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Implementation of Fuzzy Logic Control Method on Tornado Detector with Short Message Service Gateway

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Abstract
Indonesia's tropical climate makes it highly vulnerable to natural disasters, one of which is tornadoes (locally known as puting beliung), characterized by strong rotating winds originating from Cumulonimbus clouds with speeds exceeding 64.4 km/h. This study aims to design and implement an early warning system for tornado detection using a Fuzzy Logic Control method with input variables consisting of wind speed, temperature, and humidity, integrated with an SMS Gateway for delivering warning messages. The device employs a DHT22 sensor to measure temperature and humidity, an anemometer to record wind speed, and a SIM900A module to transmit short messages. The results show that after calibration, the average error rate of the DHT22 sensor compared to a digital thermometer was reduced to 1.9% for temperature and 1.8% for humidity, while the anemometer demonstrated an average error rate of 2.8%. The fuzzy logic system developed in this research produced three levels of warning conditions: safe, alert, and warning, based on 27 basic rules. Experimental results indicate that the system can detect tornado conditions more accurately than single-parameter approaches and successfully deliver SMS notifications in real time during alert and warning states. Therefore, this system has the potential to support disaster mitigation efforts for tornado events through rapid and accurate early warning dissemination.

Keywords: *Anemometer, Tornado, DHT22, Fuzzy, SMS Gateway*

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Introduction

Indonesia, as a tropical country, is highly prone to extreme weather events, one of which is tornadoes (angin puting beliung). These phenomena are often sudden, short-lived, but highly destructive, causing significant damage to residential areas, agriculture, and local infrastructure. Several regions in Indonesia, including rural and coastal areas, are highly vulnerable because they lack sufficient early warning systems and disaster preparedness mechanisms. Conventional approaches, which rely only on weather forecasts from centralized agencies, are often unable to provide real-time and localized warnings, resulting in communities being unprepared when tornadoes strike.

A tornado is a powerful rotating wind that emerges from a Cumulonimbus cloud at speeds above 34.8 knots or 64.4 km/h. Cumulonimbus (Cb) clouds are perilous due to their potential to produce severe weather phenomena, including intense precipitation, lightning, thunder, icing on airplanes, squalls or gusty winds, and hail. Intense rotating winds (vortices) typically coincide with heavy rainfall. High-velocity winds arise from a significant pressure differential between two proximate places. A tornado is a localized meteorological event that transpires rapidly. This occurrence, however brief, can inflict significant damage and result in loss of life. Wind speed classification is delineated on the Beaufort scale (Batra & Wasson, 2024; Firdausi et al., 2025; Rahardi et al., 2023, 2024; Wang et al., 2024). Fuzzy logic control is a soft computing methodology employed to articulate the ambiguity present within a system. Fuzzy logic was initially proposed by Professor Lotfi A. Zadeh in 1965. Fuzzy logic is a problem-solving methodology utilized in control systems, applicable across several platforms, including tiny systems, embedded systems, personal computer networks, multichannel systems, workstations, data acquisition, and control systems (Azzahra et al., 2024; Rahardi et al., 2022). Fuzzy logic possesses a defining characteristic, specifically the degree of membership, which ranges in value from 0 to 1.

This is in contrast to digital logic, which is characterized by binary values of 0 or 1. In fuzzy logic, membership values range from 0 to 1, indicating that a condition can simultaneously possess dual values such as "Yes and No," "True and False," or "Good and Bad." However, the membership degree significantly influences the condition value's magnitude (Hacizade, 2023; PampamallconJara & RojasnMoreno, 2022). Fuzzy logic translates a value or quantity into linguistic terms, such as categorizing living organisms' ages into young, adult, and old. Fuzzy logic determines the value of a number as either true or false. In contrast to traditional logic, fuzzy logic offers the advantage of reasoning in linguistic terms, resulting in relatively easy mathematical equations. Professor Lotfi A. Zadeh developed three fundamental operators for combining and modifying fuzzy sets: the AND, OR, and NOT operators (Li et al., 2022; Sun, 2024).

An SMS gateway is a software application that employs computer assistance and integrated cellular technology to transmit messages created by an information system using SMS via a cellular network. The rationale for utilizing an SMS gateway as a means of communication is its prevalence among the general populace, rendering it a suitable medium for interaction between devices and the community, despite its inherent limitation to one-way communication (Prakash et al., 2023).

Prior research, titled "Early Detection System for Tornadoes Based on Variations in Wind Speed and Direction Utilizing Arduino Uno with SMS Gateway Information," employed solely the HMC5883L compass for wind direction measurement and an anemometer for wind speed measurement. In this study, the detector utilized two more parameters: temperature and humidity.

The motivation behind this study stems from the urgent need for a low-cost, accurate, and community-accessible early warning system for tornado disasters. Considering the increasing frequency and intensity of extreme weather due to climate change, providing a system that can detect early indicators of tornado formation—such as wind speed, temperature, and humidity—has become a necessity. The use of Fuzzy Logic Control (FLC) provides a promising solution, as it is capable of handling uncertainties in weather data and classifying tornado risk levels effectively.

The significance of this research lies in its potential to support disaster mitigation efforts at the community level. By integrating FLC with an SMS Gateway, the system ensures that warning messages can be delivered directly and rapidly to residents, even in remote areas with limited

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internet access. This approach directly addresses the gap between meteorological data analysis and practical disaster response at the grassroots level.

The contribution of this study is threefold. First, it proposes the integration of multi-parameter weather data (wind speed, temperature, humidity) into a fuzzy-based decision-making system for tornado detection. Second, it demonstrates the application of FLC in combination with SMS Gateway technology for real-time community-level disaster communication, which has not been widely explored in previous studies on tornado detection. Third, the research provides experimental evidence through calibration and performance evaluation of the prototype system, validating its effectiveness in delivering accurate early warnings with low error rates.

In summary, this study not only advances the development of intelligent weather-based early warning systems but also contributes to disaster risk reduction efforts in Indonesia, particularly in vulnerable regions.

Literature Review

Arduino UNO

Arduino is an electronic device or circuit board capable of controlling a circuit, with various functionalities compatible with the managed device. The Arduino features multiple input and output ports that adequately fulfill requirements. In the absence of ports, additional components can be incorporated to provide them. Arduino is an open-source device designed to enhance usability. Arduino is an electronic device mostly composed of a microcontroller chip, which may also be called a microcontroller device. Microcontrollers are intrinsically linked to programming and operate according to the specified program. Thus, microcontrollers are the central processing units that govern the system based on the embedded program (Linelson et al., 2023; Sangeetha et al., 2023).

Anemometer

A tornado detector requires multiple components to function effectively. A crucial element in a tornado detection system is an anemometer. An anemometer is an instrument designed to measure wind velocity. The wind gusts typically experienced possess distinct speeds that can be quantified in knots or meters per second. This study will utilize the cup anemometer type among numerous anemometers. The cup anemometer operates by generating an analog voltage output in response to the rotation of the cup induced by wind impact. The analog voltage will be converted into a digital voltage by the Analog to Digital Converter (ADC) (Gutarra et al., 2020; Sookananta et al., 2023; J. Zhang et al., 2020).

DHT22

The DHT22 sensor measures the temperature surrounding the tornado detector. It is an electrical device capable of simultaneously measuring temperature and humidity. The sensor employs a capacitive humidity sensor and a thermistor for temperature measurement, producing temperature and humidity outputs as digital signals. Consequently, the DHT22 does not require an additional signal control circuit or ADC, as it incorporates an integrated microcontroller chip that generates digital signal outputs (Bautista et al., 2023; Malika et al., 2022; Mulawa & Fitriyanah, 2023).

The DHT22 sensor is user-friendly with microcontrollers like Arduino because of its stability, precise calibration capabilities, and compatibility with other devices. The DHT22 sensor is identical to the DHT11; however, the DHT22 provides more precise readings and a broader measurement range. The DHT22 is frequently employed in devices necessitating temperature and humidity measurements due to its compact size, allowing placement in confined spaces, and its signal transmission range of up to 20 meters, providing considerable flexibility (Mukesh et al., 2023; Widianto et al., 2022).

SIM900A Module

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The SIM900 module is a commonly used electrical component for SMS gateway applications. It features a SIM900A IC core that supports quad-band communication over 850, 900, 1800, and 1900 MHz frequencies. The SIM900A module's extensive frequency range enables compatibility with widely available providers in Indonesia and several other countries. Furthermore, the SIM900A module is compatible with Arduino, facilitating its operation (Bhardwaj et al., 2024; Paruchuri et al., 2023).

Fuzzy Logic Control

Fuzzy logic control is a soft computing methodology employed to articulate the ambiguity present in a system. It is a technique used in control systems to address difficulties, and it is applicable across various systems, including tiny systems, embedded systems, personal computer networks, multichannel setups, and data collection and control systems. Fuzzy set theory is fundamental to applying fuzzy logic, as the role of membership degrees is crucial in ascertaining the presence of an element within a set (Vladov et al., 2024; Wildani et al., 2022; T. Zhang et al., 2024).

Fuzzy logic possesses a defining characteristic, specifically the degree of membership, which ranges from 0 to 1. This contrasts with digital logic, which is characterised by binary values of 0 or 1. In fuzzy logic, membership values range from 0 to 1, indicating that a condition might simultaneously possess dual values such as "Yes and No," "True and False," or "Good and Bad." However, the membership weight significantly influences the magnitude of the condition value. Fuzzy logic translates a value or quantity through linguistic terms, categorising age in living organisms into young, mature, and old. This fuzzy logic demonstrates the value of an amount as either true or untrue. In contrast to traditional logic, fuzzy logic offers the advantage of reasoning in linguistic terms, resulting in relatively easy mathematical equations (PampamallconJara & RojasnMoreno, 2022; Sulaiman et al., 2025; Xue, 2024).

Research Methods

The stages carried out in this study are literature study, tool design and manufacture, program design, tool testing, data analysis, and report creation. In the literature study stage, literature sources related to the research to be carried out are collected. In designing and manufacturing the tool, the first step is to make a visual tool design. After the visual tool design is done, the entire tool is made. After the tool is formed, the DHT22 sensor and anemometer are tested to make the readings from the two sensors more accurate. The next stage that needs to be done is to design a fuzzy logic program, and simultaneously test the program's accuracy. The following process tests the entire tool using a laboratory scale. Then the test data obtained will be compiled as a report.

A. Hardware Design

This study uses a cup anemometer, which is a type of anemometer that has a bowl-like propeller. The anemometer used functions as a wind speed meter. Another sensor used is the DHT22 sensor, where the DHT22 functions as a temperature and humidity reader in the surrounding environment. For data processing, use the Arduino MEGA microcontroller, because it has a larger memory capacity, so you don't have to worry about using many program listings. The tool's output is on the 16 x 4 LCD and SIM 900A. The LCD will display all data on wind speed, temperature, humidity, and the results of the conditions at that time. The SIM 900A will work to send SMS when the tool decides that there is a condition of alert and standby only, so when conditions are safe, the tool will not send SMS to the telephone number to be addressed.

B. Design of Fuzzy Logic Control

From the gathered literature sources, 27 rule bases were derived to serve as the foundation for the employed fuzzy logic. Simultaneously, the three member variables of the fuzzy set—wind speed, temperature, and humidity—will be categorised into three classifications for each variable. The membership function categorises wind speed into "Lambat", "Cukup Cepat", and "Sangat Cepat". The membership function categorizes temperature as "Dingin, "Cukup Panas", and "Sangat Panas". In the

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membership function, humidity is classified as "Rendah", "Cukup Tinggi", and "Sangat Tinggi". The parameters employed will be presented in the subsequent graphic and table.

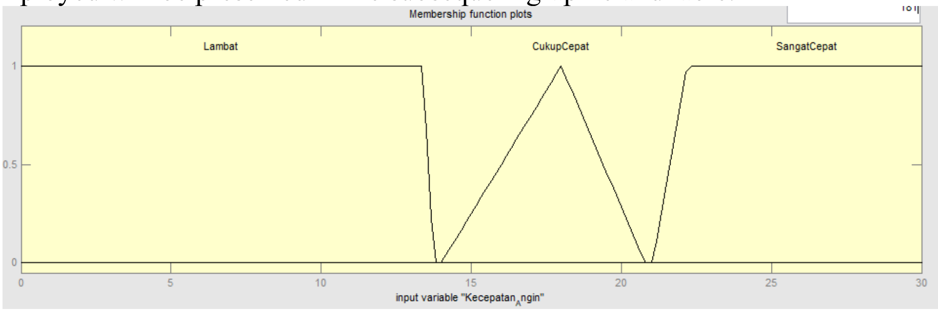

Figure 1 Wind Speed Membership Function

Table 1 Wind Speed Parameters

	Lambat	Cukup cepat	Sangat cepat
Wind Speed (m/s)	0-13	14-19	20-30

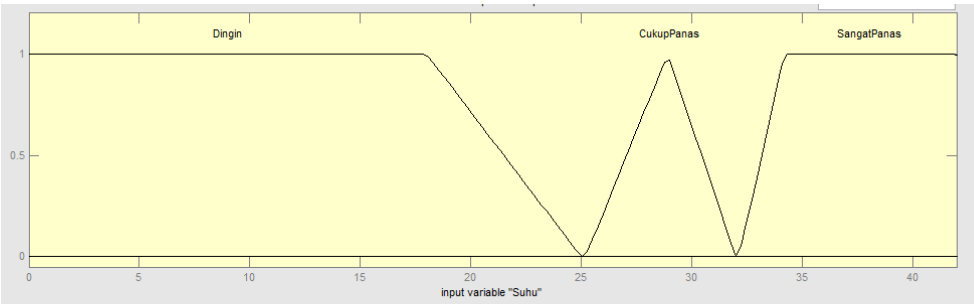

Figure 2 Temperature Membership Function

Table 2 Temperature Parameters

	Dingin	Cukup panas	Sangat panas
Suhu (°C)	0-25	26-33	34-40

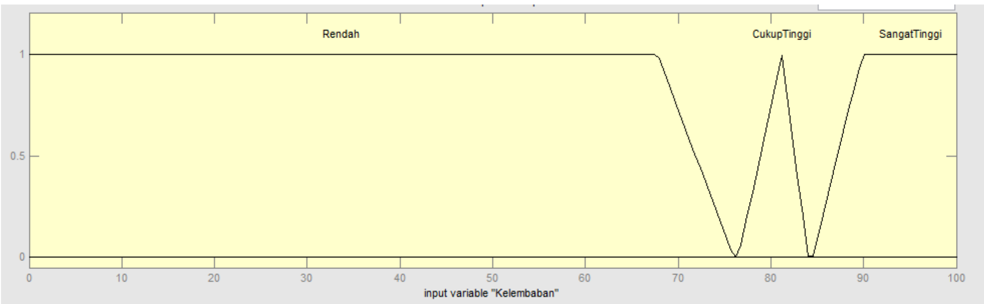

Figure 3 Humidity Membership Function

Table 3 Humidity Parameters

	Rendah	Cukup tinggi	Sangat tinggi
Humidity (%)	0-80	81-90	90-100

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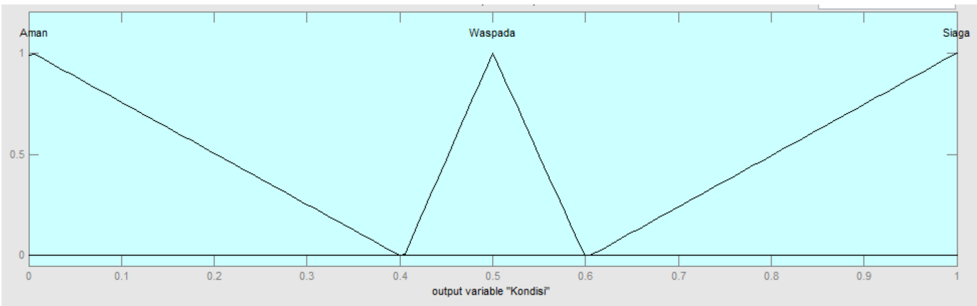

Figure 4 Conditional Membership Function

The resultant Fuzzy output manifests as a conditional judgement, yielding three determinations: safe, alert, and standby. This study used 27 rule bases, comprising 11 "Aman" conditions, 10 "Waspada" conditions, and 6 "Siaga" conditions. The output of the employed fuzzy logic yields "Aman", "Waspada", and "Siaga" conditions. Subsequently, when the gadget determines an “Waspada” and “Siaga” situation, it will transmit an SMS to the designated telephone number.

Results and Discussion

At this stage after the design of the tool is done, testing is carried out on both the sensors used and the entire tool with the addition of fuzzy logic and sending SMS.

A. Sensor Testing

Tables 4 and 5 illustrate the percentage error in comparing the temperature and humidity measurements of the DHT22 sensor with those of the digital thermometer and hygrometer. The initial data recorded by the DHT22 sensor indicated a temperature of 26.6 °C and a humidity level of 46.1%. Upon comparison with the readings indicated on the digital thermometer and hygrometer, the percentage error for the temperature reading was 8%, but the humidity reading exhibited a percentage error of 2.4%. In the second dataset, the DHT22 sensor recorded a temperature of 25 °C and a humidity level of 55.6%. Upon comparison with the digital thermometer and hygrometer readings, the percentage error was determined to be 7.4% for temperature and 4.1% for humidity. In the third dataset, the DHT22 sensor recorded a temperature of 27.2 °C and a humidity level of 63.4%. Upon comparison with the readings from the digital thermometer and hygrometer, the percentage error for the temperature measurement was determined to be 8.1%, while the humidity level exhibited a percentage error of 5.7%. In the fourth dataset, the DHT22 sensor recorded a temperature of 28.4 °C and a humidity level of 65.2%. The comparison with the digital thermometer and hygrometer yielded a percentage inaccuracy of 2.7% for temperature readings and 4.1% for humidity levels. The sixth data point from the DHT22 sensor indicates a temperature of 30.6 °C and a humidity level of 77%. Upon comparing the digital thermometer and hygrometer readings, the percentage error was determined to be 4.4% for temperature and 5.5% for humidity levels.

The data gathering operation for the DHT22 sensor persisted until it accumulated around 10 data points. In the sixth data collection, the temperature was recorded at 31.6 °C with a humidity level of 79.7%. Upon comparing the value with the digital thermometer and hygrometer readings, the percentage error is determined to be 3.1% for temperature and 2.2% for humidity. During the seventh data acquisition from the DHT22 sensor, a temperature reading of 32.3 °C and a humidity level of 85.4% were recorded. The value acquired from the DHT22 is subsequently compared with the digital thermometer and hygrometer readings. The percentage inaccuracy values are 6.3% for temperature readings and 2.9% for humidity readings. The eighth data point indicates a temperature measurement of 33.8 °C on the DHT22 sensor, with a humidity level of 87.7%. Upon comparison of the value with the readings from the digital thermometer and hygrometer, the percentage error is determined to be 5.6% for temperature and 2.6% for humidity. The ninth data point indicates a temperature of 35 °C and a humidity level of 89.6% as recorded by the DHT22 sensor. Upon comparison of the data with the readings acquired from the thermometer and digital hygrometer, the percentage error is determined to be 4.8% for temperature and 1.5% for humidity. In the most recent dataset, specifically the tenth entry, the DHT22 sensor recorded a temperature of 36.7 °C and a humidity level of 90%. The value is subsequently compared with the readings acquired from the thermometer and digital hygrometer, resulting in a percentage error of 5.8% for temperature and 3.2% for humidity. Based on the data in Table 4, the equation representing the results of the temperature sensor test on the digital thermometer is y = 1.6921x + 22.793. The equation will be incorporated into the Arduino program as a calibration value to ensure that the DHT22 temperature sensor's readings yield a percentage inaccuracy less than the pre-calibration findings.

Table 4 Temperature Sensor Reading Results Before Calibration

Temperature Sensor (ºC)	**Digital Thermometer (ºC)**	**Error (%)**
26,6	28,9	8
25	27	7,4
27,2	29,6	8,1
28,4	29,2	2,7
30,6	32	4,4
31,6	32,6	3,1
32,3	30,1	6,3
33,8	32	5,6
35	33,4	4,8
36,7	34	7,9
Average Temperature		5,8

Table 5 Humidity Sensor Reading Results Before Calibration

Humidity Sensor (%)	**Digital Hygrometer (%)**	**Error %**
46,1	45	2,4
55,6	58	4,1
63,4	60	5,7
65,2	68	4,1
77	73	5,5
79,7	78	2,2
85,4	83	2,9
87,7	90	2,6
89,6	91	1,5
90	91	1,1
Average Humidity		3,2

Tables 6 and 7 present the readings from the DHT22 sensor on the digital thermometer and hygrometer. The results achieved exhibit a reduced percent error relative to the data prior to the calibration process. The average percent inaccuracy in the temperature reading is 1.9%, whilst the average percent error in the humidity reading is 1.8%. The DHT22 sensor, given its % error value, is capable of detecting indications of tornadoes.

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Table 6 Temperature Sensor Reading Results After Calibration

Temperature Sensor (^oC)	**Digital Thermometer (^oC)**	**Error (%)**
24,1	24	0,4
25,4	26	2,3
28,2	29	2,8
31,7	32,1	1,2
31,3	31,8	1,6
32,8	32	2,5
33,2	34	2,4
35,7	35	2
38,5	39	1,3
40,1	41	2,2
Average Temperature		1,9

Table 7 Temperature Sensor Reading Results After Calibration

Humidity Sensor (%)	**Digital Hygrometer (%)**	**Error %**
46,5	49	5,1
58,1	60	3,2
63,3	64	1,1
68,2	69	1,2
73,2	74	1,1
78,3	79	0,9
80	83	3,6
84,7	85	0,4
88,7	88	0,8
91,5	91	0,5
Average Humidity		3,2

Table 8 indicates that the measurements obtained from the cup anemometer closely approximate those of the digital anemometer. This suggests increased wind gust intensity correlates with a higher recorded wind speed value. Table 8 indicates that the average percentage error is 2.8%. The % inaccuracy suggests that the cup anemometer reading is sufficiently accurate and does not necessitate calibration.

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Table 8 Anemometer Cup Test Data with Digital Anemometer

Cup Anemometer (m/s)	**Digital Anemometer (m/s)**	**Error (%)**
2,5	2,3	8,7
4,7	4,9	4,1
8,2	8,4	2,4
10,6	10,4	1,9
13,3	13,	2,3
16,5	16,9	2,4
18,4	18,1	1,7
20,7	21	1,4
23,5	23	2,2
24,2	24,5	1,2
Average Wind Speed		2,8

Table 9: Evaluation of Whirlwind Detectors

Wind Speed (m/s)	**Temperature (^{o}C)**	**Humidity (%)**	**Condition**	**SMS Status**
1,13	26,14	88,89	Aman	Not Sent
0,57	26,06	88,89	Aman	Not Sent
2,26	26,06	88,80	Aman	Not Sent
3,14	26,54	85,71	Aman	Not Sent
2,41	26,42	86,31	Aman	Not Sent
3,14	28,74	89,24	Aman	Not Sent
6,26	29,30	79,80	Aman	Not Sent
13,01	28,42	100,64	Waspada	Sent "Waspada"
10,74	30,28	100,54	Aman	Not Sent
12,44	29,79	97,80	Waspada	Sent "Waspada"
14,14	28,03	98,46	Waspada	Sent "Waspada"
20,18	28,40	99,30	Siaga	Sent "Siaga"
21,30	30,38	100,54	Siaga	Sent "Siaga"
23,18	33,40	86,80	Siaga	Sent "Siaga"
27,14	35,60	90,12	Siaga	Sent "Siaga"

B. Evaluating the Tool through the Integration of the Fuzzy Logic Control Method

After testing the DHT22 sensor and cup anemometer, the subsequent stage is to create both sensors and a SIM 900A module to provide public communication. Subsequently, upon the completion of assembly, the testing procedure will be conducted utilising the fuzzy logic control methodology. Following the calibration of the DHT22 sensor, cup anemometer, and SIM 900A module utilising the fuzzy logic control method, the subsequent stage evaluates the entire apparatus to assess its performance during operation. The tool's testing process employs two anemometers and two DHT22 sensors, wherein the readings from the anemometers are averaged to provide input values for the fuzzy logic control mechanism. Similarly, the temperature and

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humidity values utilised in the fuzzy logic control approach will be derived from the average readings of the two installed DHT22 sensors. After testing, the data acquired is presented in Table 9 below.

Conclusions

From the overall research that has been done, it can be concluded that:

The fuzzy logic algorithm plays a significant role in decision making carried out by the tornado detector, where the presence of three parameters, namely wind speed, temperature, and humidity, makes the detector more accurate in making decisions than using only one wind speed parameter without using fuzzy logic

When there is a decision that the tool detects a level of alertness for tornadoes, the tool will send a short message via SMS gateway to the intended telephone number with the contents of the message in the form of wind speed, temperature and humidity at that time and the status of the disaster that occurred, so that it can provide information to the public so that they can take disaster mitigation actions.

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