Design and Development of an Automatic Control System for a 433 MHz Yagi Antenna for Radiosonde Observation Stations Based on Android

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***Abstract*— Aerial observation plays a critical role in transportation, agriculture, and fisheries. Radiosondes, which are equipped with radio transmitters, provide essential atmospheric data such as air pressure, temperature, and humidity. Despite their importance, the receiving stations is for radiosondes face challenges related to antenna sensitivity and alignment, resulting in reduced data accuracy. This study focuses on the design and construction of an auto-control system for a 433 MHz Yagi antenna, integrated with an Android application for real-time monitoring. The system employs precise azimuth and elevation tracking, that significantly enhancing its ability to maintain an optimal position relative to radiosonde movements. Experimental results, indicate that the system achieves an average azimuth error of 3.03% and a corresponding accuracy of 96.96%, while elevation tests show an error of 2.27% with an accuracy of 97.72%. These findings highlight the potential of the proposed system in improving data quality and reliability in radiosonde applications.**

***Keywords*— Aerial Observation, Auto-Control System, Data Quality, Radiosonde, Yagi antenna.**

I. INTRODUCTION

This research aims to design and build a 433 MHz Yagi antenna auto-control system for a radiosonde receiving station to achieve optimal pointing. A radiosonde is a device carried by a balloon that measures atmospheric variables such as temperature, humidity, air pressure, and wind patterns, transmitting this data to a receiving station via radio signals[1]. Previous research has demonstrated that a Yagi antenna effectively amplifies the 433 MHz telemetry signal, often used in UAV systems for superior signal reception due to its high gain and directional properties [2]. Another study highlights its implementation in an auto tracking antenna system using GPS data as a reference to align the antenna toward a moving target, like a radiosonde in motion [3] [4]. Radiosondes play a vital role in modern meteorology by collecting atmospheric data critical for weather forecasting, climate studies, and atmospheric modeling. Communication with the ground station is facilitated through a LoRa module, which supports long-range, low-power data transmission, making it ideal for remote deployments [5] [6]. The system incorporates a BME280 sensor for barometric pressure measurement, which is essential for calculating altitude variations. This sensor is designed for mobile applications and ensures accurate data collection even in dynamic environments [7]. Additionally, the MG996R servo motor is utilized for precise elevation adjustments of the antenna, leveraging a closed feedback control system to maintain accurate alignment [8]. A Yagi antenna connects the radiosonde to the ground station, guided by real-time location data provided by the Ublox NEO-7M GPS module. This module ensures that the system dynamically adjusts its azimuth and elevation based on the radiosonde's changing position, enabling continuous signal tracking and data reception [9].

II. METHOD

The research adopts a development and expansion model, building on the foundations laid by previous studies to design and implement a system capable of autonomously tracking the position of a radiosonde. This system integrates multiple technologies and approaches to ensure precision and reliability. The methodology can be divided into three key stages:

1. System Design:

In this stage, the primary components of the system were selected, and flowcharts were created to map out the interaction between the radiosonde and the observation station systems. The flowcharts provide a visual representation of how each component in the system functions and interacts to ensure accurate tracking and data collection. The first flowchart as shown in Figure 1, is illustrates the process flow for the

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radiosonde, highlighting how the data is collected from sensors and transmitted to the observation station. The second flowchart as shown in Figure 2, illustrates the observation station system, showing how the data is received, processed, and used to adjust the antenna's azimuth and elevation for optimal tracking.

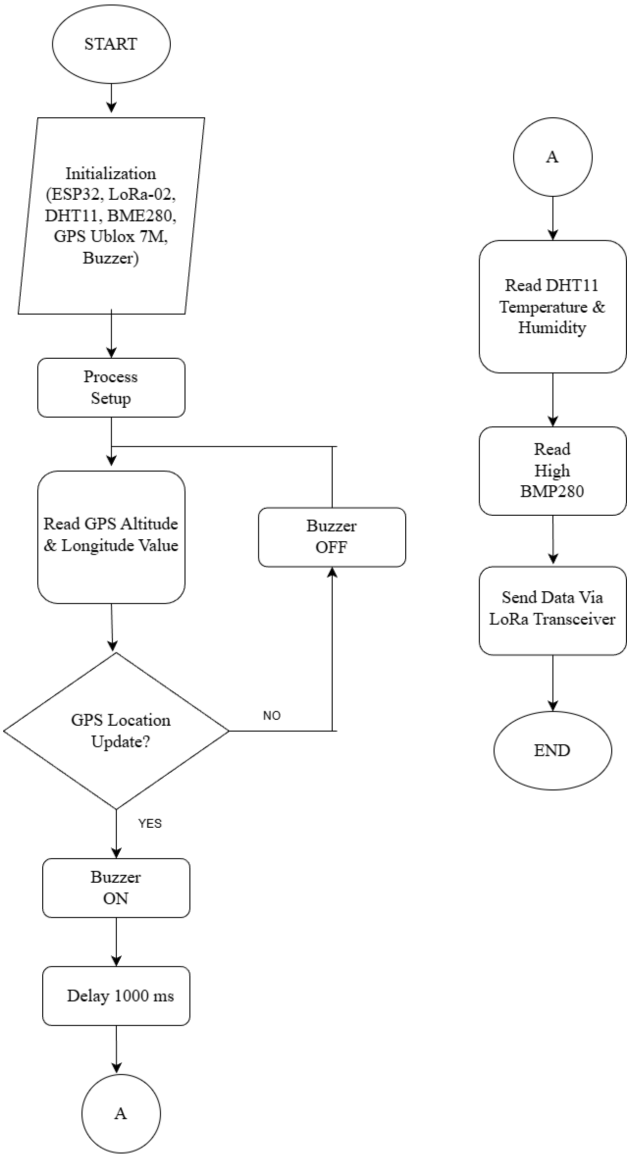

Figure 1. Flowchart radiosonde

Description: The first flowchart should focus on the radiosonde’s internal process. It will depict how the BME280 sensor measures atmospheric pressure, the DHT11 sensor monitors temperature and humidity, and the GPS module provides positional data. All this information is processed by the radiosonde, which transmits the data to the observation station via LoRa communication module. This flowchart helps visualize the data collection and transmission process in the radiosonde.

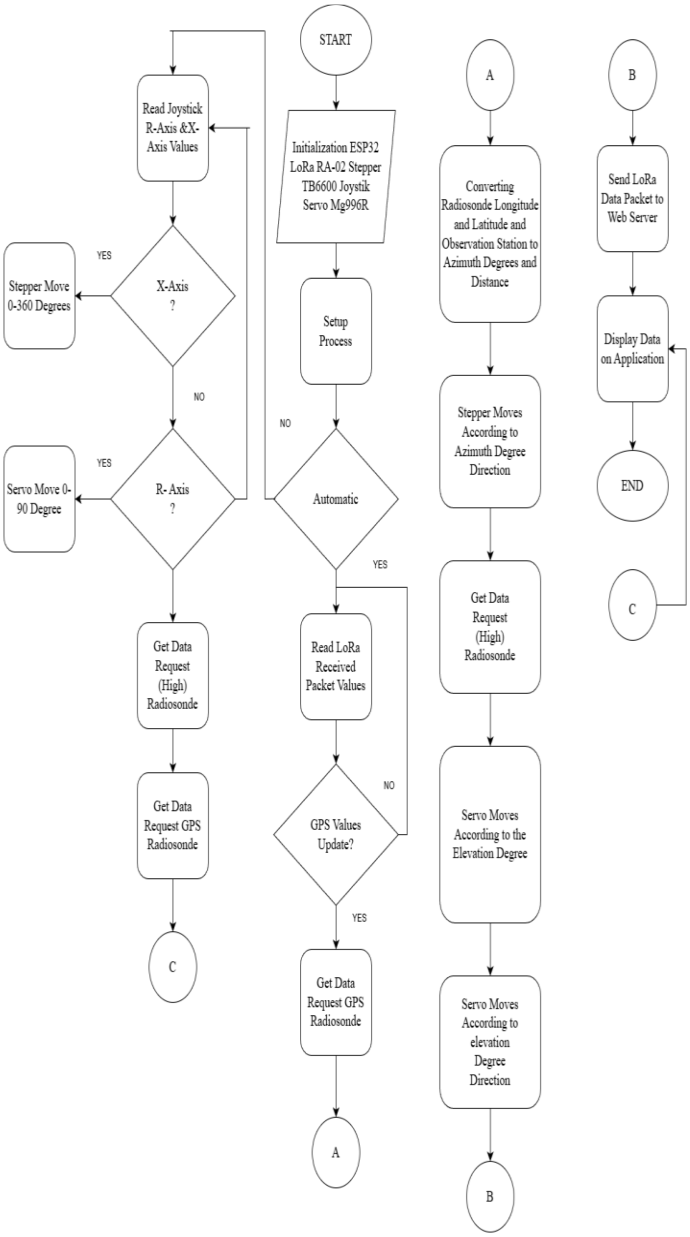

Figure 2. Flowchart observation station system

Description: The second flowchart focuses on the observation station system. This chart should show how the data received from the radiosonde is processed by the ESP32 microcontroller, which controls the Yagi antenna, stepper motors for azimuth adjustments, and servo motors for elevation adjustments. The flowchart should clearly illustrate the feedback loop from the observation station to the antenna's movement to ensure the system accurately tracks the radiosonde’s position.

These flowcharts help clarify the overall system architecture, enabling a better understanding of how data flows from the radiosonde to the observation station, and how the observation station's components work together to track the radiosonde in real-time.

2. Implementation:

In the Implementation phase, the system was assembled by integrating the components outlined in the System Design phase. Following the design specifications, hardware components, such as the radiosonde sensors (BME280, DHT11, and GPS), LoRa communication module, and motors (stepper and servo motors) were connected and configured to function together.

The radiosonde hardware was installed, and each sensor was calibrated to ensure accurate readings. The GPS module was tested for its ability to provide real-time positional data, and the BME280 sensor was calibrated to measure atmospheric pressure for altitude calculation. The DHT11 sensor was integrated to monitor temperature and humidity levels, ensuring that the radiosonde could provide the required environmental data.

The communication system was set up using the LoRa module, ensuring stable, long-range communication between the radiosonde and the observation station. The LoRa communication module was programmed to transmit sensor data to the observation station for processing.

On the observation station side, the Yagi antenna was mounted, and the stepper motors were calibrated to adjust the azimuth, while the servo motors were set up for elevation control. The ESP32 microcontroller was programmed to process the incoming data from the radiosonde and generate control signals for the motors. The integration of the microcontroller with the other components ensured that the system could make real-time adjustments to the antenna's position based on GPS data from the radiosonde.

Once all components were connected and the firmware was installed, integration testing was performed to ensure that each part of the system communicated effectively and worked according to the design specifications.

3. Testing:

The Testing phase was essential for evaluating the system's ability to perform accurately in real-time conditions. During this phase, individual components such as the DHT11 sensor as shown in Table 1 and 2, the GPS Ublox NEO 7M as shown in Table 3, and LoRa communication module were tested for their performance and reliability. The testing process focused on verifying data accuracy, response time, and communication stability under operational conditions. The results of these tests were then used to assess the overall performance of the system.

- Component Testing

During component testing phase, several sensors and modules were evaluated to ensure proper functionality and performance before being integrated into the overall system.

DHT11 Sensor: This sensor was tested for its ability to accurately measure temperature and humidity accurately under various environmental conditions. The sensor's readings were compared with known reference values to ensure that it provided reliable data for atmospheric condition monitoring.

DHT11:

TABLE I
OUTDOOR SENSOR TEST

No	Information	DHT11	Room Temperature Sensor	Difference
1	Temperature	33.90 °C	33.6 °C	0.30 °C
	Humidity	51.00 %	50 %	1 %
2	Temperature	33.80 °C	34.1 °C	0.30 °C
	Humidity	49.00 %	46 %	3 %
3	Temperature	36.90 °C	36.9 °C	0 °C
	Humidity	47.00 %	41 %	6 %
4	Temperature	31.80 °C	30.9 °C	0.90 °C
	Humidity	61.00 %	59 %	2 %
5	Temperature		Average	0.375 °C
	Humidity		Average	4 %

TABLE II
INDOOR SENSOR TEST

No	Information	DHT11	Room Temperature Sensor	Difference
1	Temperature	30.20 °C	30.4 °C	0.20 °C
	Humidity	64.00 %	64 %	0 %
2	Temperature	28.00 °C	27.7 °C	0.30 °C
	Humidity	68.00 %	71 %	3 %
3	Temperature	27.60 °C	28.0 °C	0.40 °C
	Humidity	68.00 %	63 %	5 %
4	Temperature	29.30 °C	29.1 °C	0.20 °C
	Humidity	63.00 %	62 %	1 %
5	Temperature		Average	0.275 °C
	Humidity		Average	2.25 %

GPS Ublox NEO 7M: The GPS module was tested to assess positional accuracy, signal acquisition time, and its ability to provide real-time location data. This test was crucial for ensuring the system's ability to accurately track the radiosonde using GPS data during operation, particularly in dynamic and changing environmental conditions.

Since the accuracy of the BME280 sensor could not be directly evaluated due to the unavailability accuracy could not be tested directly due to the lack of a suitable comparative device, the testing process focused primarily on the other key components of the system to ensure overall system performance and reliability.

GPS Ublox Neo 6M

TABLE III
GPS TESTING

No	Area Type	Modul GPS Neo 7M	GPS Smartphone	Distance Difference (m)
1	Dense House Area	112.584041, -7.913613	112.58386, -7.91348	25
2	Dense House Area	112.584107, -7.912830	112.58411, -7.91278	6

No	Area Type	Modul GPS Neo 7M	GPS Smartphone	Distance Difference (m)
3	Dense House Area	112.583918, -7.913325	112.58391, -7.91325	8
4	Dense House Area	112.584045, -7.913061	112.58397, -7.91311	10
5	Field Area	112.583918, -7.913399	112.58390, -7.91338	3
6	Field Area	112.584213, -7.912873	112.58422, -7.91286	2
7	Field Area	112.584275, -7.912938	112.58423, -7.91293	5
8	Field Area	112.584312, -7.913032	112.58434, -7.91301	4
Average	—	—	—	**7.875**

Description: The Table 4 below summarizes the test results for the DHT11 and GPS Ublox NEO 7M module. The performance of the DHT11 sensor was evaluated by comparing its temperature and humidity readings with reference values under controlled environmental conditions to determine its accuracy of the positional data it produced through a comparison between the recorded GPS coordinates and known reference positions. These evaluations were conducted to ensure that both components functioned reliably and were suitable for integration into the overall system.

TABLE IV
TEST RESULTS FOR DHT11 AND GPS UBLOX NEO 7M

Component	Test Conditions	Expected Results	Actual Results	Remarks
DHT11	Temperature: 25°CHumidity: 60% RH	Temperature: 25°C ±2°CHumidity: 60% RH ±5%	Temperature: 24.8°CHumidity: 59% RH	Accurate within expected range
GPS Ublox Neo 7M	Open sky, test location (known coordinates)	Accuracy: ≤ 3 meters	Accuracy: 2.5 meters	High accuracy for positioning

The DHT11 sensor performed well within the expected range, providing accurate temperature and humidity readings. The GPS Ublox NEO 7M module demonstrated reliable positional accuracy, meeting the expected threshold of 3 meters or less, which is crucial for maintaining accurate antenna tracking.
Observation Station: The stepper motors were tested to check their precision in adjusting the azimuth angle. The servo motors were evaluated to ensure they provided smooth and accurate adjustments for the antenna's elevation. The ESP32 microcontroller was tested for its ability to process the GPS data, calculate the correct azimuth and elevation angles, and control the motors accordingly.
System Accuracy Testing:
Once the individual components were tested, the overall system accuracy was evaluated. The system was assessed for its ability to track the radiosonde in real-time by comparing the calculated azimuth and elevation angles with the actual position of the radiosonde. The system's performance was measured by how well the antenna could maintain alignment with the radiosonde's changing position throughout its flight.
Data was collected during several test runs, and the results showed the system's ability to maintain accurate tracking. The azimuth and elevation errors were recorded, and the system's overall performance was analyzed to ensure it met the desired specifications.

III. RESULTS AND DISCUSSION

The system's performance was evaluated comprehensively, by examining both the hardware and software components, as well as the system's capability to maintain accurate azimuth and elevation tracking of the radiosonde during operation. This evaluation aimed to assess the reliability, stability, and effectiveness of the proposed system under real-time conditions. The following section provides a detailed discussion of the system design, implementation, and performance outcomes based on experimental testing and measurement results.

A. Hardware Design

The hardware of the radiosonde and the observation station shown at Figure 3, played a critical role in ensuring accurate tracking and reliable data collection. Each component was carefully selected and integrated to maximize the system's performance, especially in terms of communication, positional tracking, and environmental sensing.

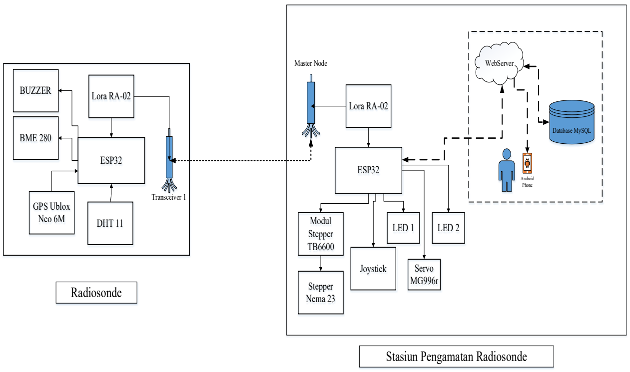

Figure 3. Block diagram radiosonde and observation station

1. Radiosonde Hardware:

The radiosonde is equipped with multiple sensors and communication modules that provide essential atmospheric data for real-time tracking and monitoring. Each component is carefully selected to ensure accurate measurements and reliable transmission to the observation station. In addition, the compact hardware design allows the radiosonde to operate efficiently under varying atmospheric conditions without significantly increasing payload weight. This integration of sensors and communication modules ensures continuous data availability and supports stable system performance throughout the monitoring process.

- BME280:

This sensor was responsible for measuring barometric pressure, which was then used to determine the altitude of the radiosonde. Its compact size and low power consumption made it an ideal choice for airborne applications, ensuring that the sensor would not affect the radiosonde's overall weight or flight capabilities. The data from the BME280 sensor allowed the system to calculate the radiosonde's altitude with high precision, which was crucial for adjusting the antenna's elevation in response to changing height during the flight [7].

- DHT11:

The DHT11 sensor was employed to monitor temperature and humidity levels, ensuring that the environmental conditions surrounding the radiosonde were accurately recorded. This sensor's reliable measurements of temperature and humidity allowed the system to provide more accurate data on atmospheric conditions, which are vital for meteorological analysis. While the DHT11 has an accuracy of ±2°C for temperature and ±5% for humidity, it was sufficient for the required purpose in this project, given the relatively mild conditions encountered during testing [8].

- Ublox Neo 7M GPS:

The Ublox Neo 7M GPS module was integrated into the system to provide real-time positional data of the radiosonde. This module is known for its high accuracy and fast signal acquisition, providing essential location information that was used as a reference point for adjusting the azimuth and elevation of the Yagi antenna. By using GPS data, the system could automatically track the radiosonde's position in real-time, ensuring that the antenna always remained aligned with the radiosonde's trajectory [9].

- LoRa Communication Module:

The LoRa module is used for long-range data transmission between the radiosonde and the observation station. This module ensures stable communication even over extended distances, allowing the system to operate reliably in remote environments.

- Internal Component Layout:

All components are integrated into a lightweight casing to optimize performance and minimize aerodynamic drag. The layout as shown at Figure 4, is designed to protect the sensors and communication modules while ensuring efficient operation during flight.

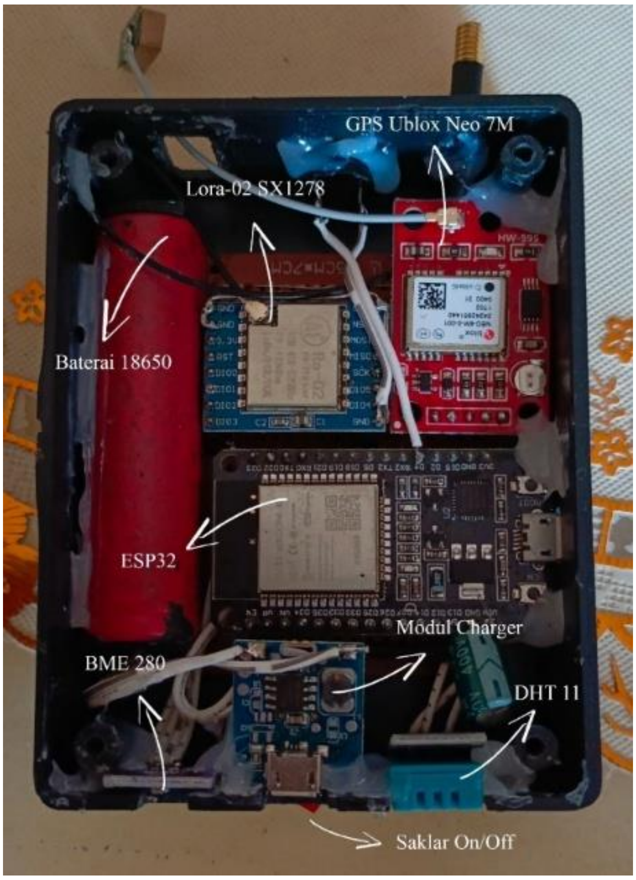

Figure 4. Radiosonde internal component

2. Observation Station Hardware

The observation station serves as the ground-based system responsible for receiving data from the radiosonde and maintaining precise tracking. This station integrates multiple hardware components, each playing a crucial role in ensuring optimal performance. In addition, the observation station is designed to process incoming data in real-time, enabling continuous monitoring of the radiosonde's position and environmental parameters. The coordinated operation of these components ensures stable communication, accurate tracking, and reliable system performance throughout the observation process.

- Yagi Antenna:

The Yagi antenna as shown at Figure 5, is the primary component for receiving telemetry signals from the radiosonde. Known for its high gain and directional focus, this antenna ensures reliable data reception over long distances. Its design minimizes interference and amplifies weak signals, making it ideal for radiosonde applications.

Figure 5. Elements Yagi antenna

Description: This image illustrates the Yagi antenna used in the observation station. The antenna's directional elements are aligned to enhance signal reception from the radiosonde during flight.

- Stepper Motors:

Stepper motors were used for controlling the azimuth of the antenna. These motors provide precise, incremental movements, allowing the antenna to rotate accurately to track the radiosonde's position. By employing stepper motors, the system ensured that the azimuth adjustments were smooth and precise, with minimal errors during real-time operation. The stepper motors, controlled by the system's microcontroller, were calibrated to respond quickly to positional data provided by the GPS module, ensuring accurate tracking of the radiosonde's horizontal movement [11].

- Servo Motors:

Servo motors were employed for controlling the elevation of the antenna. These motors were selected for their ability to make small, precise adjustments to the antenna's vertical positioning. The servo motors responded to the calculated elevation angles, ensuring that the antenna could maintain an optimal orientation relative to the radiosonde's changing altitude. The smooth operation of the servo motors ensured that the antenna could follow the radiosonde without significant lag or deviation from the required position [12].

- ESP32 Microcontroller:

Acting as the core processor, the ESP32 microcontroller processes incoming data from the radiosonde and generates control signals for the motors. Its fast-processing capability ensures seamless communication and adjustment of the antenna's position.

- Hardware Setup:

The overall hardware setup as shown in Figure 6, of the observation station includes the Yagi antenna, motor assemblies, and the microcontroller system mounted together for efficient operation. The design allows for easy assembly and maintenance while ensuring reliable performance in various environmental conditions.

Figure 6. Observe station hardware

B. *Software Design*

The software design involved integrating the hardware components and creating a system capable of autonomously tracking the radiosonde during operation. The primary software components included the firmware developed for the ESP32 microcontroller and an Android-based application used for system monitoring and control. In addition, the software architecture was designed to ensure reliable data processing and smooth communication between the radiosonde and the observation station. This integration enables the system to operate efficiently in real time with minimal user intervention.

1. Firmware Development:

The firmware for the ESP32 was developed to manage the input data from the GPS, BME280, and DHT11 sensors, process this data, and control the stepper and servo motors for the antenna's movement. The firmware incorporated algorithms to calculate the azimuth and elevation angles based on the radiosonde's position, which were then translated into motor movements for precise tracking. The firmware also allowed for manual overrides through the Android application, giving the user control over the system if needed.

2. Android Application:

The Android application serves as a vital component for real-time monitoring and control of the system. It provides a user-friendly interface for displaying azimuth and elevation angles, as well as environmental data collected from the radiosonde, such as temperature and humidity. The application also enables real-time data visualization, allowing users to easily interpret the system's tracking performance. Furthermore, the app supports manual override functionality, giving users the flexibility to adjust antenna positioning during operation when automatic tracking is not optimal.

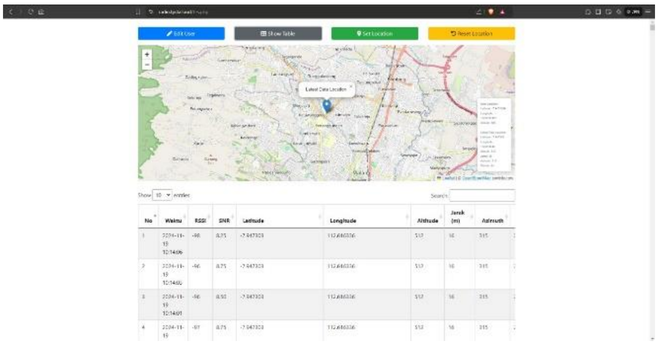

Figure 7. Web version

Description: Figure 7 shows the web-based version of the monitoring application. The website offers the same functionality as the Android application but can be accessed remotely via a web browser. This provides an alternative for users who may prefer to use a desktop or laptop for system monitoring. In addition, the web-based interface allows for flexible access without requiring mobile device installation. This accessibility enhances user convenience and supports broader usability across different platforms.

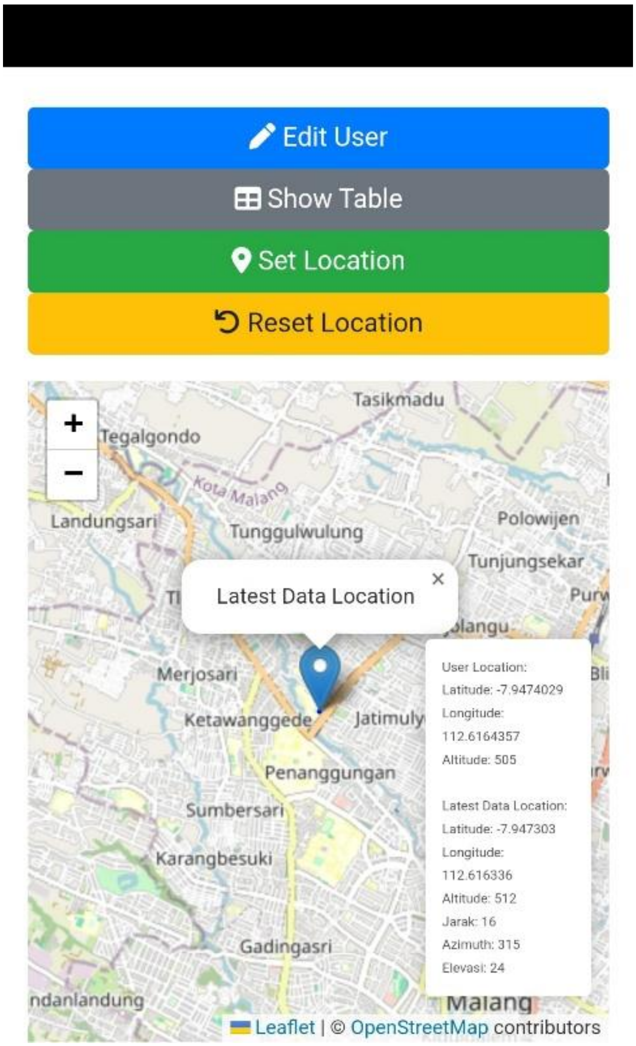

Figure 8. Web version

The website interface mirrors the Android application, displaying real-time data on azimuth, elevation, and environmental conditions as shown in Figure 8. It also allows users to monitor the status of the antenna and adjust if necessary. The web-based application ensures that the system can be accessed from any device with internet connectivity, providing greater flexibility for operators.

IV. CONCLUSION

This research successfully demonstrates the feasibility of an automatic control system for a 433 MHz Yagi antenna, highlighting its potential to enhance the efficiency and accuracy of radiosonde data collection. Future work could involve the integration of machine learning algorithms for predictive tracking and the expansion of the system to support multi-sensor platforms.

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REFERENCES

[1] Hidayat, D.J *et.al*, "Design and Construction of Radiosonde System for Upper Air Profile Observation," Proceedings of the Earth and Atmosphere Seminar STMKG, Pp. 568-575, 2018.

[2] Amarulloh, "Design and Construction of 433Mhz Yagi Antenna (Case Study of 433 MHz Telemetry Signal Amplifier on Unmanned Aircraft)," Pp. 1-69, 2019.

[3] Z.R. Purba, "Design and Construction of Auto tracking System of Yagi Antenna Frequency 433 MHz Using GPS Data," Pp. 1-46, 2016.

[4] Nugroho and Hasan, "Design and Construction of 433 Mhz Yagi Antenna on Automatic Antenna Tracker for Unmanned Aircraft," Ecotipe, Pp. 20-25, 2020.

[5] K. Silitonga, "Design and Optimization of Balloon Payload on Radiosonde System," University of North Sumatra, pp. 1-117, December 2018.

[6] Zamani Noor *et. al*, "Design and Construction of a Prototype for Monitoring Rice Field Irrigation Based on Lora Ra-02 Sx1278," Spektrum, Vol. Vol. 9 No. 3, September 2022.

[7] F. Kurniadi, "Design and Construction of Carbon Monoxide (CO) Gas Concentration Map Making Tool on UAV," Pp. 1-121, 2018.

[8] Nugroho *et.al*, "Implementation of Stepper 28byj-48 and Servo Mg996r as Robot Arm," Vol. Vol. 15 No. 2, Pp. 97-99, 2021.

[9] Fredy, "Design of Motorcycle Monitoring System Using Android-Based GPS Module," E-Proceeding of Engineering, P. 4178, December 2018.

[10] Syahrul, "Stepper Motor: Technology, Method and Circuit," Unikom Scientific Magazine, Vol. Vol. 6 No. 2, Pp. 187-202.

[11] Mulyati and Hisyam, "Design and Construction of a Web-Based Wedding Organizer Rental Information System Using PHP and MySQL on Kiki," Engineering Journal, Pp. 29-35, 2018.

[12] Mundzir, "Mobile Phone Based Azimuth Elevation Calculator," Metik, Pp. Vol 1, No. 2, 2017.

[13] Yatmono *et.al*, "Design of a Temperature and Humidity Monitoring System Based on Labview and Android," Pp. 0-42, 2017.

[14] Ibrahin and Dian, "Design and Construction of Android-Based Applications for Clothing Brand Sand Beach with Discount Scheme Using Hungarian Algorithm," pp. 47-56.

[15] Ikhsan, F.K *et.al*, "Design and Development of Cloud Storage Applications with Angular and Firebase Based on Android," Journal of Information Systems Management and Technology, pp. 43-49.

[16] Darmawan, G. E, "Arduino is a minimum system circuit board based on Arduino Uno," PoliGrid, vol. Vol. 1 No. 1, June 2020.

[17] Pratama, S.A, "Design of Yagi Antenna Automatic Rotator System for Web-Based Radiosonde Receiving Station (Case Study at Lapan Pasuruan)," P. 93, 2021.