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Design and Implementation of a GPS-Based UAV Tracking Antenna System Using LabVIEW

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Mission planner

Abstract: In disaster monitoring missions, unmanned aerial vehicles (UAVs) must cover large areas to assess the impact of a disaster. Critical to the success of such missions is the continuous transmission of Air Data and Attitude Heading Reference System (ADAHRS) data, along with stable RSSI and video feed transmission to the Ground Control Station (GCS). However, the vast coverage area poses a challenge, as omnidirectional antennas are limited by the UAV's operational range. To overcome this limitation, a high-gain directional antenna is required, which needs to be constantly aimed at the UAV to maintain a stable connection. This study presents an antenna tracker, designed and implemented using an ATmega328P microcontroller, two servo motors, and a GPS receiver, providing two degrees of freedom. The tracker allows 180-degree rotation on the azimuth axis (yaw) and 90-degree rotation on the elevation axis (pitch). The system interface was developed using LabVIEW. Experimental results demonstrate that the proposed antenna tracker significantly extends the UAV's operational range while maintaining a stable connection with minimal RSSI fluctuations compared to systems without an antenna tracker. The continuous availability of ADAHRS data, stable RSSI, and video feed ensures the success of critical mission operations.

LabVIEW Kullanarak GPS Tabanlı İHA Takip Anten Sisteminin Tasarımı ve Uygulaması

Anahtar Kelimeler
İHA-Anten izleyici,
LabVIEW,
Yer kontrol istasyonu,
Görev planlayıcı

Öz: Afet izleme görevlerinde, insansız hava araçları (İHA'lar) bir afetin etkisini değerlendirmek için geniş alanları kapsamalıdır. Bu tür görevlerin başarısı için kritik olan, Hava Verileri ve Tutum Yön Referans Sistemi (ADAHRS) verilerinin sürekli olarak iletilmesinin yanı sıra Yer Kontrol İstasyonuna (GCS) istikrarlı RSSI ve video besleme iletimi sağlanmasıdır. Bununla birlikte, çok yönlü antenler İHA'nın operasyonel menzili ile sınırlı olduğundan, geniş kapsama alanı bir zorluk teşkil etmektedir. Bu sınırlamanın üstesinden gelmek için, istikrarlı bir bağlantıyı sürdürmek için sürekli olarak İHA'ya yönlendirilmesi gereken yüksek kazançlı bir yönlü anten gereklidir. Bu çalışmada, ATmega328P mikrodenetleyici, iki servo motor ve bir GPS alıcısı kullanılarak tasarlanan ve uygulanan, iki serbestlik derecesi sağlayan bir anten izleyici sunulmaktadır. İzleyici, azimut ekseninde (yaw) 180 derecelik dönüşe ve yükseklik ekseninde (pitch) 90 derecelik dönüşe izin verir. Sistem arayüzü LabVIEW kullanılarak geliştirilmiştir. Deneysel sonuçlar, önerilen anten izleyicinin İHA'nın operasyonel menzilini önemli ölçüde genişlettiğini ve anten izleyicisi olmayan sistemlere kıyasla minimum RSSI dalgalanmaları ile istikrarlı bir bağlantı sağladığını göstermektedir. ADAHRS verilerinin sürekli kullanılabilirliği, kararlı RSSI ve video beslemesi, kritik görev operasyonlarının başarısını garanti eder.

1. INTRODUCTION

Unmanned Aerial Systems (UAS) consist of various components, including Unmanned Aerial Vehicles (UAVs) and Ground Control Stations (GCS) [1]. The GCS is crucial for overseeing UAV missions and ensuring their safe and efficient operation. It plays a key role in displaying real-time air data and Attitude Heading Reference System (ADAHRS) data, which enables operators to monitor UAV flight autonomously. Moreover, the GCS facilitates the transmission of live First Person View (FPV) video feeds from the UAV to the ground, providing operators with crucial visual information for decision-making and mission planning [2].

A critical component of UAS is the telemetry module, operating at 915 MHz for continuous data transmission to facilitate UAV monitoring. Operators utilize the GCS to plan navigation missions by setting waypoints and monitoring real-time UAV flight data. In the case where video transmission is required, a separate communication system is typically used, employing a high frequency 5.8 GHz band. The antennas, which is connected to a tracker, efficiently transmit the video to the ground using Rapid Fire modules [3]. Signal transmission requires two types of antennas: omnidirectional and directional.

Omnidirectional antennas emit radiation uniformly in all directions, resulting in a directivity of 1 dB or 0 dB [4]. In contrast, directional antennas concentrate the electromagnet wave radiation within a specific angle, reducing the signal beam-width while increasing the directivity beyond 1 dB [5]. Telemetry transmission efficiency is ensured by using a Team BlackSheep (TBS) module. Because stationary antenna systems maintain a constant position and are configured to radiate or receive signals in a predefined direction, their performance can be significantly affected by environmental factors when communicating with mobile objects [16]. These limitations make fixed antennas unsuitable for applications where signal quality, reliability, and consistent connectivity are critical, even if they are cost-effective.

In contrast, an antenna tracker is essential for maintaining a high-gain directional antenna's alignment with its target, as illustrated in Figure 1. In this context, the mobile target is a UAV. Directional antennas focus their electromagnetic radiation within a specific angle and area to achieve higher signal strength and range. However, UAVs typically employ omnidirectional antennas that radiate signals uniformly in all directions, leading to a potential mismatch in coverage [6]. An antenna tracker overcomes this challenge by dynamically adjusting the directional antenna's position to ensure the UAV remains within its radiation zone, thereby maintaining uninterrupted communication.

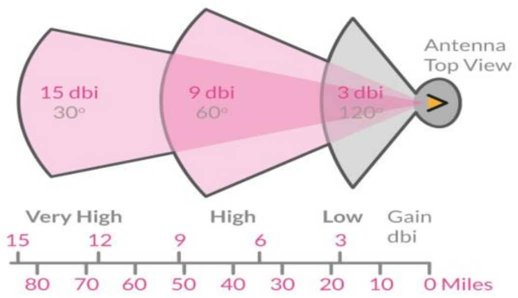


Figure 1. The Impact of Gain on Antenna Range [3]

The mechanical design of the antenna tracker must adhere to specific criteria, ensuring two degrees of freedom. The azimuth angle (yaw) must be capable of rotating 180 degrees, while the elevation angle (pitch) should achieve a 90-degree range of motion perpendicular to the planar geometry. Servo or DC motors are required to maneuver the frame along the azimuth and elevation axes [6]. To ensure high torque and smooth rotation, the design incorporates suitable gearing mechanisms. The major contributions of this work are highlighted as the following

1. A detailed mathematical model of the GPS-based antenna tracking system was developed and presented, outlining the theoretical framework and equations governing its operation.
2. The practical implementation of this tracking system was achieved using LabVIEW, which provided an intuitive interface for monitoring and control, coupled with the precise motor control of the custom PCB board.
3. To test the control system performance, Mission Planner software was employed. This software was primarily used to simulate UAV flights and provide essential GPS data, ensuring the tracking system could accurately follow the UAV's movements. The combination of LabVIEW for user interface and control logic, ATmega328P for hardware control, and Mission Planner for simulation testing resulted in a highly effective and efficient antenna tracking system.

The rest of this paper is organized as follows. Section 2 reviews tracked antenna. Section 3 gives in details about the methodology implemented. The design and the used algorithm is detailed in Section 4. Section 5 presents the simulation study of the GPS tracked antenna in the real field. Finally, Section 6 presents the conclusions and future remarks.

2. STATE-OF-THE-ART

The UAV antenna tracking problem arises when a ground control station (GCS) must maintain communication with single or multiple UAVs whose exact locations are dynamically uncertain. This uncertainty complicates antenna alignment and tracking, often leading to signal degradation or loss [19–25]. Previous research has primarily focused on fundamental design principles (e.g., MUltiple SIgnal Classification (MUSIC) algorithm for SDR-based localization [24]) and system-level integration [19, 22]. Many studies aim to optimize tracking accuracy through improved antenna alignment mechanisms [19, 21], while others explore control strategies such as PID-based stabilization [8, 23] or adaptive beamforming via deep learning [18].

However, a critical gap remains: few studies address the end-to-end workflow—spanning design, manufacturing, testing, and real-world deployment—for UAV tracking systems. Most existing work relies on simulation-driven approaches (e.g., MATLAB/Simulink [7, 9, 23, 24]) but lacks empirical validation under real-world disturbances. For example, Smith and Doe uses MATLAB-based optimization for antenna tracker systems but under idealized conditions without real-world disturbances [7]. Chen and Liu simulates UAV antenna tracking using theoretical models without extensive hardware validation [9]. Moreover, Codău et al. [24] propose an SDR-based localization system but test it only in controlled environments.

This fragmentation between theory and practice is further exacerbated by the neglect of environmental adaptability (e.g., wind, multipath interference) and real-time dynamic response in UAV missions [6, 19, 22]. While simulations provide valuable insights, their limited empirical grounding [7, 24] restricts applicability in field deployments.

To bridge these gaps, this paper presents a holistic two-degree-of-freedom (DoF) antenna tracker that integrates:
1. Design and manufacturing a hardware-software co-design approach.
2. Mathematical Modeling by leveraging LabVIEW for dynamic simulation.
3. Real-World Testing to validation under variable operational conditions, e.g., wind, signal occlusion.

Unlike prior works, this system prioritizes practical viability, enhancing UAV operational reliability and adaptability in critical applications (e.g., remote sensing, disaster response). By unifying theoretical rigor with empirical validation, this research offers a scalable framework for future UAV tracking systems, addressing both performance gaps and deployment challenges.

3. METHODOLOGY

To realize the flowchart depicted in Figure 2, a series of sequential steps must be meticulously followed:
The initial step involves the detailed design of a custom printed circuit board (PCB) using Altium Designer for the electronic control system, integrating an ATmega328P microcontroller, a GPS module, and various other essential electronic components. Utilizing the Arduino IDE, the LIFA BASE firmware is uploaded to ensure seamless communication with the LabVIEW interface.

The ensuing stage requires the careful creation of a detailed 3D model utilizing Catia Software [17]. Prior to commencing the actual design process, it is imperative to define the design requirements with utmost precision. In this critical phase, existing open-source designs [11] are carefully sourced and subsequently tailored to harmonize seamlessly with the specific design and its unique requirements.

Subsequently, a python script is developed to extract essential data from the MAVLink stream [14], including latitude, longitude, and altitude. This data is formatted to be compatible with LabVIEW, enabling easy access for subsequent mathematical calculations. The following step involves modeling the entire system in LabVIEW (using the student version) to accurately calculate angles and transmit data to the servo motors, ensuring precise control.

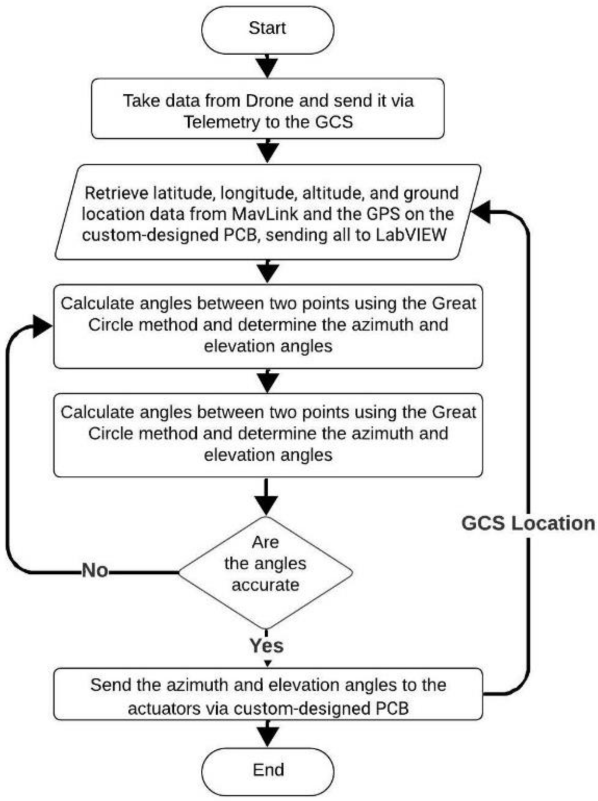


Figure 2. The flowchart of the proposed antenna tracking conceptual in this study

Table 1. Axis Rotation and Torque Magnitude

Axis	Gear Ratio	Rotation Speed (RPM)	Pinion	Gear	Torque Out (kg.cm)
Azimuth (Yaw)	3	20.67	10	30	45
Elevation (Pitch)	3	20.67	10	30	45

In this study, the proposed method was rigorously tested in a simulated environment, with real-world testing pending. Initial results were obtained by simulating the electronic board and using a small servo for demonstration purposes. Work on integrating the larger servo into the design is currently ongoing. The insightful findings presented in this paper are based on thorough experiments conducted using the initial simulation results.

4. ANTENNA TRACKER DESIGN AND IMPLEMENTATION

The antenna tracker system's custom-designed board was completely developed in our lab to meet the specific needs of the mission. Using the ATmega328P microcontroller, servo motors, and a GPS receiver, the board was engineered to provide precise control over the antenna's movement, ensuring continuous alignment with the UAV. This hands-on design process allowed us to tailor the system's functionality and performance to the unique requirements of the disaster monitoring mission, ensuring reliability and stability in real-world conditions. In the following sections, we detailed this design.

4.1 The Electronic Control System of Antenna Tracker

The antenna tracker was powered by a custom-built DIY Electronic Control System, as illustrated in Figure 3. This system integrates key components to manage power, communication, and actuation, ensuring seamless operation of the antenna tracker. The specifications of the system are as follows:

1. A Microcontroller (Atmega328P) with the following features:
- 20 MHz CPU for efficient real-time processing.
- Memory: 32KB Flash, 2KB SRAM, and 1KB EEPROM for program storage, data handling, and persistent memory needs.
- Adequate GPIO and PWM pins for peripheral control and expandability.

2. A GPS Module (NEO GPS) with the following characteristics:
   - Operating voltage: 3-5V, compatible with most microcontroller systems.
   - Positional accuracy: 2.5m, suitable for precise antenna orientation.
   - Capable of tracking up to 16 satellites, ensuring robust GPS signal acquisition.
   - Integrated 25x25mm antenna and 25x35mm module for compactness.
   - Baud rate: 9600, enabling stable communication with the microcontroller.

3. Signal Amplifier (LM7805): It consists of voltage regulation from 7-35V to a stable 5V output as well as features thermal and short-circuit protection for reliability in diverse operating conditions.

4. USB-to-Serial Converter (CH340): It facilitates seamless communication between the microcontroller and a computer. Additionally, it has a wide operating system (OS) compatibility, ensuring ease of use across various development platforms.

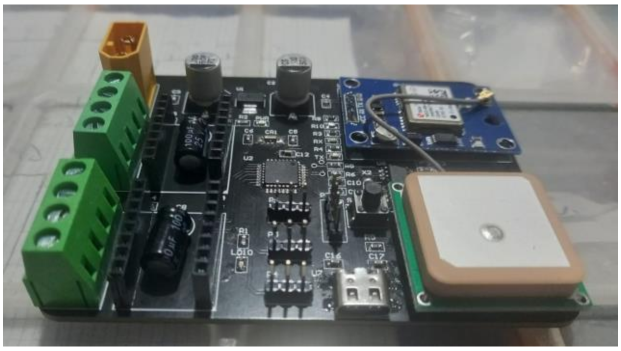


Figure 3. The designed GPS control system with its main component

The microcontroller, Atmega328P, serves as the central control unit of the system, ensuring seamless coordination among the various components. It communicates with the NEO GPS module via a UART (Universal Asynchronous Receiver-Transmitter) interface, receiving precise real-time positioning data critical for tracking. This communication ensures the antenna aligns accurately with the target, such as a UAV, based on GPS coordinates.

The LM7805 voltage regulator plays a vital role in the system's power management. By stepping down input voltages in the range of 7–35V to a stable 5V output, it provides a reliable power supply to the Atmega328P and connected peripherals. Additionally, its built-in thermal and short-circuit protection mechanisms enhance the system's safety and reliability, especially under varying operating conditions. To facilitate connectivity and programmability, the CH340 USB-to-serial converter bridges the Atmega328P with a computer. This connection enables firmware updates, real-time data logging, and debugging during development. Its wide compatibility with multiple operating systems makes it versatile for use in diverse development environments. Finally, the system employs two Pulse Width Modulation (PWM) pins of the Atmega328P to control servo motors, which are responsible for orienting the antenna dynamically. The reserved PWM pins provide scalability, allowing for future integration of stepper motor drivers or additional actuators, thereby enhancing the system's precision and functionality.

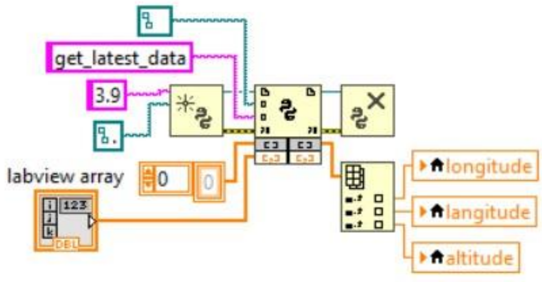
These components form the core infrastructure for the antenna tracker, ensuring robust communication, precise actuation, and reliable power management. This modular design not only facilitates current functionality but also accommodates potential upgrades for more advanced tracking requirements.

4.2 Data Acquisition and Processing using LabVIEW

The system utilizes the pymavlink library [15] to fetch real-time positional data—latitude, longitude, and altitude—from the MAVLink stream [14]. MAVLink is a lightweight communication protocol designed for UAV communication, enabling robust telemetry data exchange. Figure 4a shows part of the python setup code, which provides a flexible interface for both real-world and simulated environments:

```python
from pymavlink import mavutil
connection_string = 'tcp:127.0.0.1:5762'
mav = mavutil.mavlink_connection(connection_string)
mav.mav.request_data_stream_send(
    mav.target_system, mav.target_component,
    mavutil.mavlink.MAV_DATA_STREAM_ALL, 1, 1)
latest_data = [None, None, None]
def get_latest_data():
    global latest_data
    return latest_data
while True:
    msg = mav.recv_msg()
    if msg is not None:
        if msg.get_type() == 'GPS_RAW_INT':
            latitude = msg.lat / 1.0e7
            longitude = msg.lon / 1.0e7
            altitude = (msg.alt / 1000.0) - 200
            latest_data = [latitude, longitude, altitude]
    print(get_latest_data())
```

(a) Python script



(b) The block diagram that calls python function.

Figure 4. The interface between the python position code with the LabVIEW

- Real UAVs: The telemetry stream is accessed via the serial 0 interface, ensuring reliable data acquisition directly from the drone's onboard systems.
- Simulations: For testing and validation, the library connects via a network TCP interface to interact with simulated drone telemetry streams.

The positional data is retrieved as floating-point values and stored in an array. This structured format ensures seamless integration with LabVIEW, a graphical programming environment. LabVIEW can parse this array for further processing, as depicted in Figure 4b by calling the python function. This integration allows the antenna tracker to dynamically adjust its position based on the UAV's real-time location.

4.3 The Antenna Tracker Actuator

The servo motor serves as the actuator for the antenna tracker, providing precise mechanical movement to align the antenna with the UAV. The actuation system supports two critical axes of movement:

- Azimuth Axis (Yaw): Enables horizontal rotation through a full 180-degree range.
- Elevation Axis (Pitch): Provides vertical rotation with a range of 90 degrees.

To achieve these movements, the servo motor employs a gear transmission system, enhancing torque output for handling the mechanical load of the antenna tracker. This ensures smooth and reliable operation, even under challenging environmental conditions.

4.4 The Mechanical Design of Antenna Tracker

The mechanical design of the antenna tracker was tailored to align with the specific requirements of UAV missions, focusing on portability, ease of operation, and precision. The Ground Control Station (GCS) plays a pivotal role in UAV operations by providing real-time data and live video feeds that ensure safe operation and facilitate mission planning. To support this functionality, the antenna tracker was designed for high portability, allowing for easy disassembly and transportation to accommodate dynamic mission requirements.

The antenna tracker's mechanical system, designed and modeled using Catia CAD (Figure 5), incorporates a two-degree of freedom structure for precise tracking capabilities. These degrees of freedom correspond to the following movements:

1. Azimuth Axis:
   - Enables horizontal rotation of the antenna over a 180-degree range.
   - Ensures the system can align with the UAV's changing positions in real-time.

2. Elevation Axis:
   - Facilitates vertical rotation with a 90-degree range.
   - Allows the tracker to maintain line-of-sight communication even as the UAV gains or loses altitude.
   - Each axis is powered by a high-torque servo motor (Figures 6a and 6b), providing precise positioning through a gear transmission system. The gear transmission ensures:
   - Smooth and constant rotation without stuttering.
   - Increased torque output, enabling the tracker to handle heavier antenna payloads or resist environmental forces such as wind.

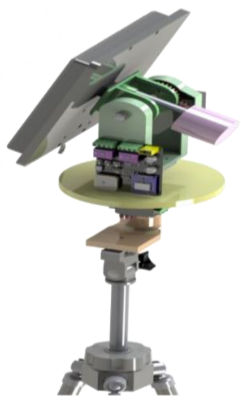
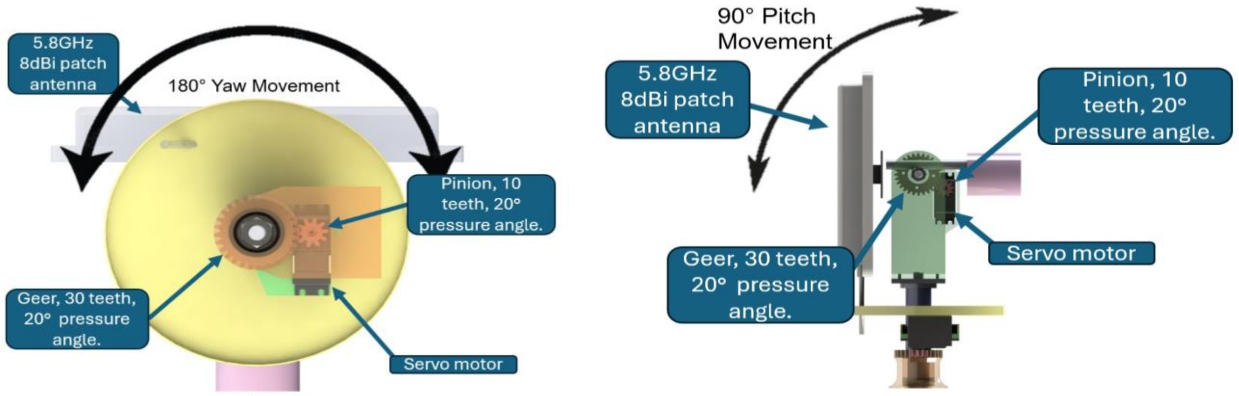


Figure 5. 3D design of antenna tracker



(a) The azimuth axis (yaw)

(b) The elevation axis (pitch).

Figure 6. Movement of every axis: (a) azimuth axis (yaw); (b) elevation axis (pitch)

Figure 6 illustrates the motion of the antenna tracker's two axes—azimuth and elevation—driven by high-torque servo motors. To achieve smooth movement and sufficient torque output, a gear transmission system with carefully calculated gear ratios was implemented for each axis. The gear ratio ensures that the servo motors can deliver both the required angular precision and torque to handle the antenna's weight under various operating conditions.

The mechanical and rotational characteristics of the system were analyzed using the following equations:

$$GearRatio \cong \frac{n_{in}}{n_{out}} \quad (1)$$

$$AngularSpeed \cong \omega_{in} GearRatio \quad (2)$$

$$TorqueOut \cong \frac{\tau_{in}}{GearRatio} \quad (3)$$

where n_{in} is rotation speed input; n_{out} is rotation speed output; ω_{in} is angular speed input and τ_{in} is torque input. Using these equations, the rotation and torque requirements for each axis of the antenna tracker were calculated to ensure optimal operation. Table 1 and 2 summarize the derived values, which guided the selection of a suitable servo motor for the design.

Table 2. Rotation and torque requirements for the antenna tracker axes

Axis	Required Rotation	Angular Speed	Torque Output
	(Degrees)	Speed (rad/s)	(Nm)
Azimuth	180	1.08	0.75
Elevation	90	0.54	0.40

4.5 Telemetry Configuration

The proper configuration of the radio and telemetry systems is crucial for establishing seamless communication between the GCS, antenna tracker, and UAV. This setup ensures that the antenna tracker can effectively maintain alignment with the UAV during its operations, as illustrated in Figure 7. To achieve secure and reliable telemetry communication, an encrypted 915 MHz telemetry system was employed [12]. This system not only provides robust resistance to interference, but also it ensures the integrity and confidentiality of data transmission.

The telemetry system operates consists of the ground telemetry computer and antenna tracker. The ground telemetry computer transmits positional and command data through a serial port to the antenna tracker. The antenna tracker, equipped with the custom-designed control board, utilizes a separate serial port to communicate with its onboard systems, including motor controllers, and to relay commands for real-time adjustments. This dual-serial configuration ensures that telemetry data is processed efficiently and enables precise control of the antenna tracker, even under dynamic conditions.

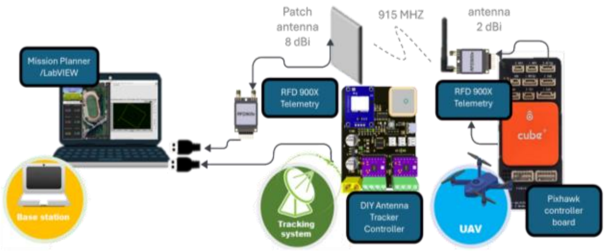


Figure 7. Telemetry configuration

4.6 Antenna

To guarantee proper data transmission between the UAV and the ground station, a directional antenna was selected for its performance characteristics and suitability for the application [7]. The antenna operates within the frequency range of 902–928 MHz, offering optimal compatibility with the 915 MHz telemetry system. Its technical specifications are summarized as follows:

- Gain: 8 dBi, providing significant signal amplification for extended communication range.
- Horizontal Beam Width: 75 degrees, ensuring broad coverage for azimuth tracking.
- Vertical Beam Width: 65 degrees, facilitating reliable elevation adjustments.
- Impedance: 50 Ohm, optimizing power transfer and minimizing signal reflection.
- VSWR (Voltage Standing Wave Ratio): Less than 1.5:1, ensuring minimal signal loss and high transmission efficiency.

The antenna's directional radiation pattern, shown in Figure 8, highlights its focused coverage, essential for maintaining a stable connection with the UAV even over extended distances.

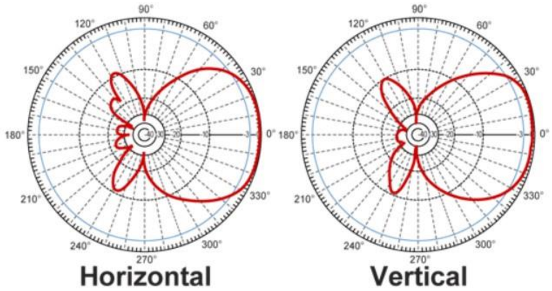


Figure 8. Radiation pattern for 8 dBi patch antenna [7]

4.7 Tracking Algorithm

To understand the operation of an antenna tracker, it is essential to delve into the principles of spherical trigonometry [8] and geolocation. The process consists of two phases: first, identifying the UAV's position, and second, steering the antenna using spherical trigonometry to ensure accurate alignment [19]. Spherical trigonometry provides the mathematical foundation for calculating positions, distances, and angles on the Earth's curved surface. These principles are indispensable for accurate navigation and location-based tracking, forming the core of the antenna tracker's algorithm.

4.7.1 Locating UAV

Given the geolocation data of both the flying platform (UAV) and the antenna tracker (GCS) in terms of latitude (φ) and longitude (ϕ), the necessary angles for orienting the tracker to the UAV location can be derived as shown in Algorithm 1. This process hinges on spherical trigonometric calculations to ensure precise alignment to dynamically locate UAVs [9]. The final output is finding the yaw angle, which serves as the azimuth reference relative to north.

Algorithm 1: Finding the Azimuth Angle to dynamically locate UAVs

- **Input:** The longitude and the latitude of the GCS and UAV.
- **Output:** Azimuth angle

Step 1: Longitude Difference Calculation [20]

$$\triangle\varphi = \varphi_2 - \varphi_1 \quad (4)$$

where φ_1 and φ_2 are the longitude of the GCS and UAV, respectively.

Step 2: Intermediate Components for Azimuth Calculation [20]

$$y = sin(\triangle\varphi) * cos\phi_2 \quad (5)$$

$$x = (cos\phi_1 * sin\phi_2) - (sin\phi_1 * cos\phi_2 * cos(\triangle\varphi)) \quad (6)$$

where ϕ_1 is the latitude of the GCS and ϕ_2 is the latitude of the UAV.

Step 3: Azimuth Angle Computation

$$\psi = tan^{-1}(y/x) \quad (7)$$

where ψ is the Azimuth angle, representing the UAV's horizontal position relative to the north pole.

4.7.2 Steering system

Accurate geolocation data for both the UAV and the GCS, including latitude (φ), longitude (ϕ), and altitude (h), is essential for precise UAV tracking. The steering system serves as the core component of the UAV tracking system, tasked with rotating the antenna in both elevation and azimuth angles, and calculated using Algorithm 1. Latitude (φ) measures the angle north or south of the equator, while longitude (ϕ) varies with latitude due to Earth's curvature, as lines of longitude converge at the poles. To ensure accuracy across Earth's spherical surface, the Spherical Law of Cosines is applied to calculate the great-circle distance, a reliable method for determining the shortest path between two points on a sphere [13]. The process is outlined in equations (8) and (9).

$$\triangle\varphi = \varphi_2 - \varphi_1 \quad (8)$$
$$\triangle\phi = \phi_2 - \phi_1 \quad (9)$$

where φ_1 and φ_2 are the latitudes of the GCS and UAV, respectively, and ϕ_1, ϕ_2 are their respective longitudes. The distance d between the UAV and the GCS is calculated using

$$d = cos^{-1}(sin\phi_1 * sin\phi_2 + cos\phi_1 * cos\phi_2 * cos\triangle\varphi * R) \quad (10)$$

where R is the Earth's radius, typically taken as 6371 km [6]. This equation accounts for the spherical nature of the Earth, ensuring accuracy over large distances. The vertical elevation difference, $\triangle h$, is given by (11)

$$\triangle h = h_2 - h_1 \quad (11)$$

where h_1 and h_2 are the altitudes of the GCS and UAV, respectively. Using d and $\triangle h$, the elevation angle θ, which represents the angular inclination from the GCS to the UAV, is calculated as:

$$\theta = \tan^{-1}(\triangle h/d) \quad (12)$$

In this context, θ is the rotation angle of the antenna tracker relative to the horizon and ensures vertical alignment based on altitude differences, with h_1 being the altitude of the GCS and h_2 being the altitude of the UAV. The distance d remains positive, and θ varies between -90^o and $+90^o$.

5. EXPERIMENTS AND RESULTS

This section presents the experimental setup, results, and observations regarding the implementation and testing of the antenna tracker system. The experiments were designed to validate the functionality of the tracking algorithm, servo motor control, and the integration of real-time data with LabVIEW.

5.1 The Software

The development and testing of the antenna tracker relied on several key software tools to ensure seamless integration and operation. LabVIEW was used for the mathematical calculations, real-time data visualization, and controlling the servo motors via PWM signals. Its graphical programming environment facilitated the design and simulation of the control system, while its serial communication capabilities ensured smooth data transfer between the antenna tracker and external devices. Mission Planner, an open-source software, was employed for simulating UAV movements, planning missions, and visualizing the UAV's path in real-time, which helped test the antenna tracker's ability to accurately follow the UAV's position. Python, using the pymavlink library, enabled communication with the UAV's telemetry system through the MAVLink protocol, retrieving real-time positional data such as latitude, longitude, and altitude for processing by LabVIEW. This integration allowed for a comprehensive system that could track the UAV's movements with precision, linking theoretical calculations to practical hardware control. These software platforms provided a robust framework for the antenna tracking system, ensuring accurate operation through real-time monitoring, and precise motor control. They facilitated the development, testing, and validation of the antenna tracker, showcasing the successful integration of hardware and software in a dynamic tracking environment.

5.2 The Mathematical Modulations in LabVIEW

One of the primary goals of this experiment was to implement the mathematical calculations necessary for determining the azimuth and elevation angles, as well as the distance between the UAV and the ground station, within the LabVIEW environment. The calculations were employed to generate a graphical representation of the motor rotation angles responsible for azimuth and elevation. These values were dynamically updated to track the live movement of the UAV in real time, as illustrated in Figure 9, which shows the LabVIEW block diagram. LabVIEW was also used to simulate PWM signals corresponding to the calculated angles, which were then transmitted through the serial port (COM*). The servo motors, in turn, interpreted these signals to adjust their positions, providing a direct link between theoretical computations and physical outcomes. This workflow demonstrates the seamless integration of LabVIEW's graphical programming capabilities with the real-world actuation of servo motors.

5.3 GPS Location Visualization

The GPS location data, acquired from the UAV and ground station, was plotted graphically in LabVIEW. Figure 10 depicts the GPS location graph, showcasing the tracking of live UAV positions relative to the ground station. This visualization confirmed the accurate acquisition and processing of GPS data.

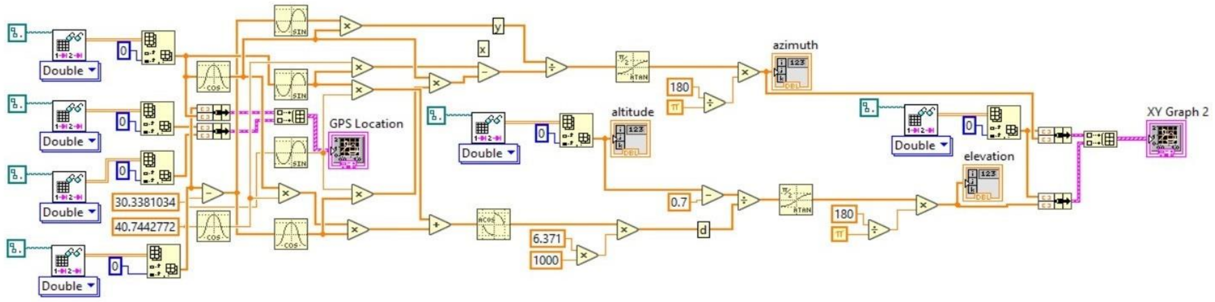


Figure 9. The LabVIEW Block diagram of mathematical calculations

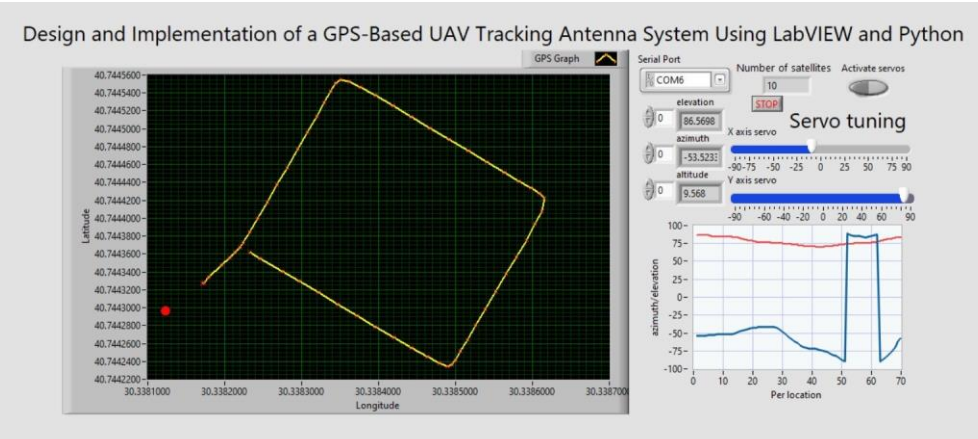


Figure 10. The LabVIEW front panel

5.4 Mission Simulation and Monitoring

The Mission Planner software autonomously executed a simulation mission, as demonstrated in Figure 11. The map-based visualization highlighted the UAV's path, confirming the successful integration of telemetry data with the Mission Planner. This step was critical for ensuring the UAV's trajectory was correctly tracked and communicated to the antenna tracker.

Figure 11. Simulation Mission planner at Skaraya University Stadium

5.5 LabVIEW Front Panel

The LabVIEW front panel provided a centralized control interface, displaying all relevant data, including GPS coordinates, calculated angles, and servo motor outputs. As shown in Figure 10, this interface facilitated the real-time observation of system performance, linking live data acquisition to actuator control.

5.6 Gimbal Verification and Testing

To validate the system's overall functionality, a gimbal setup was used to test the accuracy of servo motor control. Figure 12 illustrates the gimbal used during this test. The system demonstrated accurate tracking of the UAV's position and orientation in a virtual environment, confirming the reliability of the implemented tracking algorithm and servo settings.

Figure 12. The Gimbal

5.7 Environmental Robustness

Further testing was conducted to evaluate the antenna tracker's performance under various environmental conditions. The system was subjected to:

- Rain: Ensuring waterproofing and consistent data transmission.
- Wind: Testing the stability of the antenna tracker's mechanical structure.
- Temperature Fluctuations: Verifying the system's reliability under extreme hot and cold conditions.

The tracker maintained stable operation across these scenarios, demonstrating its suitability for diverse mission environments.

5.8 Comparative Benchmarking Against Existing Tracking Methods

To validate the efficacy of the proposed antenna tracker, a quantitative comparison was performed against two state-of-the-art approaches, e.g. PID-Based Tracking [23] and Lyapunov-based control system [6], shown in Table 3. Compared to İşcan et al. [6], the proposed system's 3:1 gear ratio yields 18% higher torque at a comparable rotation speed (20.67 vs. 15 RPM), enabling better resistance to environmental disturbances (Sec. 5.7) without requiring complex Lyapunov stability proofs. While [23] achieves higher torque (50 kg·cm), its 25 RPM operation may introduce oscillations in turbulent conditions, as evidenced by their need for aggressive PID tuning.

Table 3. Comparative Comparison

Metric	Proposed System	İşcan et al. [6]	Jayadi et al. [23]
Controller Type	PID-controlled	Lyapunov-based control	PID-controlled
Gear Ratio	3:1	4:1	2.5:1
Torque Output	45 kg·cm	38 kg·cm	50 kg·cm
Rotation Speed	20.67 RPM	15 RPM (stabilized)	25 RPM (high-speed)

6. DISCUSSION AND CONCLUSION

This work presents a holistic design, implementation, and validation of a two-degree-of-freedom (DOF) antenna tracking system for UAV applications, addressing critical gaps in prior research by integrating real-time data processing, adaptive control, and environmental robustness. In this study, we demonstrated a fully integrated antenna tracking system capable of real-time acquisition of a drone's positional data and seamless processing through LabVIEW's graphical programming environment. This work advances UAV antenna tracking by proving that real-time data fusion (GPS, inertial measurements) with adaptive control (PID tuning via LabVIEW) can significantly enhance tracking accuracy and mission efficiency.

While this study focused on drone tracking, the underlying principles of real-time data processing and seamless integration with physical systems can be extended to other domains, including autonomous vehicles and robotics, where accurate and reliable tracking is crucial.

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Ethics Committee Approval

There is no need for an Ethics Committee Certificate for our study.

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