ISSN (Print) : 2337-9030 ISSN (Online) : 2685-2608
PILLAR OF PHYSICS
JURNAL BERKALA ILMIAH FISIKA
Vol. 18 (1), 2024, page. 31-40
DOI : 10.24036/16851171074

Drone-Based Monitoring Design with IoT System for Surface Temperature and Humidity Measurement

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ABSTRACT

Vertical temperature and humidity profiling plays a crucial role in meteorological studies, especially in analyzing phenomena such as temperature inversion. Such observation requires a flexible monitoring system capable of collecting accurate data and storing in efficiently. This study represents the design and implementation of drone-based monitoring system integrated with the Internet of Things (IoT), featuring dual data logging via microSD and cloud storage (Google Spreadsheet). System performance was evaluated through several test, including sensor characterization, transmission range assessment, and accuracy and precision measurement. Accuracy was calculated by comparing the system's readings with standard instrument which are thermometer and hygrometer. The result showed an average accuracy of 99% for temperature and 97.8% for humidity. The average precision was 1.00 for temperature and 0.99 for humidity, indicating high reliability of the readings. However, limitations were noted, particularly signal interference in dense urban areas and occasional disconnection due to wiring problem during flight turbulence. These issues suggest the need for more robust transmission modules and better handling of device's components connection in future development. Overall, the system demonstrates reliable functionality for vertical atmospheric monitoring.

Keywords : *Monitoring system, Temperature, Humidity, Drone, Climate*

I. INTRODUCTION

Climatology is the study of long-term weather patterns and atmospheric conditions [1]. Understanding climatological phenomena is essential, as it affects various aspects of life such agriculture, urban planning, and disaster mitigation [2-3]. For instance, the monitoring of climate change is important [4]. Meteorology examines atmospheric phenomena to provide accurate weather forecasts, which are vital for sectors like agriculture and utilities, as they help inform decisions on energy use and disaster preparedness by offering crucial data on temperature, rainfall, and wind patterns [5-6]. One significant atmospheric phenomenon is temperature inversion.

Temperature inversion is a phenomenon that requires vertical atmospheric profile observation, occurring when the lapse rate reverses or when the air temperature changes with altitude. This phenomenon impacts air quality [7]. Formation of temperature inversions occurs when a layer of warm air traps cooler air at the surface, hindering vertical mixing, a phenomenon common during clear nights and winter months, and these inversions can be classified into surface-based inversions (SBIs), which are prevalent at night, and elevated inversions (EIs), which can occur during the day and influence pollutant dispersion in different ways [8-9]. In order to observe such phenomena, vertical measurements of atmospheric parameters, especially temperature and humidity, at varying altitudes are required. However, conventional monitoring methods face several limitations, including lack of device mobility, restricted altitude range, and the absence of automated data storage systems. This limitation can be solved by using current technological advancements because the developments in technology and communication have significantly influenced various aspects of life today [8]. Unmanned vehicles like drones and the Internet of Things (IoT) concept are products of this phenomenon and there are many various IoT devices that

Submitted: Nov 18, 2024 Accepted: April 29, 2025 Published: April 30, 2025

have revolutionized many fields [10] that can support the need to develop a monitoring system for atmospheric parameters observation.

Monitoring temperature and humidity in hazardous and remote areas needs to be conducted from a distance [11]. Therefore, flexibility is required in monitoring systems and in measuring air temperature and humidity. Several studies have created systems for monitoring temperature and humidity. Several previous studies have attempted to develop temperature and humidity monitoring system [12-13], however, these systems typically lacked either mobility or automated data storage. For instance, some IoT -based system relied on fixed ground sensors, which limited their ability to observe vertical atmospheric profiles. Other study used drone for environmental data collection but did not include real-time or automated data logging, increasing the risk of data loss. This research addresses both limitation by integrating a drone-based platform for flexible vertical measurement and a dual data logging system (microSD and cloud-based storage) for automatic data recording and real-time access.

This research aims to design a monitoring system that facilitates climate parameter observation, specifically air temperature and humidity, using drones. The system is designed to be compact and lightweight to ensure drone mobility. Device communication uses the NRF24L01 radio communication module, which operates independently of the internet. Measurement data from the sensor is stored in a data logger using a microSD module and an RTC module to maintain continuous timing. The receiver system employs the Internet of Things (IoT) to connect to the internet, allowing measurement data to be stored in cloud storage, accessible in real time by anyone with internet access.

II. METHOD

This study is an engineering research project, which involves a design activity requiring new contributions in each step, whether in the form of processes or products/prototypes. The discussion in this study involves relatively new elements [14]. Engineering research begins with generating ideas and clarifying concepts, followed by design conceptualization, geometric arrangement, functionality, detailed design, model creation, and testing phases. The output of this research is a monitoring system utilizing IoT for drone-based air temperature and humidity measurement. This research follows a procedure that begins with defining ideas and task clarification, conceptual design, functional geometry arrangement, detailed design, device creation, and testing.

Ideas and task clarification were obtained through a literature review relevant to the research topic, therefore this research draws ideas from various articles and journals related to climatology and monitoring systems. The design concept in this research is a measuring device that also functions as a monitoring tool, designed with small mass and dimensions for use in measuring and monitoring vertical surface temperature and humidity change patterns. The system arrangement and geometry are designed in a block diagram, as shown in Figure 1.

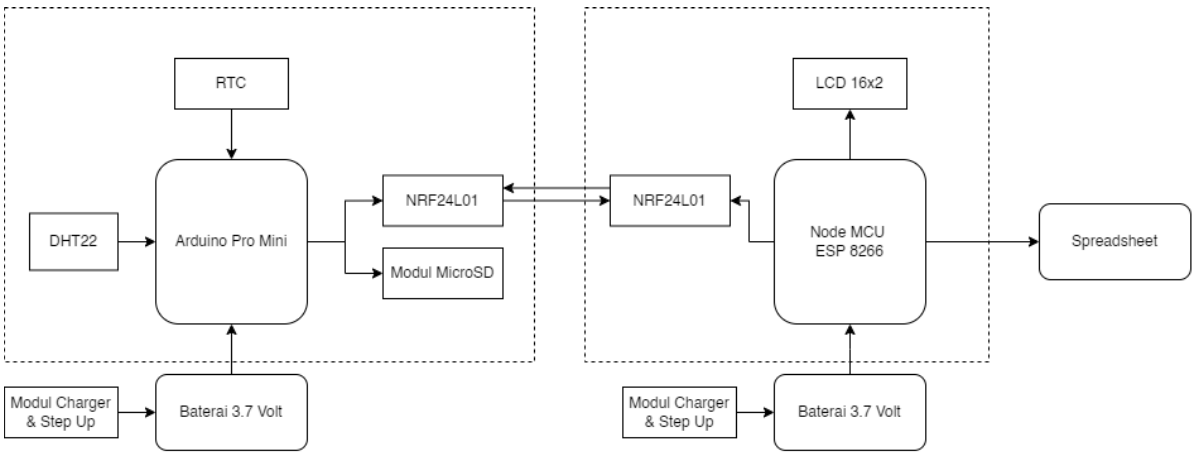


Fig. 1. Block diagram of the drone-based IoT monitoring system.

Fig. 1 shows the connections between each component, such as the DHT22 sensor, Arduino Pro Mini microcontroller, ESP8266, NRF24L01 radio communication module, microSD module, RTC, and spreadsheets.

Each device is powered by a 3.7 volts battery. The battery voltage gets stepped-up using step up module. This module is also used to charge the battery. Illustration of the system's working concept can be seen in Fig. 2.

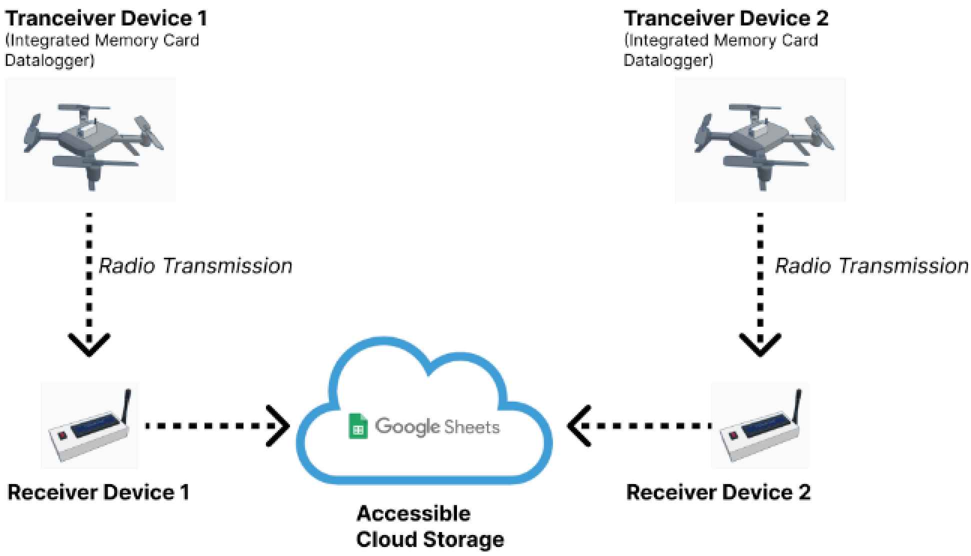


Fig. 2. The concept of work from the drone-based IoT monitoring system.

As it shows in Fig. 2, the device consists of two units connected via radio communication. One unit is a monitoring device equipped with an LCD display and will integrate with an IoT system for online data storage. The other unit is a measurement device with integrated temperature and humidity sensors and has the capability to store data offline via a memory card. The transmitting device, equipped with temperature and humidity sensors, will be flown vertically to a certain altitude. The temperature and humidity readings by the transmitting device will be stored in a data logger on a memory card and sent via radio waves to the receiving device on the ground. This receiving device will display the temperature and humidity readings on an attached LCD and upload them to a cloud-based data logger. The Algorithm of the system is shown in Fig. 3.

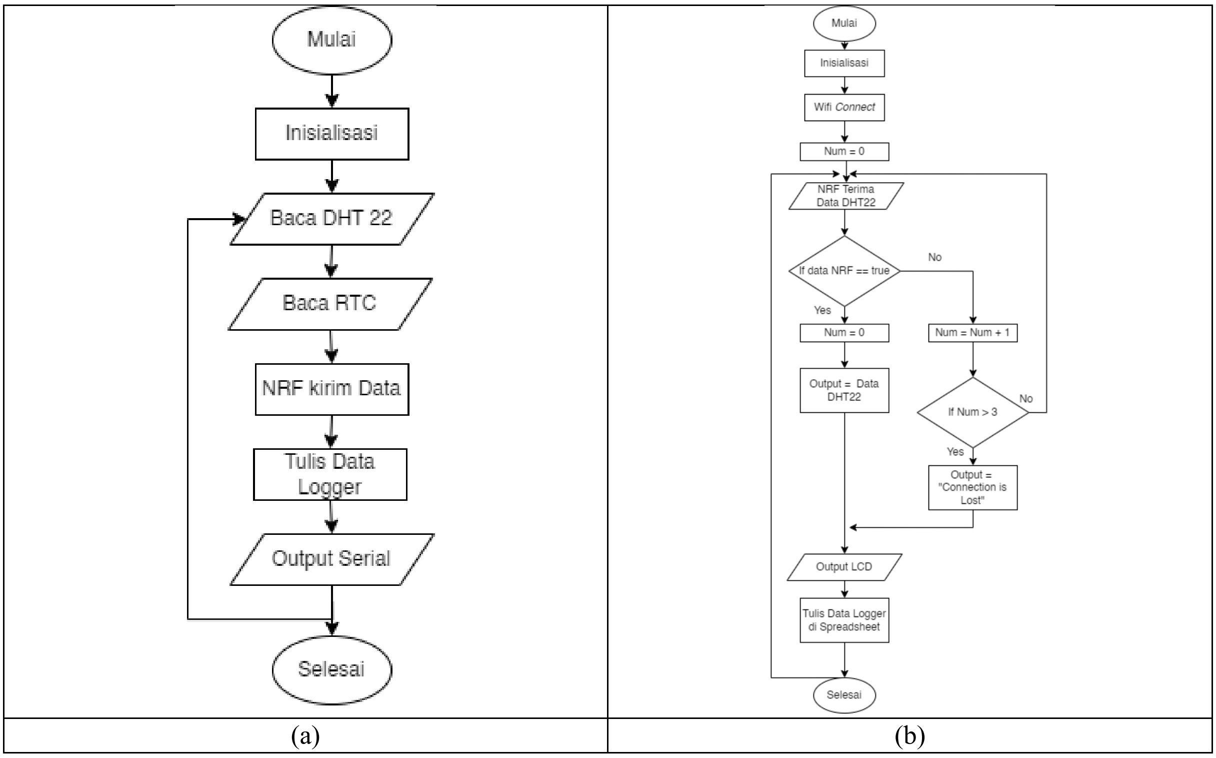


Fig. 3. System flowchart of (a) Transmitter device (b) Receiver device

Based on Fig. 3 (a), the transmitter system will initialize all components, such as the NRF24L01 module, DHT22 sensor, RTC, and Micro SD module. The system then reads the values from the DHT22 sensor, transmits these values to the receiver system, and writes them to the data logger. This process continues until the system is turned off.

In the receiver system, shown in Fig. 3 (b), the system begins by connecting to the internet and initializing all components. It creates a variable named 'num,' initially set to 0. This variable serves as an indicator of whether the receiver system is receiving data. The NRF24L01 module will receive data from the transmitter, and when data is received, it will display on the LCD and upload to a spreadsheet. If no data is received, the 'num' value increments. If 'num' exceeds 3, indicating that the NRF24L01 has failed to receive data three times in a row, the LCD will display "Connection is lost." When the NRF24L01 starts receiving data again, the 'num' value resets to 0. The IoT based monitoring system in this study utilize the ESP8266 microcontroller to transmit measurement data to cloud platform for real-time access and storage. Specifically, Google Sheets is used as the cloud storage solution. Data transmission is carried out using HTTP GET requests from the ESP8266 to a Google Apps Script web application, which is deployed as web service linked to the target spreadsheet. The transmitted data includes temperature and humidity values, which are appended to the spreadsheet along with a timestamp generated by the script. This method allows remote access to the monitoring data through any device connected to the internet, without the need for additional cloud services.

Data collection in this research will begin by comparing the readings from the developed device with a standard measuring instrument for air temperature and air humidity. Digital thermometer will be used to measure temperature and digital hygrometer will be used to measure air humidity. The monitoring data will be taken once in each location. There are three chosen locations based on their population density, the rural area will be represented by Lubuk Minturun, sub-urban area will be represented by Physics Laboratory of UNP, and urban area will be represented by BPBD Office Area. The data readings will be taken at 9.00 am in clear sky condition at the range of altitudes between 0 meter to 500 meters and the data readings will be taken every 100 meters. The measurements of physical quantities from the device will be compared with readings from the standard measuring instrument. Based on these data, the accuracy, represented by A%, of the device will be determined. By repeatedly measuring each physical quantity, the precision, represented by P, of the device will also be established. In order to determine the level of accuracy, the measurement data will be processed using Equation (1) where Y_n represents the reading using digital thermometer and X_n represents the reading of the drone-based IoT monitoring system.

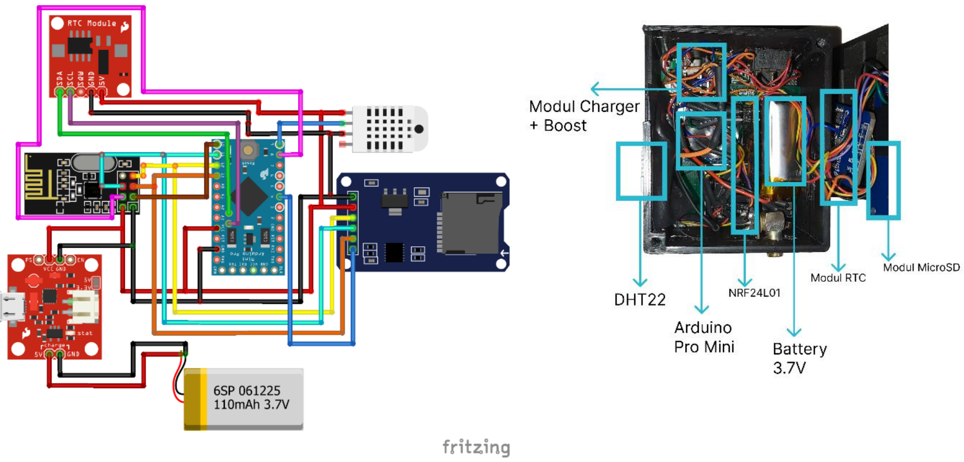
$$A\% = \left[1 - \left|\frac{Y_n - X_n}{Y_n}\right|\right] x100\% \quad (1)$$

Precision of this system can be determined using Equation (2) where $\bar{X}_n$ represents the mean of the measurements using the drone-based IoT monitoring system.

$$P = 1 - \left|\frac{\bar{X}_n - X_n}{\bar{X}_n}\right| \quad (2)$$

III. RESULTS AND DISCUSSION

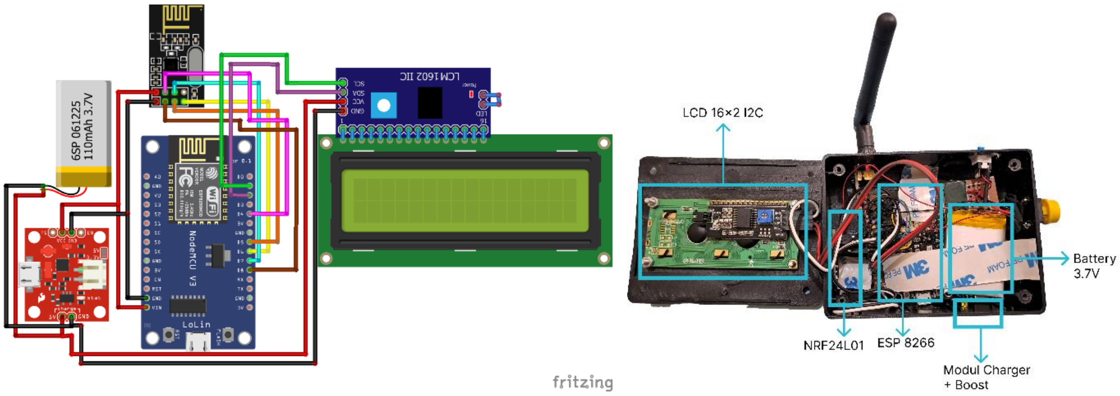
Performance specifications cover the performance of each component within the monitoring system. The performance specifications conducted in this research include the characterization of the DHT22 temperature and humidity sensor, testing the data transmission function on both devices, testing data storage on the data logger for both memory card and cloud storage, as well as the mechanical aspects of the monitoring system. The components forming the system device are connected using a PCB and jumper wires. Each component is assembled according to the previously designed circuit schematic. The circuit schematic and the assembled circuit layout are shown in Figure Fig. 4.



(a) (b)

Fig. 4. (a) Circuit schematic of the transmitting device (b) Circuit layout of the transmitting device

In Fig. **4**, it can be seen that components such as the microcontroller and NRF24L01 are mounted directly on the PCB. Other components are connected to the pins on the PCB using jumper wires. The use of jumpers is intended to add flexibility in positioning them within the casing of the transmitting device to optimize space utilization. The receiving device also uses a PCB and jumper wires to connect the components. The electronic circuit can be seen in Figure 5.



(a) (b)

Fig. 5. (a) Circuit schematic of the receiving device (b) Circuit layout of the receiving device

Fig. **5** shows the circuit schematic of the monitoring system's receiving device. The microcontroller is mounted directly on the PCB, while other components such as the LCD, NRF24L01, and battery are connected using jumper wires. Similar to the transmitting device, the use of jumpers for connecting these components allows for more flexibility in positioning them within the casing.

1. Characterization

Data from temperature readings by the system and the standard measuring instrument were taken every 30 minutes from 6:30 AM to 3:30 PM at the same location. The system characterization data can be seen in Fig. **6**.

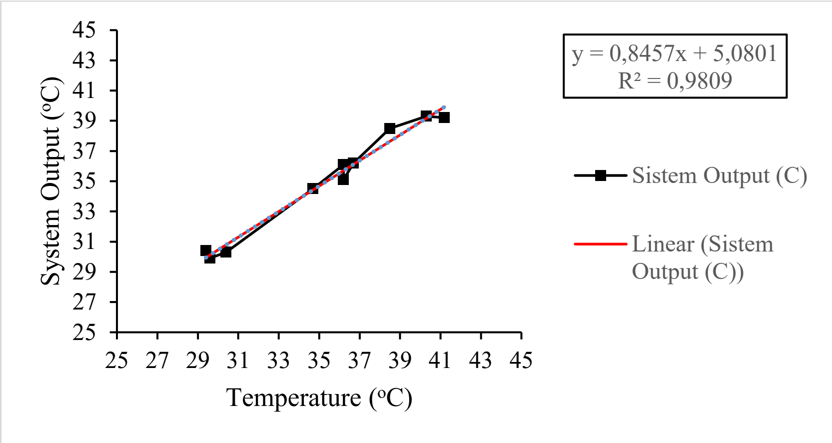


Fig. 6. Temperature Characterization

Based on Fig. 6, it can be seen that the characteristics of the DHT22 temperature sensor are linear with changes in temperature. The graphic analysis shows that the reading value of this system is very close to the reading results using a standard tool, this is shown from a good linear curve with an R^2 value close to 1, precisely R^2 = 0.9809. The result of this characterization shows that the system can provide accurate reading to monitor surface temperatures.

Humidity characterization in this system was performed by comparing the humidity readings from the system with the actual value. The standard measurement tool that used to measure the humidity is hygrometer. Data were collected by performing ten measurements, with a time interval of 30 minutes between each. The measurements were taken at the same location. The obtained data can be seen in Fig. 7.

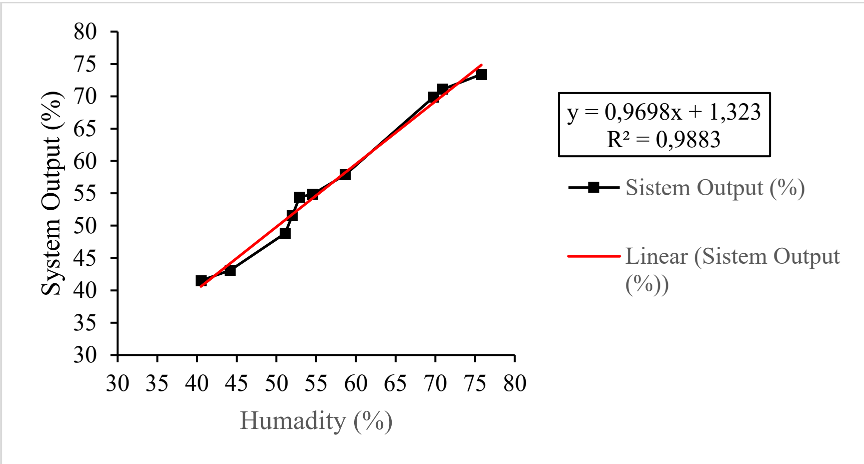


Fig. 7. Humidity Characterization

Based on the graph in Fig. 7, it can be seen that the characteristics of the DHT22 humidity sensor are linear with changes in humidity. The graphic analysis shows that the reading value of this system is very close to the reading results using a standard tool, this is shown from a good linear curve with an R^2 value close to 1, precisely R^2 = 0.9883. The result of this characterization shows that the system can provide accurate reading to monitor surface humidity.

2. Transmission

The data transmission between the sending and receiving devices was tested at a maximum altitude of 500 meters on the rural area to avoid noise, specifically in Lubuk Minturun. Transmission data was collected at every 50-meter increase in altitude. The transmission test data results can be seen in

Table 1.

Table 1. System's data transmission test

Height (*m*)	Transmission status
0	Transmitted successfully
50	Transmitted successfully
100	Transmitted successfully
150	Transmitted successfully
200	Transmitted successfully
250	Transmitted successfully
300	Transmitted successfully
350	Transmitted successfully
400	Transmitted successfully
450	Transmitted successfully
500	Transmitted successfully

Based on the data from the

Table 1, it is known that the device's transmission can reach a height of 500 meters without issues. This distance was selected based on its application, which is monitoring temperature and humidity for observing temperature inversion phenomena occurring at altitudes of 250m to 300m, as stated in the study by Liou & Yan in 2006. These results indicate that the data transmission works well.

3. Accuracy

The accuracy of the temperature readings by the monitoring system was determined by comparing the measurement results from the system with those from the standard measuring instrument. The measurements were taken 10 times at the same location, from morning to afternoon. The interval between each measurement and the previous one was 30 minutes. The obtained measurement results were then entered into Table 2.

Table 2. System's accuracy data

Temperature (^oC)			Humidity (%)		
System	**Thermometer**	**Accuracy**	**System**	**Hygrometer**	**Accuracy**
32,3	32,3	100,0%	66,6	66,5	99,8%
32,2	32,1	99,7%	68,1	69,6	97,8%
32	31,7	99,1%	69,3	70	99,0%
32,3	31,8	98,4%	69	70,3	98,2%
33,1	32,8	99,1%	78	80	97,5%
33,5	33	98,5%	85	89	95,5%
33,6	33	98,2%	75	72,1	96,0%
34	33,7	99,1%	73,1	75	97,5%
37	36,6	98,9%	74,1	73,1	98,6%
38,1	37,6	98,7%	74,6	73,8	98,9%
Average		99%			97,77%

Based on Table 2, the system's reading for temperature and humidity are accurate to the accrual value. The data shows that the average temperature measurement accuracy is 99%, with the lowest accuracy at 98.4% and the highest at 100%. The mean of temperature readings error percentage is 0,1% and the error percentage of humidity readings is 2,23%. These results are consistent with studies by [15-17], which also used DHT22 sensor. The studies reported that the temperature measurement errors of 2.33% and 2.31% indicated that the accuracies are 97.67% and 97.69%, and humidity measurement errors of 2.29% and 2.99% indicates that the precisions are 97.71% and 97.01%. This result also aligns with the information that is provided by the DHT22 datasheet.

4. Precision

Precision for humidity measurement was determined through repeated measurements in a room with controlled humidity. The temperature and humidity readings were collected every 10 minutes. The results are presented in

Table 3.

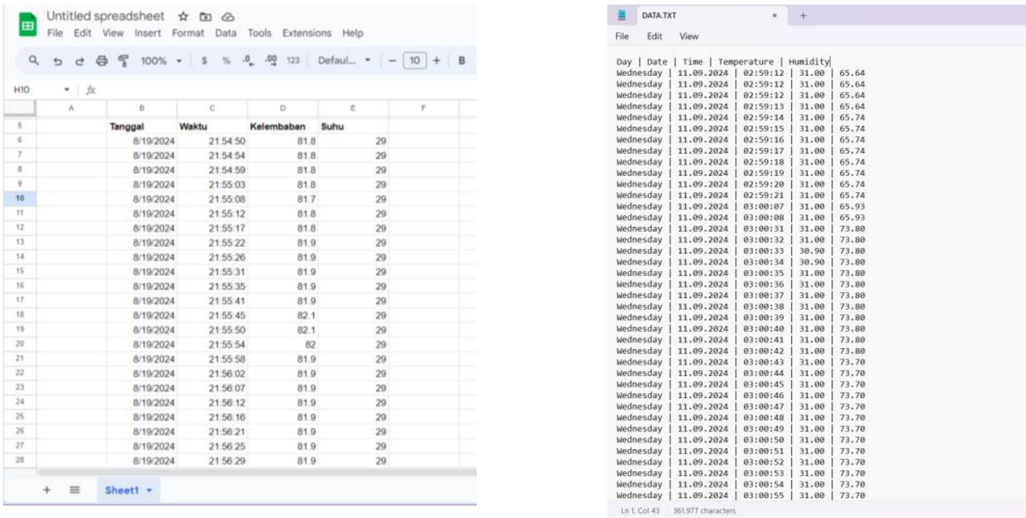
Table 3. System's precision data

No	Temperature		Humidity	
	Temperature (°C)	**Precision**	**Humidity (%)**	**Precision**
1	32,3	1,00	64,6	0,99
2	32,3	1,00	64,2	0,99
3	32,3	1,00	64,4	0,99
4	32,3	1,00	64,1	0,99
5	32,3	1,00	63,9	0,98
6	32,3	1,00	65,1	1,00
7	32,3	1,00	65,6	0,99
8	32,3	1,00	65,9	0,99
9	32,3	1,00	65,9	0,99
10	32,3	1,00	66,2	0,98
Average	32,3	1,00	64,6	0,99

Based on the

Table 3, the precision data obtained for air temperature and humidity showed that the system's readings are highly precision. This is indicated by the temperature readings from the system have an average precision of 1.00. The humidity measurements by the system have an average precision (P) of 0.99. The highest precision is 1.00, while the lowest precision is 0.98. These results align with the study by Oktaviani in 2023 [18], which found an average precision of 1.00 for the DHT22 temperature sensor. This results of the accuracy and precision test shows that the system can provide highly precision measurement for the drone-based monitoring system.

5. Logging



(a) (b)

Fig. 8. (a) Data logger display on memory card **(b)** data logger display on spreadsheet

Fig. 8. (a) shows the data logger in this system is stored on a MicroSD memory card and Fig. 8. (b) shows cloud base storage in Spreadsheet. In order to access the memory card, a MicroSD module is installed in the system. The result of the data logger test provided the desired outcome as the readings of temperature and humidity are successfully stored on the data logger within the memory card. The data logger display can be seen in the Figure. In addition to using the memory card as a data logger, measurement data is also stored on a cloud-based data logger. Access to this cloud storage requires Internet of Things (IoT) technology. IoT access is available on the receiving device in the system because the microcontroller used, the ESP8266, supports IoT functionality.

6. System Transmission Testing in Various Location

Drone-base monitoring system was deployed to test the system. The data was collected in various location. The readings data is shown in Table 4.

Table 4. Transmission Range Data of the Device at Different Locations

Physics Laboratory of UNP			**BPBD Office Area**			**Lubuk Minturun**		
Height (*m*)	**Temperature (*^oC*)**	**Humidity (*%*)**	**Height (*m*)**	**Temperature (*^oC*)**	**Humidity (*%*)**	**Height (*m*)**	**Temperature (*^oC*)**	**Humidity (*%*)**
0	30,4	73,4	0	30	79,1	0	32,4	72,8
50	73,9	29,7	100	29,6	78,8	100	31,7	70,5
100	29	74,2	200	28,4	83,5	200	30,8	72,1
150	28,7	75,7	300	-	-	300	30,1	75,3
-	-	-	400	-	-	400	29,1	77,9
-	-	-	500	-	-	500	28,6	77,5

As it shown in Table 4, the system was tested in three locations. One of the locations is rural area which has minimal communication towers or electronic devices using radio signals on the same frequency as the system. This location also had few tall buildings. Test results at this site indicated that the system could transmit data effectively up to a height of 500 meters. In contrast, the other two locations were densely populated urban areas with many high-rise buildings and various electronic devices operating on the same radio frequency as the system that interfere the system transmission. Test results in these urban areas showed significant difficulties in data transmission, with data failing to reach heights of 500 meters.

The average temperature measurement accuracy in this system is 99%, with the lowest accuracy at 98.4% and the highest at 100%. These results are consistent with the articles by [15-17], which reported temperature measurement errors of 2.33% and 2.31%. The precision of the system for air temperature and humidity showed the expected results. The temperature readings from the system have an average precision of 1.00. The humidity measurements by the system have an average precision (P) of 0.99. The highest precision is 1.00, while the lowest precision is 0.98. These results align with the study by Oktaviani in 2023 [18], which found an average precision of 1.00 for the DHT22 temperature sensor. The device's transmission can reach a height of 500 meters without issues. However, transmission between the sending and receiving devices is prone to interference when located in large urban areas. This interference can be seen in Table 10, which shows data transmission at different locations. According to [19-20], this interference is caused by concrete walls, trees, utility poles, and other objects that absorb, reflect, and scatter NRF24L01 radio waves. This problem needs to be fixed in future study by upgrading the transmission module to a better module with features to solve this particular problem. Additionally, the transmitting device sometimes experiences issues with its electronic system wiring. This occurs due to the thin wires that is used to connect components to the microcontroller or to other components occasionally becoming disconnected because it detached when the device experiences a disturbance in the air. This problem can be solved by soldering all components to the PCB instead of using wire to connect system's components.

IV. CONCLUSION

The development of this monitoring system has provided a solution in the fields of climatology and meteorology for observing and studying the atmospheric profile, particularly air temperature and humidity, vertically. The use of drones in this system offers mobility advantages. This monitoring system has a temperature measurement accuracy of 99% and a humidity reading accuracy of 97.77%. The device also has a precision of 1.00 for temperature measurements and 0.99 for humidity measurements. The transmission of this device has been proven to work well up to a height of 500 meters. The data storage system works efficiently in saving data either on a memory card or in a cloud-based data logger. This device is expected to contribute to the advancement of scientific knowledge, particularly in the study of climate and climatology in the future.

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