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A Real-Time IoT-Integrated Ground Control Station (GCS) for Unmanned Aerial Vehicle (UAV) Monitoring System

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Abstract_ *Conventional Ground Control Stations (GCS) for UAVs are often platform-bound (PC-only or Android apps), creating installation overhead and constraining mobility. This work introduces a browser-native, web-based GCS that runs across devices without prior installation and ingests MAVLink telemetry from a RadioLink Mini Pix V1.0 flight controller via 433 MHz UART radio telemetry, then streams decoded data to the UI over websocket/JSON. The system visualizes attitude (yaw, pitch, roll/IMU), GPS position and mapping, compass bearing, altitude, and flight status in real time, with user authentication and a structured landing/login flow. In controlled tests, the application delivered stable live visualization and accurate mapping during a 100 m out-and-back flight, with reported coordinates matching the route. Link-budget characterization across 95, 100, 180, 190, and 240 m showed the expected RSSI degradation with distance and a pronounced dip at 190 m, a practical safe range of ~100 m was identified where signal strength stayed >50% with low interference. Compared with PC or Android-based GCS, the proposed approach improves accessibility (zero-install, multi-device) and operational flexibility, while maintaining reliable real-time telemetry for mission monitoring.*

Keywords: *UAV; Website; Telemetry; IMU; Flight Control; Real-time*

I. INTRODUCTION

An Unmanned Aerial Vehicle (UAV) is an aircraft that operates without a pilot on board and is controlled remotely through radio signals, allowing flight operations to be conducted from a distance [1][2]. To ensure safety and efficiency, UAVs are commonly monitored using a Ground Control Station (GCS), a software application that provides real-time flight data. Currently, the most widely used and continuously developed GCS is Mission Planner from Ardupilot, which can only be operated on a Personal Computer (PC) or laptop. This dependency restricts operator mobility and requires a stable power supply [3][4].

These limitations highlight the need for GCS solutions that can also run on alternative platforms such as Android or web-based systems, enabling more flexible and user-friendly access [4]. Based on this background, the proposed solution in this study is to design a website-based GCS application. Choosing the website as a platform makes the system accessible from anywhere via an internet connection, without requiring prior installation, and usable across multiple devices.

Previous research by Heimsch et al. [5] developed a PC-based GCS capable of integrating weather data at UAV flight sites and displaying no-fly zones on the system map. Weather data were provided to help users assess flight risks, while no-fly zone visualization served as a reference for UAV pilots. Based on these considerations, this study proposes the design of a web-based GCS that provides real-time monitoring of UAV telemetry data through a browser interface. To ensure security and multi-user capability, the system includes a login mechanism with unique tokens and stores monitoring data in a cloud-based database.

II. METHODS

The methodology employed in this study focuses on the design and implementation of an "Internet of Things (IoT)-based Monitoring System" for Unmanned Aerial Vehicles (UAVs). This implementation is carried out through several steps in accordance with the research implementation methodology. In the first stage, before designing and working on the research, a literature study was conducted by searching and finding references in

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advance with the aim of gaining knowledge and insight into the things that will be used in building this system, as shown in Figure 3, which is a diagram of a simple Unmanned Aerial Vehicle (UAV) monitoring system in general, where the Unmanned Aerial Vehicle (UAV) is flown and controlled by a Remote Control (RC). The Unmanned Aerial Vehicle (UAV) can be monitored during flight through data obtained from the Inertial Measurement Unit (IMU) sensors (yaw, pitch, and roll), barometer sensors, and Global Positioning System (GPS) sensors. The Desktop Ground Control Station (GCS) can obtain flight data from the Unmanned Aerial Vehicle (UAV) through a radio telemetry communication device, and the Ground Control Station (GCS) unit can obtain flight data from the Unmanned Aerial Vehicle (UAV) using a websocket communication protocol with JavaScript Object Notation (JSON) data format.

[Figure 1 about here.]

2.1 System Design

In Figure 1, the overall system architecture consists of three main components. The airborne unit (UAV X Quadcopter), the desktop-based Ground Control Station (GCS), and the web-based GCS developed in this study, which together handle communication and monitoring functions.

The UAV employs a Mini Pix V1.0 flight controller as its microcontroller, integrating multiple sensors: the Inertial Measurement Unit (IMU) for attitude data (yaw, pitch, roll), a barometer for altitude, and a Global Positioning System (GPS) for flight location and mapping. A Remote Control (RC) transmitter and receiver module enables manual UAV operation. Flight data from these sensors are first collected by the flight controller, which performs a data packing process to convert raw, unstructured measurements into structured telemetry packets following the Micro Air Vehicle Link (MAVLink) protocol. These structured packets allow real-time data transmission and visualization.

Communication between the UAV and the desktop GCS unit is established using 433 MHz radio telemetry, selected because it natively supports MAVLink message transmission. On the desktop GCS, the incoming MAVLink packets undergo a parsing process, in which a dedicated parsing library extracts and converts the structured telemetry data into meaningful values. Sensor units are processed for visualization by converting radian to degree (IMU yaw, pitch, roll), millimeter to meter (barometer altitude), and standard GPS coordinate formatting. This ensures that UAV flight data can be displayed accurately in the desktop interface.

To extend functionality to the web-based GCS, real-time communication between the desktop GCS and the web unit is implemented using websockets. A REST API architecture was designed to transfer UAV telemetry (IMU and GPS) from the desktop unit to the web server. The backend of the web GCS is developed using Node.js, where telemetry data are stored in a PostgreSQL database. The frontend is built with Vue.js, a JavaScript framework for creating the user interface, enabling real-time UAV flight data to be displayed in any modern web browser without installation. For comparison, Figure 2 shows the Ground Control Station (GCS) Mission Planner application, which represents the conventional PC-based approach still widely used in UAV operations.

[Figure 2 about here.]

2.2 UAV Hardware

2.2.1 The UAV airframe

The Unmanned Aerial Vehicle (UAV) used in this research is a Quadcopter X-type, which employs four main rotors in a cross configuration, as shown in Figure 3. The X-type quadcopter forms an “X” shape, with adjacent rotors spinning in opposite directions: rotors 1 and 2 rotate counter-clockwise (CCW), while rotors 3 and 4 rotate clockwise (CW). The detailed technical specifications of the quadcopter are presented in Table 1.

[Figure 3 about here.]

[Table 1 about here.]

2.2.2 Flight Controller (FC) Specifications

The flight controller component used in the Unmanned Aerial Vehicle (UAV) for this project is the Mini Pix v1.0, as it is capable of operating an X-type quadcopter, is equipped with various supporting sensors, and supports additional functionality through the Micro Air Vehicle Link (MAVLink) protocol, as shown in Figure 4.

[Figure 4 about here.]

The Mini Pix v1.0 is powered by an STM32F4 microcontroller with a 168 MHz CPU frequency. Both CPU frequency and memory capacity strongly influence the performance of the Micro Air Vehicle Link (MAVLink) protocol. A higher CPU frequency accelerates the execution of MAVLink-related processes without affecting the primary flight control functions of the UAV. Likewise, larger memory capacity supports handling MAVLink’s relatively large data packets efficiently, ensuring smooth operation without interfering with other flight control tasks.

2.2.3 Global Positioning System (GPS) Specifications

The Global Navigation Satellite System (GNSS)

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module GG-1802 was selected as the GPS component for this project, as it offers a good balance of size, power consumption, and accuracy for UAV applications, as shown in Figure 5.

[Figure 5 about here.]

The module achieves a Circular Error Probable (CEP) of 2.5 meters under standard conditions, meaning that 50% of position measurements fall within a 2.5-meter radius of the true location. When integrated with Satellite-Based Augmentation Systems (SBAS) such as WAAS, EGNOS, MSAS, or GAGAN, the accuracy improves to 2.0 meters CEP. In addition, the module has a maximum sensitivity of –167 dBm, enabling reliable satellite signal reception even in weak-signal environments, thereby enhancing performance across diverse operating conditions.

2.2.4 Micro Air Vehicle Link (MAVLink)

Micro Air Vehicle Link (MAVLink) is a communication protocol specifically designed for communication between unmanned systems, including Unmanned Aerial Vehicles (UAVs). Micro Air Vehicle Link (MAVLink) is used by most flight controllers on the market [6]. A Ground Control Station (GCS) must be able to use the Micro Air Vehicle Link (MAVLink) protocol to receive telemetry from Unmanned Aerial Vehicles (UAVs). Micro Air Vehicle Link (MAVLink) is a message-based protocol, so it has specific identifiers. These identifiers include the sender's identity and the type of data being transmitted.

Micro Air Vehicle Link (MAVLink) version 2.0 is the recommended version for new implementations. The implementation of Micro Air Vehicle Link (MAVLink) 2.0 is backward-compatible, meaning it can still receive Micro Air Vehicle Link (MAVLink) 1.0. Micro Air Vehicle Link (MAVLink) 2.0 adds a message signature to prevent data tampering, ensuring the integrity of messages when received by the Ground Control Station (GCS). Figure 4 shows the message format of the Unmanned Aerial Vehicle (MAVLink) 2.0, which has a total length of 11–279 bytes. The Unmanned Aerial Vehicle (MAVLink) 2.0 message consists of named sections to indicate the function of the values within each section.

[Figure 6 about here.]

2.3 Communications

2.3.1 Radio Telemetry Universal Asynchronous Receiver/Transmitter (UART)

Radio telemetry communication media is implemented using radio frequency modules whose spectrum falls within the Industrial, Scientific, and Medical (ISM) band. In the field of Unmanned Aerial Vehicles (UAVs), the radio devices commonly used are products from 3D Robotics (3DR). This product consists of an Air module connected to the flight controller on the Unmanned Aerial Vehicle (UAV) via a Universal Asynchronous Receiver-Transmitter (UART) Serial RX/TX, and a Ground module connected to the Ground Control Station (GCS) via a Universal Serial Bus (USB) port.

[Figure 7 about here.]

This Radio Telemetry Module from 3D Robotics (3DR) uses Time-Division Duplexing (TDD) communication, which means that it alternates between receiving and transmitting modes at the same time. The mode change occurs very quickly and in a very short period of time, so it appears to be running full-duplex communication. This module can be configured with the configuration tool provided by 3D Robotics (3DR).

2.3.2 Design of MAVLink Message Parsing

The parsing of Micro Air Vehicle Link (MAVLink) messages is designed to transform incoming telemetry packets into usable values for the Ground Control Station (GCS). The results of this process provide sensor data that can be visualized and updated in the desktop GCS application. To obtain actual sensor readings, the GCS must correctly parse MAVLink messages according to the type of sensor installed on the UAV.

In this research, the system implements MAVLink version 2.0, as illustrated in the flowchart shown in Figure 8. The parsing procedure begins by checking for the MAVLink message header (STX), as presented in Figures 8 and 9. If the STX header is detected, the GCS proceeds with parsing; otherwise, the process terminates and restarts. Once successfully parsed, the MAVLink packets are stored and used by the GCS for subsequent functions such as real-time monitoring and data updates.

[Figure 8 about here.]

[Figure 9 about here.]

This parsing design ensures that structured telemetry including IMU values (yaw, pitch, roll), GPS coordinates, and altitude can be reliably extracted from raw MAVLink packets and integrated into the GCS interface for continuous UAV monitoring.

2.4 Sensor Data Visualization Design

Sensor data visualization design is done to display data from sensors installed on Unmanned Aerial Vehicles (UAV) in the form of moving animations or status icons.

2.4.1 Inertial Measurement Unit (IMU) Sensor

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Data Visualization (Attitude)

Attitude data is a set of data with Yaw, Pitch, and Roll components obtained after the Flight Controller processes the InertialMeasurement Unit (IMU) sensor. Attitude data in the aeronautical field is a representation of the rotation of the Unmanned Aerial Vehicle (UAV) in three dimensions relative to the Unmanned Aerial Vehicle (UAV). In Figure 10 an Unmanned Aerial Vehicle (UAV) is presented with the Roll component being the rotation on the X-axis (side-to-side), the Pitch component being the rotation on the Y-axis (front-to-back), and the Yaw component being the rotation on the Z-axis (left-to-right/right-to-left).

[Figure 10 about here.]

The attitude data of the Unmanned Aerial Vehicle (UAV) is initially in radians, ranging from -π to π. To visualize this data on the Graphical User Interface (GUI), it must be converted into degrees using the formula:

$$Derajat = radian \frac{180°}{\pi} \quad (1)$$

This results in UAV attitude data in degrees, with a range of -180° to 180°. For accurate representation on the artificial horizon, simple input of Pitch and Roll data may result in incorrect visualizations. To correct this, rotational and translational transformations are applied using a mathematical formula to calculate the endpoint coordinates (P(x,y)) based on the Roll angle and the starting point coordinates. The formula for the rotation is:

$$P(x, y) = (Ox \times \cos(Roll))$$
$$-Oy \times \sin(Roll), Ox \times \sin(Roll)$$
$$+Oy \times cos(Roll)) \quad (2)$$

For example, with Pitch = 60° and Roll = 45°, the transformation provides new coordinates (P(x,y)) for the visualization of the Inertial Measurement Unit (IMU) sensor. Using the formula, the new values (-42.42, 42.42) are derived, which are then used for accurate IMU sensor visualization.

[Figure 11 about here.]

2.4.2 Visualization of Global Positioning System (GPS) Coordinates

GPS coordinates, consisting of latitude and longitude, are received from the UAV via the MAVLink protocol and initially range in tens of millions (10^7). To obtain the correct GPS values, the coordinates are divided by 10^7. For example, a latitude value of 71234567 becomes 7.1234567° after conversion. These corrected values are then used to plot the UAV's position on a map as a location marker.

The process begins when the GPS data is decoded from the MAVLink message. After division by 10^7, the values are used to display the UAV's real-time position. If the UAV remains connected, the system continues to update the coordinates with each new MAVLink message. otherwise, the visualization process ends and can be restarted for the next session.

2.5 Application Programming Interface (API)

An Application Programming Interface (API) is a set of protocols that enable applications to communicate, such as between a Ground Control Station (GCS) and a GPS application. API development allows access without changing the main code or database, and facilitates communication between different platform systems [8]. Research by Gumelar et al. developed a web server-based GCS that can connect to UAVs via the internet without transmitter range limitations [9]. The system consists of two units: a flying unit with a Raspberry Pi, modem, webcam, and ADAHRS module for UAV data detection [9] [10], and a GCS unit that receives data via the internet and modem. Data is received, processed, and displayed on the interface [11] [12].

Representational State Transfer Protocol (REST) is a web service development method that emphasizes simplicity and uses existing features in the Hypertext Transfer Protocol (HTTP) to obtain resources when using the web service. REST API connects applications and databases using data in JSON format, chosen for its high performance and stability. REST uses the HTTP protocol with four main methods: GET (retrieve data), POST (send data), PUT (replace data), and DELETE (delete data) [13] [14].

III. RESULTS AND DISCUSSION

System testing was conducted to determine the effectiveness of the system developed based on the ideas proposed in this study. If the system did not meet expectations, the factors causing the system to fail could be identified.

3.1 Testing the communication distance of the Universal Serial Bus (USB) Universal Asynchronous Receiver-Transmitter (UART) telemetry.

The Received Signal Strength Indicator (RSSI) measurement method is used to indicate the strength of the signal received by the receiving device using a laptop and the 3drradioconfig application software as the receiver (RX) from the transmitting device (TX). In telemetry communication distance testing, the Received Signal Strength Indicator (RSSI) value is measured at distances of 95 meters, 100 meters, 180 meters, 190 meters, and 240 meters between the TX and RX devices. Factors influencing the measurement of the Received Signal Strength Indicator (RSSI) include the distance from the transmitter, physical obstacles such as walls, noise, and interference. The Received Signal Strength Indicator (RSSI) value is measured in decibel-milliwatts (dBm). The test was conducted to determine the maximum distance that can be reached for Universal Serial Bus (USB) Universal Asynchronous Receiver-Transmitter (UART) telemetry communication media. The distance for a single communication medium is considered maximum if the Received Signal Strength Indicator (RSSI) value is greater than 50% [9] [15]. Distance testing was conducted by measuring the Received Signal Strength Indicator (RSSI) value using the 3DR Radio Config software. The remote RSSI indicates UAV telemetry data (TX), while the local RSSI indicates GCS telemetry data (RX). Remote noise and local noise are each interpreted as interference (TX) and (RX). The data collected is the average RSSI value at 5 different positions for the GCS (RX) and UAV (TX), which remain stationary, conducted on the rooftop of the Smart Automation Workshop (SAW) building, PENS, 12th floor. Distance measurements were taken using Google Maps.

Test results show that the Received Signal Strength Indicator (RSSI) value decreases as the distance between the transmitter (TX) and receiver (RX) increases, can be seen in Figure 12 and optimal value in Table 2.

[Figure 12 about here.]

[Table 2 about here.]

3.2 Testing the operation of the Ground Control Station (GCS) website application.

The landing page of the Ground Control Station (GCS) website application is equipped with several buttons and displays. The login button is used for users who already have an account, the sign in button is for users who do not yet have an account and want to register, and the get start button allows users to directly access the login menu. If the landing page is scrolled down, the features of the GCS website application will appear, such as map view, flight view, and Inertial Measurement Unit (IMU) statistics data, as shown in Figures 13-16.

[Figure 13 about here.]

[Figure 14 about here.]

[Figure 15 about here.]

[Figure 16 about here.]

In the flight view menu, the map display shows the position of the Unmanned Aerial Vehicle (UAV) along with a table of latitude, longitude, altitude, and bearing values. Additional displays include roll and pitch sensors that produce an artificial horizon visualization, an altitude sensor that displays a needle to indicate altitude, and a compass sensor for east, west, south, and north navigation. If the communication medium for the 433 MHz telemetry radio receiver (RX) module on the Ground Control Station (GCS) is not connected via the (COM&LPT) port, the value table will be empty with the message "N/A," and navigation displays such as the artificial horizon, compass, and altitude will not appear.

3.3 Testing the mapping of the Unmanned Aerial Vehicle (UAV) on the Ground Control Station (GCS) website application.

The test was conducted using an Unmanned Aerial Vehicle (UAV) that moved from the starting point, which was the Ground Control Station (GCS), and then moved 100 meters away. After that, the UAV returned to the starting point of the GCS, producing a mapping display that corresponded to the movement of the UAV, which was depicted by blue lines that can be seen in Figure 14.

[Figure 17 about here.]

Figure 12 shows the latitude and longitude values at the UAV location, namely -7.4570198, 112.6911898, which confirms the accuracy of the UAV location point. Proof of the accuracy of the Unmanned Aerial Vehicle (UAV) location points can be found in Figure 13.

[Figure 18 about here.]

Visualization of UAV altitude data facilitates monitoring with a needle display, while yaw sensor data is visualized in the form of bearings. The compass sensor display shows the maximum number of rotations, which is 360 degrees, returning to 0. Distance measurements are made using Google Maps, starting from the GCS position and measured up to a distance of 100 meters. Data transmitted by the Global Positioning System (GPS) module indicates the UAV's location corresponding to the recorded coordinates.

IV. CONCLUSION

This research developed a web-based Ground Control Station (GCS) capable of monitoring UAV telemetry in real time across multiple devices. The main contribution is the demonstration that a browser-native GCS can provide platform independence, simultaneous multi-user access, and zero-installation deployment, offering greater flexibility compared to existing PC-based or Android-based solutions.

The findings indicate that the system performs reliably within an optimal operational range of about

100 m, where RSSI remains above the stability threshold and visualization of IMU and GPS data is accurate. Nonetheless, the research has several limitations. Tests were restricted to a single 433 MHz telemetry channel and a maximum distance of 240 m, making results site-specific. In addition, the visualization module focused only on core flight data without extended telemetry support.

Future work should include longer-range experiments in varied environments, integration of adaptive communication technologies, expanded sensor data visualization, and stronger security mechanisms for multi-user access. These improvements will strengthen the system's applicability for broader UAV operations.

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Vol. 9, No. 2, October 2025
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LIST OF TABLE

JEEE-U
Journal of Electrical and Electronic Engineering-UMSIDA
ISSN 2460-9250 (print), ISSN 2540-8658 (online)
Vol. 9, No. 2, October 2025
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Table 1. QuadCopter Specifications

Specifications	QuadCopter
Body Frame	Type X with Diagonal Wheelbase 450 mm
Weight	800 grams
Drivers	a) 4 x Brush-Less Direct Current (BLDC) Motor 2212/920KV b) 4 x 30A Electronic Speed Controller (ESC) c) 2x (9 x 6 CW and CCW blades)
Battery	3S Lithium Polymer (Li-Po) 4200 mAh
Electric	5V Voltage Regulator
Flight Controller	Mini Pix V1.0
Remote Control Receiver	FlySky i-A6B 2.4 GHz

Table 2. Optimal Value of Received Signal Strength Indicator (RSSI) and Noise testing at distances of 95 meters, 100 meters, 180 meters, 190 meters, and 240 meters

Jarak (meter)	RSSI Remote Tx (dBm)	RSSI Lokal Rx (dBm)	Noise Remote Tx (dBm)	Noise Local Rx (dBm)
95	89	88	62	69
100	83	81	62	55
180	67	83	54	65
190	10	79	8	72
240	32	78	27	69

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Vol. 9, No. 2, October 2025
10.21070/jeeeu.v9i2.1710

LIST OF FIGURES

JEEE-U
Journal of Electrical and Electronic Engineering-UMSIDA
ISSN 2460-9250 (print), ISSN 2540-8658 (online)
Vol. 9, No. 2, October 2025
10.21070/jeeeu.v9i2.1710

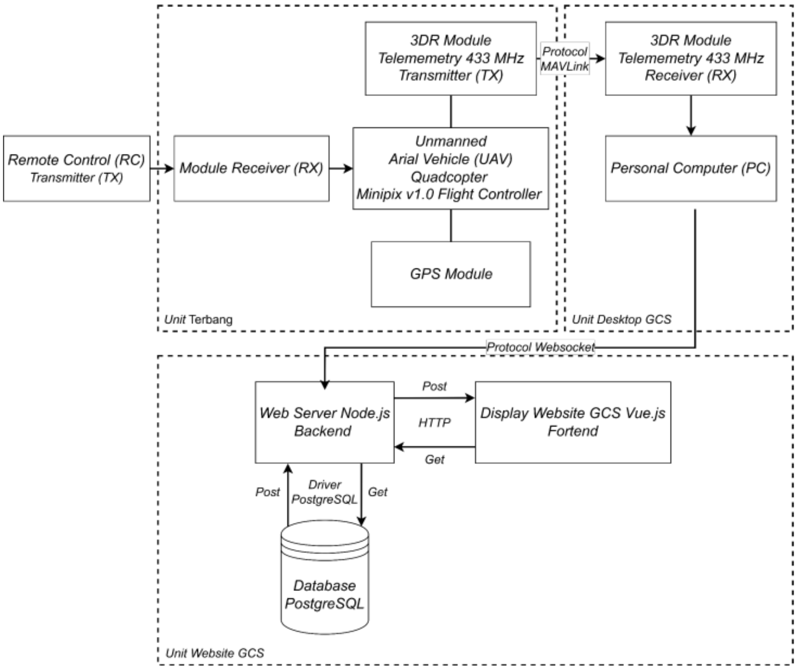

Figure 1. System Block Diagram

Figure 2. Ground Control Station (GCS) Mission Planner Application

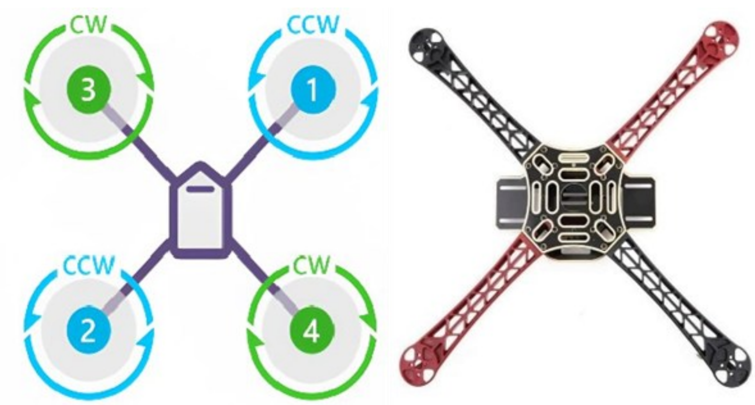

Figure 3. QuadCopter tipe X

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Vol. 9, No. 2, October 2025
10.21070/jeeeu.v9i2.1710

Figure 4. Flight Controller Mini Pix .v1.0

Figure 5. Global Positioning System (GPS) GNSS GG-1802

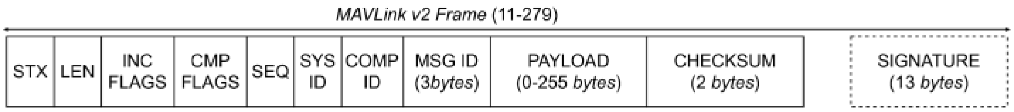
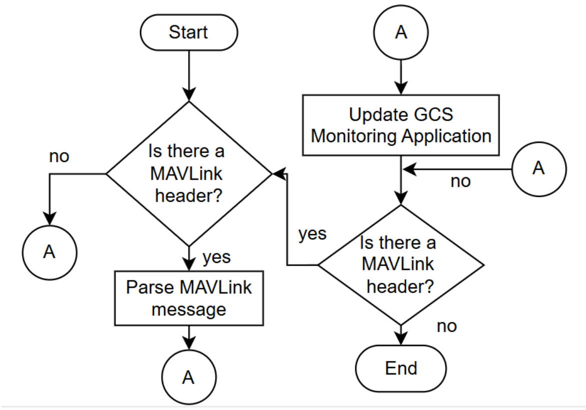


Figure 6. Micro Air Vehicle Link (MAVLink) 2.0 message format

Figure 7. A pair of 3D Robotics (3DR) 433 MHz Radio Telemetry Modules



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Vol. 9, No. 2, October 2025
10.21070/jeeeu.v9i2.1710

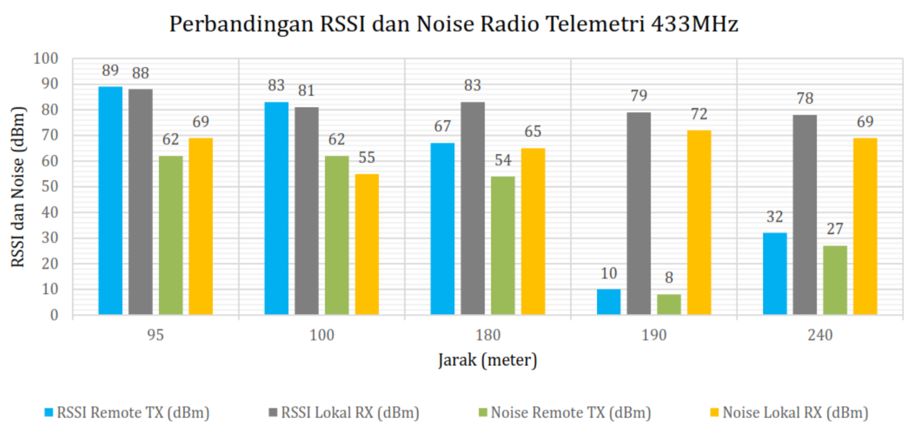
Figure 8. Flowchart of Micro Air Vehicle Link (MAVLink) Message Parsing

Byte-0 0xFD	Byte-1 0x10	Byte-2 0x00	Byte-3 0x00	Byte-4 0x3A	Byte-5 0x00	Byte-6 0xC8	Byte-7 0x1E
Byte-8 0x00	Byte-9 0x00	Byte-10 0xBD	Byte-11 0x12	Byte-12 0x01	Byte-13 0x00	Byte-14 0x83	Byte-15 0xA1
Byte-16 0xE9	Byte-17 0xBB	Byte-18 0xB4	Byte-19 0x2D	Byte-20 0x4B	Byte-21 0xBC	Byte-22 0x37	Byte-23 0xD0
Byte-24 0xAA	Byte-25 0x3F	Byte-26 0x0E	Byte-27 0xA6				

Figure 9. Example of a Micro Air Vehicle Link (MAVLink) 2.0 Message

Figure 10. Three axes of rotation on an Unmanned Aerial Vehicle (UAV)

(a)……………………………………………….……(b)
Figure 11. (a) Poor; and (b) Correct Visualization



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Vol. 9, No. 2, October 2025
10.21070/jeeeu.v9i2.1710

Figure 12. Graph showing the results of Received Signal Strength Indicator (RSSI) and Noise testing at distances of 95 meters, 100 meters, 180 meters, 190 meters, and 240 meters

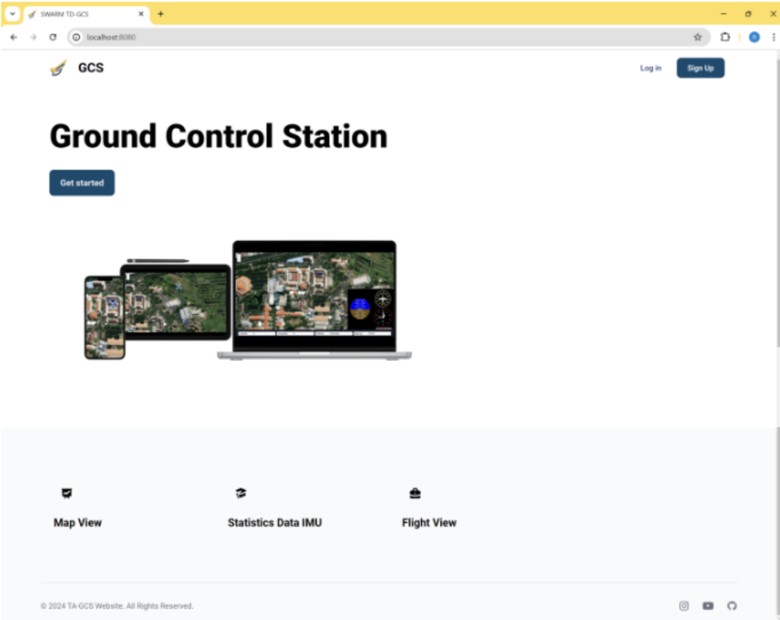

Figure 13. Landing Page Menu Display

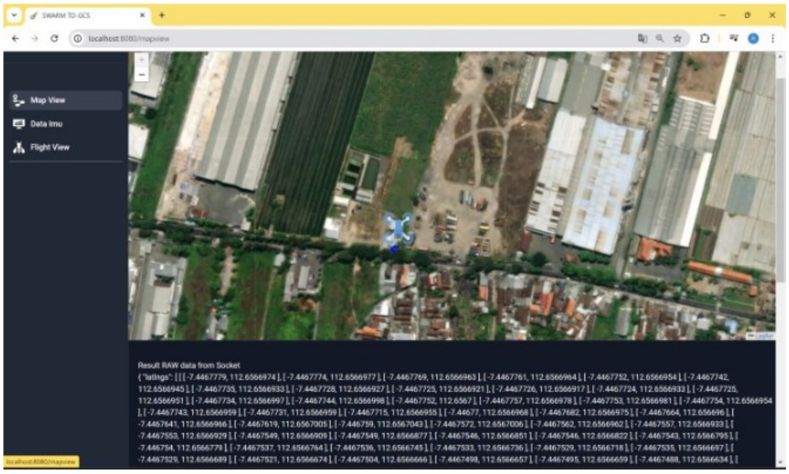

Figure 14. Map View Display

Figure 15. Inertial Measurement Unit (IMU) Data Menu Display

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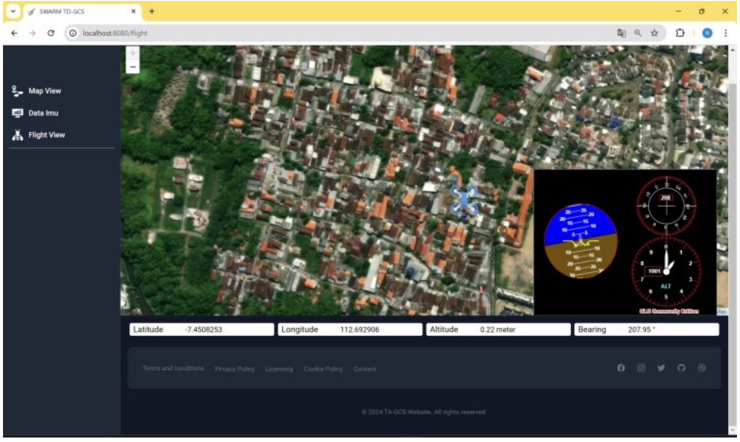

Figure 16. Flight View Menu Display

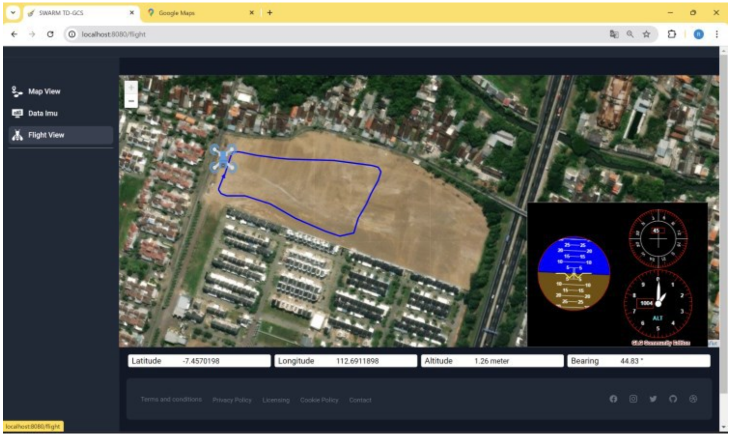

Figure 17. Results of Mapping the movement of Unmanned Aerial Vehicles (UAVs)

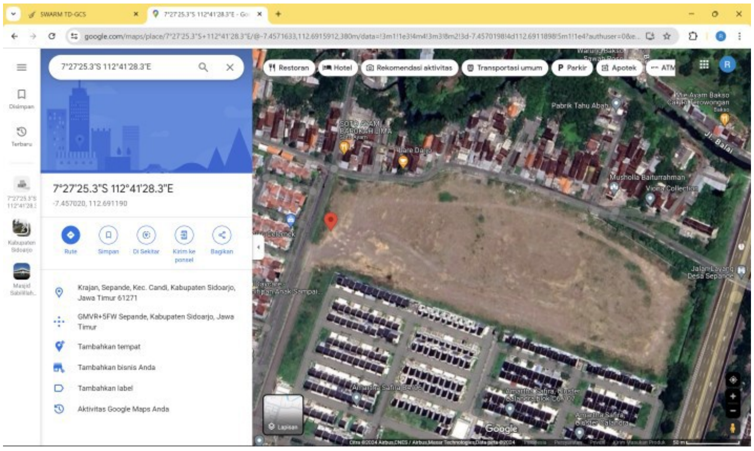

Figure 18. Latitude and Longitude of -7.4574515, 112.6942047