areas. Indonesia has a total of 17,508 islands, both large and small. This fact is the basis for calling Indonesia an “archipelagic state”. With an area of 5.4 million km² consisting of 2.01 million km² of land and 3.5 million km² of ocean, Indonesia is geographically a maritime country. In addition, Indonesia also has a population of around 277,534,122 people. [1]

Research related to wind speed parameters, microcontrollers, and the Internet of Things (IoT), the author analyzes wind speed using an anemometer sensor, then processes the data with an Arduino Uno microcontroller. Next, the processed data is sent to the cloud via an ESP8266 WiFi module. The final results are displayed on the Android application interface, making it easier for users to monitor wind conditions. This solution is considered effective because smartphones have become devices owned by almost all levels of society. [2]

The prototype developed is a weather monitoring system based on three input variables of air temperature, air humidity, and air pressure with a case study in Semarang in June 2022. Data was taken from Semarang Climatology Station located at 6°59'4” LS (South latitude) and 110°22'52” East (East longitude) at an altitude of 6 meters above sea level (masl). The analysis was conducted by comparing the defuzzification results of the Mamdani and Sugeno methods, then classifying the output into five categories of rain intensity: no rain, light rain, moderate rain, heavy rain, and very heavy rain, in order to evaluate the performance of the system in predicting local weather conditions. [3]

An Internet of Things (IoT) based weather monitoring system to present real-time weather information that is easily accessible. The system uses three main input variables: air temperature, humidity, and direct rainfall measurement through Hall Effect Sensor A3144. The data obtained is then transmitted and processed through the ThingSpeak web server, which serves as an interface to visualize real-time changes in weather parameters at a particular location. With this approach, users can monitor weather conditions more accurately and practically through a digital platform. [4]

Fishermen are the dominant profession in the coastal areas of Riau Islands Province, especially in Batam City with its surrounding small islands. Based on data from the Directorate General of Population and Civil Registration (Dukcapil) of the Ministry of Home Affairs as of December 31, 2021, there were 1.34 million people or 0.49% of the total Indonesian population who work as fishermen [5]. Traditionally, the livelihood of fishermen relies on the utilization of marine resources such as fish, shrimp, crabs, and various other fishery commodities through catching and collecting marine products.

Thus, fishermen's activities are highly dependent on sea conditions, especially wind and rainfall factors that can cause high waves and storms, hindering fishing activities. Based on the synthesis of the three studies reviewed, an effective solution to mitigate this problem is the implementation of optimized Internet of Things (IoT) technology. IoT enables connectivity between devices via the internet, facilitating remote monitoring and control. In this context, the implementation of IoT on the weather monitoring system is able to provide real-time information on meteorological conditions around the fishermen's operation area, which can significantly improve the safety and effectiveness of fishing activities. [6] [7]

Therefore, this research implements a modernly designed IoT system with a minimalist approach to the main device. The system integrates a BME280 sensor for precision measurement of air temperature and humidity parameters, and an anemometer sensor for monitoring wind speed. In the data processing part, Mamdani fuzzy algorithm is applied which is able to handle the uncertainty in weather data. For data management optimization, researchers developed a ring buffer structure as an innovation in IoT data storage systems, which enables better memory efficiency and data access speed in continuous monitoring operations.

II. Materials And Methods

Ring buffers are circular data structures that implement the first-in-first-out (FIFO) mechanism through a circular approach. This structure facilitates asynchronous data read and write operations, where the head and tail of the buffer rotate dynamically within a fixed memory allocation. In the context of IoT systems, the implementation of ring buffers provides several critical advantages such as preventing data loss through a controlled overwrite mechanism when the buffer is full, minimizing complex dynamic memory allocation, and allowing data production and consumption processes to run in parallel without deadlock. These characteristics make ring buffers an optimal solution for embedded systems that require handling real-time data streams with limited resources [8].

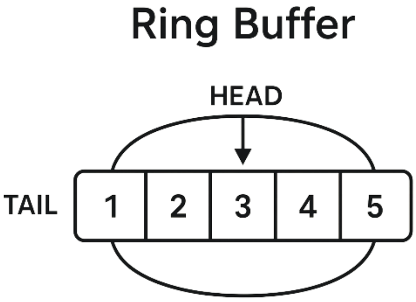

FIGURE. 1. RING BUFFER

Fuzzy logic, introduced by Prof. Lotfi A. Zadeh in 1965, is an intelligent control system that processes partial truth values (between 0 and 1) to handle uncertainty. This methodology is widely applied from home appliances, embedded systems, industrial control, to complex data acquisition. Its implementation is flexible in hardware (microcontrollers, FPGAs), software (processing algorithms), and hybrid systems. Its operation involves three core stages namely, fuzzification (conversion of numerical inputs to fuzzy sets), inference (application of logic rules), and defuzzification (transformation of outputs to applicative values). Its main advantage lies in its ability to model complex non-linear systems with tolerance to ambiguous data, making it an ideal solution for adaptive control systems, intelligent decision-making, and real-time signal processing in various technological fields.

FIGURE. 2. BASIC FUZZY TERMS

- Fuzzification, is the stage of determining input and output values in a fuzzy membership. The incoming data in the form of crisp membership will later be converted into fuzzy membership based on the gap for each input variable. In this process, there are things that are of particular concern, namely the input and output values and the membership function that will be used to determine the fuzzy value of the input and output crisp value data. [9] The following is a fuzzification representation as shown below and if the mathematical formula refers to Equations (1)-(3), the Curve Representation used by the researcher:

  - Rising Linear Curve Representation

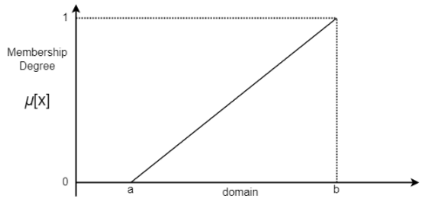

FIGURE. 3. RISING LINEAR CURVE REPRESENTATION

Mathematical Representation

$$f(x) = \begin{cases} 0, & x \leq a \\ \frac{(x-a)}{(b-a)}, & a \leq x \leq b \\ 1, & x \geq b \end{cases} \quad (1)$$

  - Descending Linear Curve Representation

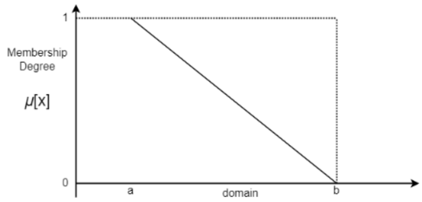

FIGURE. 4. DECREASING LINEAR CURVE REPRESENTATION

Mathematical Representation:

$$f(x) = \begin{cases} 1, & x \leq a \\ \frac{(b-x)}{(b-a)}, & a \leq x \leq b \\ 0, & x \geq b \end{cases} \quad (2)$$

  - Trapezoidal Curve Representation

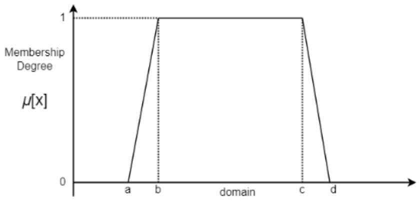

FIGURE. 5. TRAPEZOIDAL CURVE REPRESENTATION

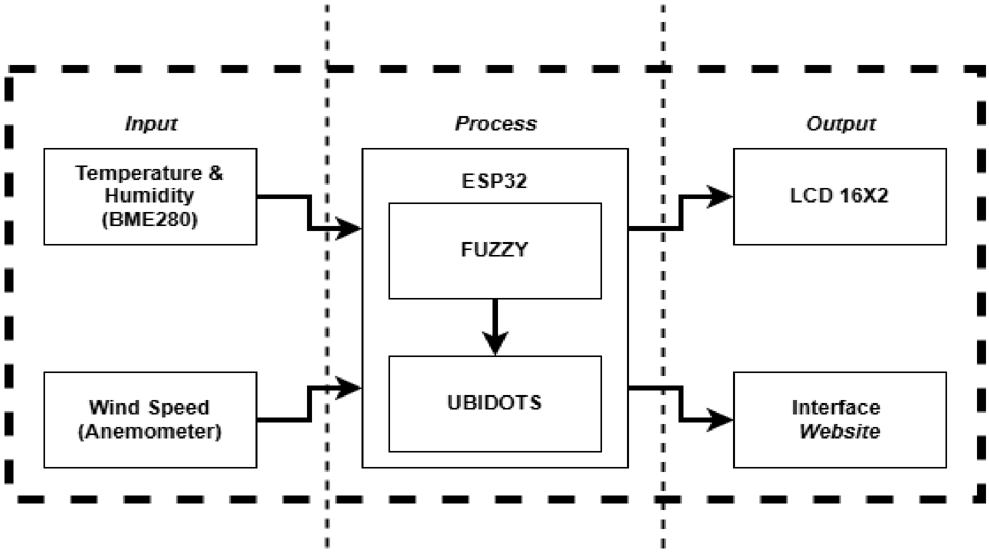

FIGURE. 6.SYSTEM BLOCK DIAGRAM

Mathematical Representation

$$f(x) = \begin{cases} 0, & x \leq a \ \ or \ x \geq c \\ \frac{(x-a)}{(b-a)}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \frac{(c-x)}{(c-b)}, & b \leq x \leq c \end{cases} \quad (3)$$

- Rule-base, is a fuzzy part that contains a collection of rules that will carry out the fuzzification process to produce defuzzification or fuzzy output. There are 3 methods that can be used in performing fuzzy system inference, [10] among others:
  - Max Method *(Maximum)*
    In this method, the fuzzy set solution is obtained by taking the maximum value of the rule, using it to transform the fuzzy region, and then applying it to the output using the OR (union) operator. If all propositions have been evaluated, the output will contain a fuzzy set that reflects the contribution of each proposition. In general, the equation is (4):

$$\mu_{sf}[x_i] \leftarrow \max(\mu_{sf}[x_i], \mu_{kf}[x_i]) \quad (4)$$

Description:
$\mu_{sf}[x_i]$ = membership value of the fuzzy solution for the i-th rule
$\mu_{kf}[x_i]$ = fuzzy consequent membership value for the i-th rule

  - Additive Method *(Sum)*
    In this method, the fuzzy set solution is obtained by finitely summing all the outputs of the fuzzy regions. In general, the equation is (5):

$$\mu_{sf}[x_i] \leftarrow \min(1, \mu_{sf}[x_i] + \mu_{kf}[x_i]) \quad (5)$$

Description:
$\mu_{sf}[x_i]$ = membership value of the fuzzy solution for the i-th rule
$\mu_{kf}[x_i]$ = fuzzy consequent membership value for the i-th rule

- Defuzzification is the fuzzy membership resulting from the composition of fuzzy rules. The output of this process is a numerical value in a fuzzy set. So when a fuzzy membership is expressed with a certain range, it must be able to take a certain crisp value as output. In this defuzzification process, there are several methods in mamdani rule composition, [11] among others:
  - Centroid Method *(Composite Moment Method)*
    This technique converts fuzzy solutions into crisp values by determining the center point (z*) of the fuzzy distribution area. The mathematical formulation is expressed in the equation: (6):

$$z^* = \int \frac{\mu_x(z)zdz}{\pi_x(z)dz} \rightarrow continius \quad (6)$$

Description:
$\mu_x(z)zdz$ = moment
$\pi_x(z)dz$ = area

III. RESULTS AND DISCUSSION

In this chapter researchers will display system design and implementation. With the parameters used in this study are inputs in the form of temperature, humidity, and wind speed with output parameters in the form of status. Then the data will be processed with fuzzy mamdani type 1 by passing 27 rules, to produce a maximum monitoring system. The process refers to the monitoring system block diagram below.

A. System design

At this stage the researcher makes a plan to get a research map.

a. Modeling fuzzy logic control of the monitoring system

In this study, researchers have 3 input variables and 1 output variable. As in Table I Lingusitic Term of Input, the input variables are temperature, humidity, and wind speed. Then for the output variable refers to Table II Output Linguistic Terms, the output variables are recommended, not recommended, and very dangerous. [12]

TABLE I
LINGUSITIC TERM OF INPUT

Temp	Param	Humy	Param	Wind	Param
Dingin	23,27	Kering	39,43	Lambat	28,35
Hangat	23,27,29,33	Normal	34,43,59,62	Sedang	28,35,56,64
Panas	29,33	Lembab	59,62	Cepat	56,64

TABLE II
OUTPUT LINGUISTIC TERMS

Status	Param
Disarankan	0,5,25,30
Tidak Disarankan	25,30,55,60
Sangat Berbahaya	55,60,95,100

1) Temperature

The temperature variable has three membership sets namely, Cold, Warm, Hot. With 3 different curves namely descending, trapezoidal, and ascending.

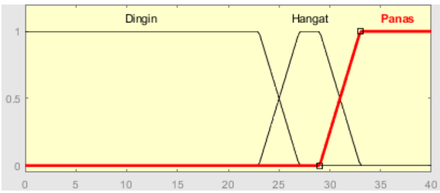

FIGURE. 7. TEMPERATURE MEMBERSHIP

2) Humidity

The Humidity variable has three membership sets namely, Dry, Normal, Humid. Based on the membership function of the input humidity image, this humidity variable forms a trapezoidal curve.

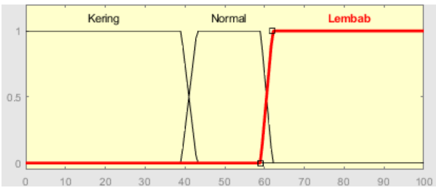

FIGURE. 8. AIR HUMIDITY MEMBERSHIP

3) Wind Speed

The Wind Speed variable has three membership sets and different curves, namely, Slow descending curve, Medium trapezoidal curve, Fast ascending curve.

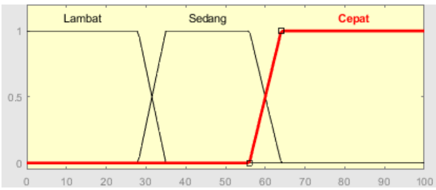

FIGURE. 9. WIND SPEED MEMBERSHIP

4) Status

Status is the output, this variable has three membership sets Recommended, Not Recommended, Very Dangerous. These three output variables the author uses a trapezoidal curve.

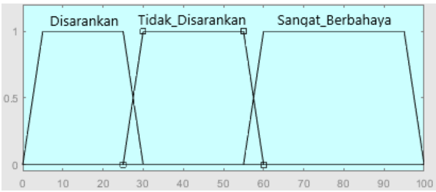

FIGURE. 10. MEMBERSHIP STATUS OUTPUT

5) Rules

In this study, researchers had 27 Rules for sorting. Table III System-Based Rules below will describe the rules created by researchers.

TABLE III
SYSTEM-BASED RULES

Rules	Temp	Humy	Wind	Status
1	Dingin	Kering	Lambat	Disarankan
2	Hangat	Kering	Lambat	Disarankan
3	Panas	Kering	Lambat	Disarankan
4	Dingin	Normal	Lambat	Disarankan
5	Hangat	Normal	Lambat	Disarankan
6	Panas	Normal	Lambat	Disarankan
7	Dingin	Lembab	Lambat	Disarankan
8	Hangat	Lembab	Lambat	Disarankan
9	Panas	Lembab	Lambat	Disarankan
10	Dingin	Kering	Sedang	Tidak Disarankan
11	Hangat	Kering	Sedang	Tidak Disarankan
12	Panas	Kering	Sedang	Tidak Disarankan
13	Dingin	Normal	Sedang	Tidak Disarankan
14	Hangat	Normal	Sedang	Tidak Disarankan
15	Panas	Normal	Sedang	Tidak Disarankan
16	Dingin	Lembab	Sedang	Tidak Disarankan
17	Hangat	Lembab	Sedang	Tidak Disarankan
18	Panas	Lembab	Sedang	Tidak Disarankan
19	Dingin	Kering	Cepat	Sangat Berbahaya
20	Hangat	Kering	Cepat	Sangat Berbahaya
21	Panas	Kering	Cepat	Sangat Berbahaya
22	Dingin	Normal	Cepat	Sangat Berbahaya
23	Hangat	Normal	Cepat	Sangat Berbahaya
24	Panas	Normal	Cepat	Sangat Berbahaya
25	Dingin	Lembab	Cepat	Sangat Berbahaya
26	Hangat	Lembab	Cepat	Sangat Berbahaya
27	Panas	Lembab	Cepat	Sangat Berbahaya

b. Implementation

In making the structure of the tool building, researchers use angle iron as a chassis and panel box as a place to store the controller and protect the controller from heat and rain. It can be seen in the Figure. 11. Chassis below, researchers use solar panels as a source of battery charging, and the position of the anemometer is located at the top of the left side. [13]

FIGURE. 11. CHASSIS

Description:

1) Anemometer is a sensor used to measure wind speed.
2) Solarcell with 10Wp capacity is used as charging battery.
3) This 40x30x10cm panelbox is for storing research items that are not waterproof.
4) The chassis of this part is the structure for making the tool stand made of iron.

In accordance with the picture of the inside of the panel box, on the inside of the panel box there is a mcu which is used to process data, then there is an LCD as a local interface to equalize the actual value and the value on the website, then there is a solar charging controll for solar panel control, and finally there is a battery with a BMS 3s configuration to manage a 20Ah capacity battery.

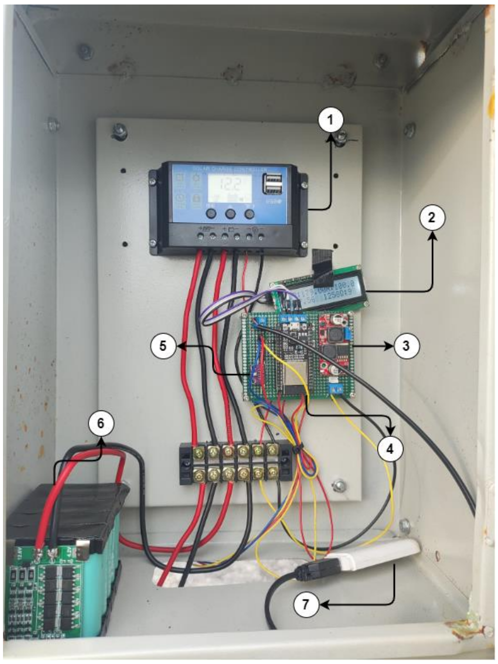

FIGURE. 12. INSIDE OF PANEL BOX

Description:

1) SCC 20A is a device used for battery control under charge and discharge conditions, as well as on and off control according to the set time.
2) The 12x6 I2C LCD is used by researchers to debug offline so that they can see the values read in each variable.
3) Stepupdown module is a module used to ensure the system will continue to turn on even if the voltage is more than 12v or less than.
4) This ESP32 is the main component of the system used for fuzzy processing.
5) BME280 is a sensor used to measure
6) temperature and humidity.

7) Lithium battery is a component to store energy reserves from solar cells, this battery has a capacity of up to 20Ah.
8) Mifi is a portable modem used by researchers to get internet access.

B. Research Results

In this section, the researcher writes down the results of the researcher's achievements in data collection starting from the fuzzification process, interference, to defuzzification. At this stage of data processing, researchers use Matlab as a reference for success in making predictions. To validate the search for error values, the author uses MAD and MAPE to get the absolute error value.

TABLE IV
EXPERIMENT DATA

Date	Temp	Humy	Wind	Status
2024-12-29 21:48:00	30℃	73%	32.76 Km/h	Tidak Disarankan
2024-12-29 21:48:00	29℃	73%	58.68 Km/h	Tidak Disarankan
2024-12-29 21:44:00	29℃	73%	32.76 Km/h	Tidak Disarankan
2024-12-29 21:42:00	30℃	73%	58.68 Km/h	Tidak Disarankan
2024-12-28 18:26:00	30℃	55%	32.04 Km/h	Tidak Disarankan
2024-12-28 18:24:00	31℃	67%	25.92 Km/h	Disarankan
2024-12-28 18:22:00	30℃	56%	8.28 Km/h	Disarankan
2024-12-26 12:44:00	38℃	45%	47.52 Km/h	Tidak Disarankan
2024-12-26 12:38:00	39℃	42%	67.68 Km/h	Sangat Berbahaya
2024-12-26 12:34:00	39℃	43%	41.76 Km/h	Tidak Disarankan
2024-12-26 12:28:00	38℃	44%	40.68 Km/h	Tidak Disarankan
2024-12-26 12:18:00	36℃	47%	38.88 Km/h	Tidak Disarankan

a. Experiment Data

The researcher will present the data that has been collected during the research period. This data is obtained through a system that has been created by researchers with realtime data acquisition in accordance with environmental conditions. **Error! Reference source not found.** are some examples of data that researchers can display.

b. Modeling Fuzzy Logic Control on Monitoring System

In this section, researchers will prove by formula or manual calculation the system that has been implemented on the microcontroller.

One example is that the researcher takes one of the measured values and will recalculate it in the following manual calculation. In this test, researchers took a sample of temperature 29° C, humidity 75%, wind speed 29.52 Kmh and status 22.1.

- **Step 1. Determination of fuzzy set**
  - **Temperature**

    In this case the temperature value obtained is 29◦C, based on the linguistic terms written in Table II Output Linguistic Terms and Air Humidity Membership The value of 29◦C is in the position of $^{\mu}$Hangat and $^{\mu}$Panas, based on MF (Membership Function) then the degree of membership is as in Equation (7) and (8).

$$\mu_{Hangat[29]} = \frac{33-29}{33-29} = 1 \quad (7)$$

$$\mu_{Panas[29]} = \frac{29-29}{33-29} = 0 \quad (8)$$

  - **Air humidity**

    As for humidity, it is 75%, based on the linguistic terms written on Table II Output Linguistic Terms and Figure. 8. Air Humidity Membership the value of 75% is in the position of µMoist, based on the MF (Membership Function), the degree of membership is as in Eq. (9).

$$\mu_{Lembab[75]} = 1 \quad (9)$$

  - **Wind Speed**

    Furthermore, the wind speed measurement obtained a measured value of 29.52Kmh, based on the linguistic terms written in Table II. Membership of Wind Speed, the value of 29.52 kmh is in the position of µModerate and µSlow, based on the MF (Membership Function), the degree of membership is as in Eq. (10)&(11).

$$\mu_{Sedang[29.52]} = \frac{29.52-28}{35-28} = 0.21417 \quad (10)$$

$$\mu_{Lambat[29.52]} = \frac{35-29.52}{35-28} = 0.78285 \quad (11)$$

- **Step 2. Function implications**

  In this subsection, researchers will process the membership degree value obtained from determining the fuzzy set through equations (7) to

(11). In sorting these rules, researchers use min so that only the membership degree with the smallest value is selected so that other membership degrees will be eliminated. From the process of determining these rules, two rules are obtained, namely [R8] and [R17].

[R8] : IF Temperature Hangat **And** Humidity Lembab **And** Wind Speed Lambat **THEN** Status Disarankan.

$$\begin{aligned} {}^{\alpha}R8 &= {}^{\mu}Hangat \cap {}^{\mu}Lembab \cap {}^{\mu}Lambat \\ &= min({}^{\mu}Hangat \cap {}^{\mu}Lembab \cap {}^{\mu}Lambat) \\ &= min(1; 1; 0{,}78285) = 0{,}78285 \end{aligned}$$

[R17] : IF Temperature Hangat **And** Humidity Lembab **And** Wind Speed Lambat **THEN** Status Tidak Disarankan.

$$\begin{aligned} {}^{\alpha}R17 &= {}^{\mu}Hangat \cap {}^{\mu}Lembab \cap {}^{\mu}Sedang \\ &= min({}^{\mu}Hangat \cap {}^{\mu}Lembab \cap {}^{\mu}Sedang) \\ &= min(1; 1; 0{,}21417) = 0{,}21417 \end{aligned}$$

the output value and the output value will be the determination of the overall system status (Z*).

- **Monitoring system moments**

$$M_1 = \int_0^5 \frac{z}{5} z dz = 8.3333 \quad (12)$$

$$M_2 = \int_5^{25} 0{,}78285 z dz = 234.855 \quad (13)$$

$$M_2 = \int_{25}^{30} \frac{30 - z}{5} z dz = 266.6667 \quad (14)$$

- **Area monitoring system**

$$A_1 = \int_0^5 \frac{z}{5} dz = 2.5 \quad (15)$$

$$M_2 = \int_5^{25} 0{,}78285 dz = 15.657 \quad (16)$$

$$M_2 = \int_{25}^{30} \frac{30 - z}{5} dz = 2.5 \quad (17)$$

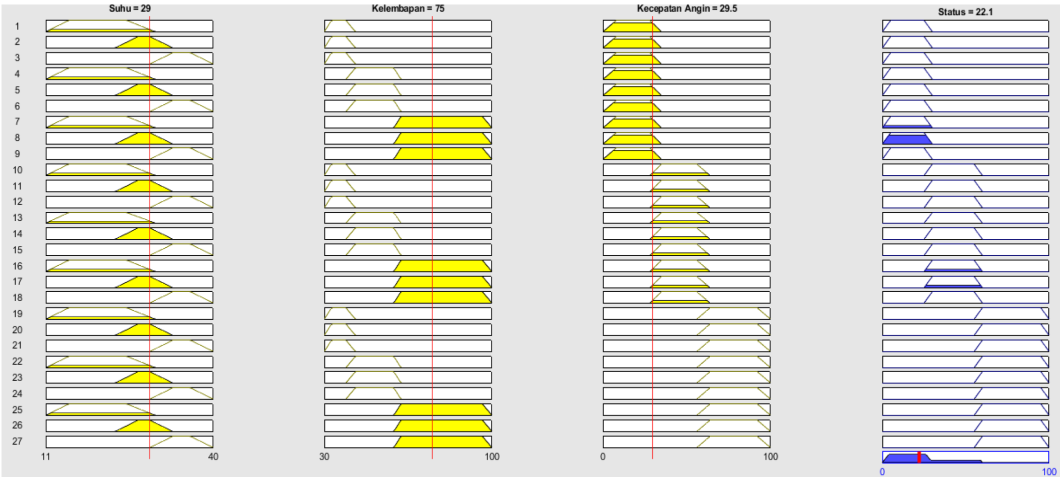

FIGURE. 13. RULES

- **Step 3. Defuzzification**

In this subchapter, researchers will write the final process of the fuzzy system, namely defuzzification. This defuzzification is a stage where the system will process real numbers into fuzzy sets obtained through the fuzzification process and inference rules. In this process, the author determines the defuzzification process using the centroid method by finding areas and moments. Determination of the defuzzification value using the centroid method can use Eq. (6) as follows.

The next stage, the researcher will write down the process of obtaining moments (M1) to (M3) and areas (A1) to (A3) which will later become

- **Centroid Execution**

$$\begin{aligned} Z^* &= \frac{M1 + M2 + M3}{A1 + A2 + A3} \\ &= \frac{8{,}3333 + 234{,}855 + 266{,}6667}{2{,}5 + 15{,}657 + 2{,}5} \\ Z^* &= 24.7 \end{aligned}$$

After passing the manual calculation stage, it is found that if the temperature is 29◦C, the humidity is 75% and the wind speed is 29.52Kmh, then the output value of the fuzzy system is 24.7 when referring to the rules, this value is included in the normal status category. On the same input, the value of the simulation software, namely matlab, shows 22.1 as shown in the table below. Figure. 13. Rules.

c. Error Validation

In this subsection, researchers will validate the error or difference between the output value generated by the system and the matlab application as an absolute reference that the value generated by the system can be accounted for. To validate the value, researchers use the MAD and MAPE methods.

TABLE V
DATA VALIDATION ERROR

Num.	Sistem X_a	MatlabX_p	Abs Error	% Error
1	34.5856	34.6	0.0144	0.042
2	56.7475	56.7	0.0475	0.084
3	34.5856	34.6	0.0144	0.042
4	56.7475	56.7	0.0475	0.084
5	31.9892	32	0.0108	0.034
6	15	15	0	0
7	15	15	0	0
8	42.5	42.5	0	0
9	77.5	77.5	0	0
10	42.5	42.5	0	0
11	42.5	42.5	0	0
12	42.5	42.5	0	0
MAD		**0.012236364**		
MAPE		**0.0258583%**		

Based on Table V Data Validation Error , we can calculate the average absolute error or MAD and absolute percentage error or MAPE as follows.

- **MAD**, is a mathematical equation to calculate the average absolute error and the resulting value will always be positive. The following is the equation used to find the MAD value. [14]

$$MAD = \frac{1}{N}\sum |X_a - X_p| \quad (18)$$

$$= \frac{1}{11}(0.1346) \quad (19)$$

$$MAD = 0.012236364 \quad (20)$$

- **MAPE**, is a mathematical calculation to obtain the absolute average percentage error. The following is the equation used to find the MAPE value. [15]

$$MAD = \frac{1}{N}\sum \frac{|X_a - x_p|}{X_a} x100\% \quad (21)$$

$$= \frac{1}{11}(0.003)x100\% \quad (22)$$

$$MAD = 0.0258583\% \quad (23)$$

d. End result monitoring

After all the experiments that have been carried out by researchers, researchers will display the final results through the user interface on ubidots, ubidots is a server used by researchers as an interface in mqtt communication. Seen on Figure. 14. Interface Ubidots**Error! Reference source not found.** it reads that the temperature is 37°C humidity 46% Wind speed is 3.24Kmh and the status is 15.00 (Tidak Disarankan).

FIGURE. 14. INTERFACE UBIDOTS

IV. CONCLUSIONS

Based on the explanation above, it can be concluded that the research that has been conducted by researchers with the title IoT Optimization on Marine Weather Monitoring for Maritime Activities with the Mamdani Fuzzy Analysis Method with a sample calculation of temperature 29°C, humidity 75% and wind speed 29.52Kmh, the status output on the implementation of the tool is 22.1, then the output on matlab is 22.1 and the output on manual calculation is 24.7. Fuzzy performance as a processor in monitoring tools works quite well characterized by a MAD value of 0.012236364 and a MAPE of 0.0258583%, but it is still necessary to do long-term tuning to get product perfection, and if you want to make it a mass product, some components also need to be categorized as industrial grade or military grade components such as mcu, if it is still in the hobby category, problems such as those experienced by researchers such as overheating will occur again.

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