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Design of a Radiosonde System for Air Quality Monitoring in the Tangerang City Area

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A B S T R A C T

Tangerang City, located in Banten Province, Indonesia, experiences high rainfall levels that often lead to damaging floods. Climate change has exacerbated these disasters with increasingly unpredictable weather extremes. To address these challenges, upper-air observations using radiosondes are crucial for real-time atmospheric monitoring. Radiosondes effectively measure meteorological parameters such as air pressure, temperature, and humidity when flown into the atmosphere by balloons. This study developed a cost-effective and easily implementable radiosonde system to enhance meteorological data collection in Tangerang City. Thus, the system supports accurate weather analysis and improves disaster management and environmental decision-making in the region.

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1. INTRODUCTION

Tangerang is one of the main buffer cities in the Greater Jakarta metropolitan area, occupying the third position after Bekasi City and Depok City in West Java. According to the Central Bureau of Statistics (BPS) in 2024, the population of Tangerang City will reach 1963.97 thousand people. Tangerang City is located in Banten Province, Indonesia, with geographical coordinates of approximately 6 ° 10 ′ N and 106 ° 38 ′ E. The city is bordered by Jakarta on the one hand, and on the other hand, by Jakarta on the other. The city borders Jakarta to the east, Tangerang Regency to the west and north, and South Tangerang City to the south. Tangerang has a strategic role as one of the main supports of the capital city of Jakarta in various aspects, including economy, transportation, and housing.

Early warning systems for air quality have progressed rapidly thanks to the Internet of Things technology, which enables real-time monitoring of air pollutants such as PM2.5, NO2, and CO through interconnected sensors [1][2]. Recognising the significance of monitoring air quality and providing precise and fast data to the public. Almost every work site has the possibility of hazards, ranging from the materials used, the way of working, to the waste produced (liquid, solid, and gas). If not handled properly, this way of working can pose a serious threat to the safety and health of the workforce [3][4][5].

Since the period of the 1950s, under the guidance of the World Meteorological Organisation (WMO), radiosonde measurements have been carried out to produce good quality vertical data that can measure temperature, humidity and wind data in an area measured by the radiosonde [6][7]. The use of radiosonde data can be used for weather forecasting [8], re-analysis of atmospheric history [9], calibration of data from satellites [10], and research on extreme regions [11]. Specifically, temperature information from radiosondes is crucial in assessing and linking atmospheric warming patterns [12], measuring atmospheric moisture levels and water vapour patterns [7], and analysing atmospheric instability and buoyancy changes [13]. Internet- based

According to data from the Central Bureau of Statistics (BPS), the level of rainfall in Tangerang City in the period 2021-2023 is quite high. The highest rainfall occurred in February 2021 at 446.30 mm [14]. Global weather changes can affect hydrological aspects, such as very high rainfall and variations in rainfall patterns, both of which lead to increased flooding in urban areas and negative impacts on existing city infrastructure [15]. This leads to loss of assets, especially infrastructure and household property, as well as impacts on people and the economy, especially income in the industrial and transport sectors, and disruptions in trade activities [16].

Air quality monitoring has been done by many researchers before [17] conducted research related to air quality where they created an air quality monitoring system that predicts pollutants and measures air pollution levels. In addition, air quality monitoring techniques are carried out differently which are spatiotemporal based which can predict air pollution by considering the spatial distribution and interaction characteristics between regions [18].

Julio Buelvas et al. [19] focused their innovation on data quality in IoT-based air quality monitoring systems. They focus on improving data accuracy and precision by means of sensor calibration techniques. Research by Ade Silvia Handayani et al [20] created a multi-sensor network to monitor air in a closed parking area, especially motor vehicle exhaust gas. This IoT system provides real-time data with high accuracy, helping users avoid areas with high levels of air pollution.

There are many methods developed by researchers to facilitate air quality monitoring, namely the SVM method [21], LSTM model [22][23], using ICEEMDAN, WOA, and ELM techniques [17], spatial spill techniques and cognitive fuzzy models [18], internet-based [24], [25], [26], [27].

2. RESEARCH METHOD

The method applied in this study is through a literature review, which involves collecting and reviewing various relevant reading sources. These sources consist of books, academic journals, research reports, articles, and other documents related to the issue under study. These sources were then used as references for the design of the Radiosonde System for Air Quality Monitoring in Tangerang City.

In addition, this method also includes a critical assessment of the existing literature to find gaps in the research, as well as summarising previous results to strengthen a more in-depth analysis. This approach aims to gain in-depth insight into the topic of study and create a strong theoretical foundation to support the research results.

2.1 Place of Research

Fig. 1. Place of research map

The research was conducted in Semarang City, Central Java. Semarang City is located between 6°50‘7°10’ South latitude and 109°35‘- 110°50’ East longitude. To the west, Semarang City is bordered by Kendal Regency, to the east by Demak Regency, to the south by Semarang Regency.

2.2 Research Stages
The research stages carried out in this study can be seen in Fig. 2.

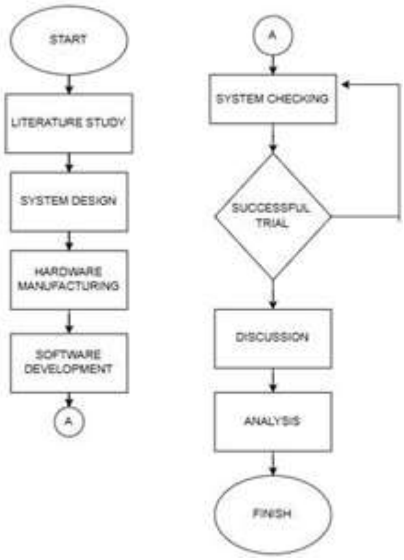

Fig. 2. Flowchart of Research Stages

The flowchart shown in Fig. 2. illustrates the sequence of work in the research process undertaken. The first stage is the system study, which includes the theoretical basis and review of the systems that support this research. This system study is important to understand the background and scientific context of the research to be conducted. After that, the next stage is system design, which is a detailed plan for making the system in this research. At this stage, the initial design of the system is made by considering all the needs and technical specifications that have been identified.

The next stage is hardware manufacturing, which involves making the necessary hardware for the system. This includes the selection and assembly of electronic components, as well as ensuring all the parts work well together. Next, the software is created, which includes developing software for the microcontroller and creating a graphical user interface (GUI) programme. The software is in charge of controlling the hardware and allowing users to interact with the system effectively.

2.3 Work System
The system starts with sensors that detect temperature, relative humidity (RH), and air pressure parameters. In addition, the GPS system will obtain location and altitude data of the radiosonde transmitter. All this data is then sent to the receiver using radio waves at a frequency of 433 MHz.

The receiver receives the signal and processes it into data that can be displayed on a PC. Thus, users can know the data of temperature, RH, air pressure, wind direction and speed, as well as the location and altitude of the radiosonde transmitter. This system is designed to monitor air quality in the Tangerang City area, so as to provide accurate real-time information about local atmospheric conditions. This information is very useful in weather analysis and mitigation of potential disasters such as floods, especially considering the high rainfall and flood vulnerability in Tangerang City. This easy-to-implement and low-cost system is expected to be adopted by various observation stations in the region, to increase meteorological data density and support better decision-making in environmental management.

3. RESULT AND DISCUSSION
3.1 System Design
The designed system is divided into two main components, namely the transmitter and receiver. The transmitter consists of several elements, including a temperature sensor, relative humidity (RH) sensor, air pressure sensor, GPS system, microcontroller, telemetry module, and battery. Meanwhile, the receiver consists of a receiving antenna, telemetry module, and microcontroller. The sender is planned to be mounted on a vehicle, such as a balloon filled with helium gas, for flight purposes.

Various parameters such as temperature, RH, air pressure, wind direction and speed, and the location and altitude of the sender will be measured using sensors and GPS, and then the collected data will be sent to the receiver. At the receiver, a laptop or PC is used to display the results of the measurements that have been made. The measurement data can also be read and stored on the device. The system block diagram shows the overall structure of this system.

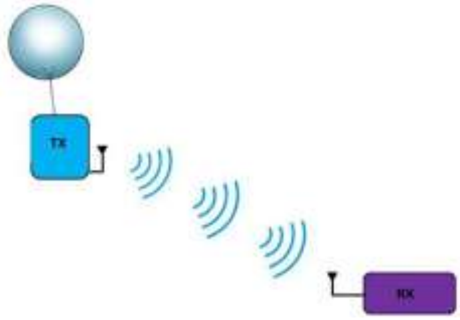

Fig. 3. Radiosonde system

3.2 System Components

The system consists of transmitter and receiver parts. The components in the transmitter system consist of sensors, GPS, microcontroller and telemetry module. Figure 3 shows the block diagram of the transmitter system.

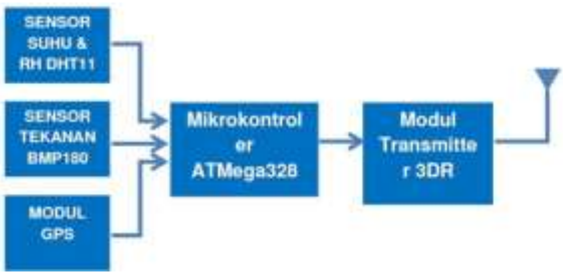

Fig. 4. Radiosonde components diagram

In Fig. 4, the DHT11 sensor, BMP180 sensor, and GPS module act as components that generate the data needed to measure temperature, relative humidity (RH), air pressure, and location parameters. The information obtained from these sensors will be transferred to the ATMega328 microcontroller for further processing. After going through the processing stage, the data will be sent through a 3DR- type transmitter module operating at a frequency of 433 MHz.

Fig. 5 provides a visualisation of the entire transmitter system that has been successfully assembled and prepared for use. In the figure, it can be clearly seen how the components are arranged and connected to each other, showing that the transmitter system has been successfully completed and is ready to perform its functions.

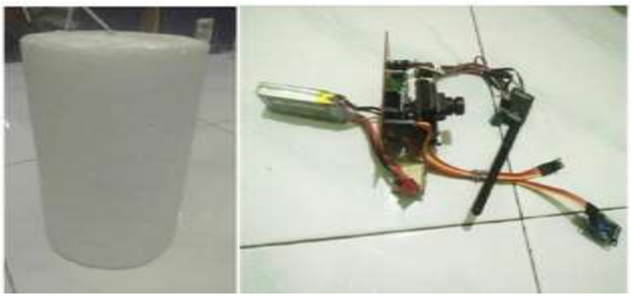

Fig. 5. Transmitter casing and transmitter without casing

Fig. 6. Receiver system

Fig. 6 is a visual representation of the receiver system block diagram, which operates on the principle of receiving the signal sent by the transmitter through the receiving antenna. The next process involves channelling this signal to the ATMega328 microcontroller, where it is processed to conform to a format that can be displayed. Once processed, the data is ready to be displayed on a laptop or PC screen for further observation and analysis. In other words, this block diagram illustrates the series of processes from signal reception to data presentation that can finally be interpreted by the user through a computer interface.

Fig. 7. Built receiver system

Fig. 7 is a visual representation of the receiver system that has been designed and built. In the figure, the components that form part of the receiver system can be seen, which include the receiving antenna, telemetry module, and microcontroller. This entire system has been successfully assembled and prepared to receive and process the signals received from the transmitter. Fig 6 thus gives an overview of how the receiver system has been completed and is ready to be used in its application context.

3.3 System Testing

Testing the radiosonde system includes several important steps, namely sensor calibration, telemetry system communication distance testing, and transmitter power consumption analysis.

a. Communication Distance Testing

This test aims to determine the maximum distance at which the telemetry system can function properly. Table 1 shows the data from the communication distance test of the radiosonde system.

Table 1. Communication Distance Testing Results

Height (metres) Success rate	Height (metres) Success rate
100	Success
1000	Success
2000	Success
3000	Success
4000	Success
5000	Success
6000	Success
7000	Success
>7000	Success

The data in Table 1 show that the radiosonde communication system, when flown by balloon, works well under vertical Line of Sight conditions up to an altitude of 7000 metres above sea level. Communication is lost when the altitude exceeds 7000 metres.

b. Sensor Calibration

Calibration is the process of comparing the measurement results of observation tools with known and tested standard values. In the radiosonde system for monitoring air quality in Tangerang City, calibration is important to ensure the accuracy and consistency of temperature, relative humidity (RH), and air pressure sensor data. This process helps identify and correct inaccuracies, so that the resulting data is reliable.

Sensor testing aims to ensure the sensors function properly under the expected conditions of use. In this radiosonde system, testing includes sensitivity, response time, reliability and stability of the sensor. This is important to ensure that the sensor is capable of producing accurate and consistent data in various situations.

Sensor testing and calibration ensures that the radiosonde system can provide accurate real-time data, which is crucial for weather analysis and potential disaster mitigation in Tangerang City.

c. Telemetry Testing

Telemetry testing on the radiosonde system aims to determine whether the transmitter and receiver components can function properly in the process of monitoring air quality in the Tangerang City area. This process involves sending data from the transmitter attached to the radiosonde to the receiver located at the monitoring station. The success indicator of this system test is the receiver's ability to receive the data intact and save it in .txt or .xls format. This is important to ensure that the data received can be processed and analysed further.

Successful telemetry testing showed that the radiosonde system was able to accurately transmit critical information such as temperature, relative humidity (RH), air pressure, wind direction and speed, and location and altitude. This data is invaluable for monitoring air quality in Tangerang City, providing accurate real-time information on local atmospheric conditions. In addition, the system can support weather analysis and mitigation of potential disasters such as flooding, given the high rainfall and flood vulnerability in the region. Therefore, telemetry testing not only ensures the technical reliability of the radiosonde system but also supports better decision-making in environmental management in Tangerang City.

3.4 Analysis of Test Result

a. Data Transmission Success

Analysis of the test results is carried out to evaluate the overall performance of the radiosonde system after going through the design and testing stages. The following are some of the main points discussed in this analysis:

The test results show that the radiosonde system is able to transmit data up to an altitude of 7000 metres above sea level with a high success rate. Communication was lost when the altitude exceeded 7000 metres. This shows that the telemetry system works well under vertical Line of Sight conditions, but needs improvement for communication at higher altitudes.

b. Sensor Data Accuracy

Sensor calibration shows that the temperature, relative humidity (RH), and air pressure sensors provide accurate and consistent results according to known and tested standard values. The calibration process helps identify and correct inaccuracies, making the resulting data reliable for air quality analysis.

c. System Reliability

Sensor testing ensures that the sensors function properly under expected conditions of use, including sensitivity, response time, reliability and stability of the sensors. The system is able to provide accurate real-time data, which is crucial for weather analysis and potential disaster mitigation in Tangerang City.

d. Ease of Implementations

The radiosonde system is designed to be easy to implement and low cost. This is expected to increase the adoption of the system by various observation stations in Tangerang City area, in order to increase meteorological data density and support better decision-making in environmental management.

e. Potential Use for Disaster Mitigations

Data obtained from radiosonde systems are very useful for weather analysis and mitigation of potential disasters such as flooding. Real-time information on local atmospheric conditions can help in responding to emergency situations more quickly and effectively, especially considering the high rainfall and flood vulnerability in Tangerang City.

4. CONCLUSION

This research successfully designed and developed a radiosonde system to monitor air quality in Tangerang City. The system, which consists of sender and receiver components, is proven to be able to measure and transmit meteorological data accurately up to an altitude of 7000 metres. The sensors used are well calibrated, producing reliable data for weather analysis and disaster mitigation. The system is also easy to implement and low cost, enabling wider adoption by local observation stations, thereby increasing meteorological data density and supporting better decision-making in environmental management.

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