
Design and Implementation of an Offline-Capable Drone Tracking System for Agricultural Spraying Verification Using GPS and Multi-Level Water Tank Monitoring**Haryono¹, Handri Santoso^{2*}**haryono@pradita.ac.id¹, handri.santoso@pradita.ac.id²^{1,2} Universitas Pradita

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Abstract

Agricultural spraying drones have become an effective solution for increasing productivity and spraying uniformity in modern agriculture. However, landowners often face difficulties verifying whether spraying operations have actually been performed within designated areas. Conventional verification methods rely heavily on manual observation, which is labor-intensive, time-consuming, and prone to inaccuracies. This research presents the design and implementation of an offline-capable Drone Tracker system capable of recording drone operational activities through the integration of high-precision GPS tracking and multi-level water tank monitoring. The proposed system records location, speed, positioning quality, and tank liquid level every second, storing all information locally on an SD Card. Since agricultural areas frequently lack reliable internet connectivity, a store-and-forward synchronization mechanism is implemented, allowing data to be uploaded automatically once internet access becomes available. Experimental results demonstrate that the prototype operates continuously for approximately 10 hours, records GPS and water-level data at one-second intervals, achieves positioning accuracy approaching one meter under favorable conditions, and successfully synchronizes locally stored data using a store-and-forward mechanism after internet connectivity becomes available.

A. Introduction

The rapid advancement of precision agriculture has led to the increasing adoption of Unmanned Aerial Vehicles (UAVs) for agricultural spraying applications. Compared with conventional spraying methods, UAV-based spraying systems offer significant advantages, including reduced labor requirements, lower operational costs, improved spraying uniformity, and the ability to operate in difficult terrain conditions. Recent studies have demonstrated that agricultural drones can significantly improve efficiency and productivity in modern farming operations while supporting sustainable agricultural practices [1].

The integration of UAV technologies into agricultural activities has expanded beyond aerial imaging and crop monitoring to include precision spraying, fertilization, and field management. Modern agricultural drones provide accurate and efficient coverage of large agricultural areas while reducing chemical waste and improving operational effectiveness [2]. Consequently, the adoption of UAV-based spraying systems continues to increase in plantations, horticultural farms, and large-scale agricultural operations [3].

Along with the growing use of agricultural drones, the need for monitoring and verification systems has become increasingly important. Landowners, agricultural companies, and service providers often require reliable evidence that spraying operations have been performed correctly within designated areas. Existing verification methods commonly rely on manual observation, operator reports, or post-operation field inspections. These approaches are labor-intensive, time-consuming, and susceptible to human error. Furthermore, UAV-based agricultural management systems still face challenges in providing objective operational verification beyond trajectory and positioning information alone [4].

Recent developments in Internet of Things (IoT) technologies have enabled the integration of sensors, wireless communication, and cloud computing into agricultural monitoring systems. IoT-based smart agriculture platforms have demonstrated significant potential for improving agricultural data collection, monitoring, and decision-making processes through real-time sensing and intelligent data management [5]. Wireless sensor network technologies have further enhanced monitoring capabilities by enabling distributed sensing across large agricultural environments [6].

In addition, UAV monitoring and mapping technologies have contributed to the collection of spatial information for agricultural management and operational assessment [7]. Recent studies have also explored the utilization of LoRa communication, cloud-based infrastructures, and edge computing architectures to improve agricultural monitoring performance while reducing communication costs and energy consumption [8].

Despite these advancements, internet connectivity remains a major limitation in many agricultural environments, particularly in plantations, mountainous regions, and rural farmlands. Long-range low-power communication technologies such as LoRa have been widely investigated to address communication challenges in remote areas where conventional network infrastructure is unavailable or unreliable [9]. Consequently, monitoring systems deployed in such environments must be capable of autonomous operation while preserving data integrity during connectivity interruptions. This requirement is consistent with the broader

challenges identified in IoT deployments, where reliable operation under intermittent network conditions remains a critical design consideration [10].

Existing agricultural drone monitoring studies mainly focus on flight trajectory, telemetry, crop imaging, or cloud-based monitoring. However, very few studies provide objective verification that spraying has actually occurred by correlating flight trajectory with spraying liquid consumption while supporting fully offline operation.

To address these challenges, this research proposes an offline-capable Drone Tracker system that integrates high-precision GNSS positioning and multi-level water tank monitoring. The proposed system continuously records drone trajectory information, flight parameters, and spraying liquid consumption at one-second intervals. All data are stored locally using SD Card storage and subsequently synchronized to a cloud server using a store-and-forward communication mechanism. Unlike conventional drone tracking approaches, the proposed system combines GPS trajectory analysis with water-level monitoring to provide objective verification of spraying activities. The primary contribution of this work is the development of a practical and field-deployable verification framework capable of operating reliably in remote agricultural environments without requiring continuous internet connectivity.

B. System Requirements and Design Objectives

The proposed Drone Tracker system was designed to address the operational challenges encountered during agricultural spraying missions in remote areas where continuous internet connectivity cannot be guaranteed. The primary objective is to provide an autonomous monitoring solution capable of recording reliable evidence of spraying activities while maintaining uninterrupted operation under intermittent network conditions.

To achieve this objective, several system requirements were established. First, the system must operate independently of continuous internet access by storing all operational data locally during field deployment. Second, it must accurately record the drone's geographic position using high-precision GNSS technology to enable reliable reconstruction of flight trajectories. Third, the system must continuously monitor spraying liquid consumption through a multi-level water tank sensor, allowing spraying activities to be verified rather than relying solely on flight paths.

Furthermore, all operational data must be securely stored to prevent information loss during long-duration missions. Once internet connectivity becomes available, the system should automatically synchronize the recorded data with a cloud server using a store-and-forward mechanism without requiring user intervention. Considering the payload limitations of agricultural UAVs, the hardware must also maintain a compact and lightweight form factor suitable for practical deployment. Finally, by combining GPS trajectory information with water-level monitoring, the system is expected to provide objective and verifiable evidence that agricultural spraying has actually been performed within the designated operational area.

C. System Architecture, Result And Discussion

C.1. Hardware Architecture

The proposed Drone Tracker system is built around an ESP32 microcontroller that serves as the main processing unit. Positioning information is obtained using a u-blox ZED-F9P GPS receiver and external GPS antenna, enabling high-accuracy location tracking throughout spraying operations. To monitor spraying activities, a multi-level water-level sensor is attached to the drone tank and continuously measures liquid availability during operation.

All acquired data are stored locally using an SD Card module, allowing the system to operate in locations without internet connectivity. The device is powered by a rechargeable battery system integrated with a charging circuit to support portable field operation. Operational status is displayed through a four-digit display that provides information regarding battery condition, SD card availability, GPS status, and water-level detection. To ensure reliability in outdoor agricultural environments, the electronics are enclosed within an IP67 protective casing equipped with mounting straps for installation on the drone body.

The final prototype has compact dimensions of approximately 6 cm × 7 cm × 5 cm and is capable of operating continuously for approximately ten hours on a single battery charge.

C.2. Software Architecture

The software architecture consists of three primary layers: the embedded layer, cloud layer, and presentation layer.

The embedded layer is implemented on the ESP32 microcontroller and is responsible for GPS acquisition, water-level monitoring, local data storage, WiFi communication, and device management. The firmware continuously records operational information and stores it in the SD Card at one-second intervals.

The cloud layer consists of a REST-based Web API developed using ASP.NET Core, a MySQL database server, and deployment on an Ubuntu-based Virtual Private Server. This layer manages data reception, storage, authentication, and historical data retrieval.

The presentation layer is developed using React and provides visualization of drone trajectories, operational reports, and device management functions through a web-based interface.

C.3. Operational Workflow

The Drone Tracker operates through three main operational modes: Normal Mode, Configuration Mode, and Data Upload Mode.

In Normal Mode, the device continuously acquires GPS coordinates and water-level information while recording operational data every second. Before operation begins, the water-level sensor is attached to the spraying tank through a DB9 connector. After power-up, the system verifies all hardware components and automatically starts recording when the GPS receiver, SD Card, and sensors are functioning properly.

A four-digit display provides operational feedback to the user. The first digit indicates battery status, the second digit indicates SD Card status, the third digit indicates GPS availability, and the fourth digit represents the detected water level

inside the spraying tank. This simple interface enables rapid system inspection before deployment.

Configuration Mode allows operators to configure communication parameters through a web-based interface without modifying firmware. Parameters such as Device ID, Server URL, API endpoint, user credentials, and authentication settings can be modified through WiFi connectivity. This approach simplifies deployment and maintenance of multiple devices.

Data Upload Mode is designed specifically for agricultural environments where internet connectivity is unavailable during spraying operations. During field deployment, all operational records are stored locally within the SD Card. After spraying is completed and internet access becomes available through a mobile hotspot or other connection, the stored data are transmitted automatically to the cloud server.

The upload subsystem implements a store-and-forward mechanism. This mechanism ensures that operational data are never lost due to communication failures and allows reliable synchronization once connectivity becomes available. Failed transmissions are automatically retried until successful delivery is confirmed by the server.

C.4. Data Acquisition Method

The Drone Tracker records operational information at one-second intervals throughout the spraying mission. Each record contains timestamp information, geographic coordinates, flight speed, horizontal dilution of precision (HDOP), battery status, and water-level measurements. The continuous acquisition process enables complete reconstruction of drone activities after mission completion. Because all information is stored locally before transmission, data integrity can be maintained even in locations without internet coverage.

C.5. Spraying Verification Method

The proposed verification approach combines GPS trajectory information and water-level monitoring to determine whether spraying activities have actually been performed.

The verification process begins by analyzing GPS trajectories to determine drone movement throughout the mission. Simultaneously, the water-level sensor continuously monitors liquid availability inside the spraying tank. Changes in tank level indicate liquid consumption during operation.

The recorded trajectory and water-level information are then correlated. A mission is considered valid when continuous drone movement is observed together with measurable liquid consumption. The combination of these two independent observations provides stronger evidence of spraying activity compared with conventional GPS-only tracking systems.

This data-fusion approach represents the primary contribution of the proposed system because it enables objective verification of agricultural spraying operations even in remote environments without real-time communication infrastructure.

D. Results and Discussion

Implementation results demonstrate that the proposed Drone Tracker successfully records operational information throughout spraying missions. The ZED-F9P GNSS receiver provides positioning accuracy approaching one meter under favorable satellite visibility conditions. Combined with continuous water-level monitoring, the system can verify both drone movement and spraying activity simultaneously.

The store-and-forward synchronization mechanism allows the system to operate reliably in remote agricultural environments where cellular connectivity is unavailable.

Compared to conventional GPS tracking systems, the proposed solution offers additional verification capability through liquid consumption monitoring, significantly improving the credibility of spraying reports.

Figure 1 shows the multi-level water tank sensing subsystem connected through a DB9 interface. The sensor is mounted externally on the spraying tank and continuously monitors liquid availability during flight operations. The sensing mechanism enables the system to detect changes in tank volume as spraying progresses. By recording liquid-level variations together with GPS trajectory information, the proposed system provides objective evidence that spraying activities have actually occurred within the target area. This sensing subsystem represents a critical component of the spraying verification framework because it allows differentiation between simple drone flights and actual spraying missions.



Figure 1. Multi-Level Water Tank Sensor Assembly

Figure 2 presents the internal architecture of the Drone Tracker prototype. The system integrates an ESP32 microcontroller, power management circuitry, data storage subsystem, GNSS positioning module interface, and a four-digit status display within a compact enclosure. During operation, the embedded firmware acquires GPS positioning data and water-level measurements at one-second intervals and stores them locally on an SD card. The status display provides real-time feedback regarding battery condition, storage availability, GPS signal status, and sensor operation. The integrated design enables autonomous operation in remote agricultural environments where communication infrastructure may be unavailable.



Figure 2. Internal Electronics of the Drone Tracker

Figure 3 shows the final Drone Tracker prototype enclosed within an IP67-rated protective housing equipped with adjustable mounting straps for installation on agricultural unmanned aerial vehicles (UAVs). The enclosure protects the electronics from dust, moisture, vibration, and harsh field conditions commonly encountered during spraying operations. The compact form factor minimizes payload impact on the UAV while maintaining sufficient battery capacity for approximately ten hours of continuous operation. The resulting platform provides a practical and field-deployable solution for offline monitoring and verification of agricultural spraying activities.



Figure 3. Final Drone Tracker Prototype for Agricultural UAV Deployment

Table 1 summarizes the field evaluation results of the proposed Drone Tracker. The prototype successfully recorded GPS and water-level data at 2-second intervals, operated continuously for approximately 10 hours, achieved approximately 1-meter GPS accuracy, stored all data locally without loss, automatically synchronized records after connectivity was restored, and successfully detected water-level changes during spraying operations.

Table 1. Prototype Evaluation Results

Parameter	Result
GPS logging interval	2 s
Battery endurance	≈10 h
GPS accuracy	≈1 m

Parameter	Result
Local storage	Successful
Upload after reconnect	Successful
Water level detection	Successful

Figure 4 shows the field implementation and evaluation of the proposed Drone Tracker integrated with an agricultural spraying UAV. The figure presents the installation process, pre-flight inspection, hardware integration, and flight operation. The field test confirmed that the system operated successfully during spraying missions by continuously recording GPS positioning and water-level data, storing all operational records locally for subsequent synchronization when internet connectivity became available.



Figure 4. Field Implementation and Evaluation of the Proposed Drone Tracker

E. Conclusion

This research presented the design and implementation of an offline-capable Drone Tracker system for agricultural spraying verification. The proposed system integrates high-precision GPS tracking, multi-level water tank monitoring, local SD Card storage, and cloud synchronization using a store-and-forward mechanism. Field evaluation demonstrated that the prototype successfully recorded operational data at 2-second intervals, achieved approximately 1-meter positioning accuracy, operated continuously for approximately 10 hours, and reliably synchronized locally stored data after internet connectivity was restored. By combining GPS trajectory analysis with water-level monitoring, the proposed system provides objective and reliable verification of agricultural spraying activities in remote environments without requiring continuous internet connectivity. Future work will focus on integrating LoRa communication, real-time

telemetry, geofencing functionality, and machine-learning-based operational analysis.

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