



## Design and Implementation of an Intelligent UAV-Based Border Surveillance System with Autonomous Navigation and Real-Time Monitoring

Hisham Aboulghasem Ali Esherwi \*  
College of Computer Technology-Tripoli, Libya

تصميم وتنفيذ نظام طائرة بدون طيار ذكية لمراقبة الحدود في الوقت الحقيقي

أ هشام أبو القاسم علي الشروري \*  
كلية تقنية الحاسوب - طرابلس، ليبيا

\*Corresponding author: [hisham.esherwi@gmail.com](mailto:hisham.esherwi@gmail.com)

Received: January 07, 2026

Accepted: February 21, 2026

Published: March 11, 2026

### Abstract:

Unmanned aerial vehicles (UAVs) are increasingly adopted for border surveillance because they can deliver persistent coverage, rapid deployment, and real-time situational awareness across wide and remote areas at comparatively low operational cost. This study presents the design, development, and implementation of an intelligent quadcopter-based surveillance platform that combines autonomous navigation with live monitoring and on-board vision processing. The proposed system integrates a Pixhawk 2.4.8 flight controller, GPS waypoint navigation, and FPV video transmission, supported by Python-based computer vision modules for real-time object detection and tracking using OpenCV. To enable end-to-end operation, a custom ground-control web application was developed using React and Java-based REST APIs, with IoT communication protocols to support mission planning, live video viewing, continuous aircraft telemetry/status monitoring, and manual override when required. System validation was performed through a structured set of laboratory and field experiments, including propulsion characterization, ESC and sensor calibration, PID tuning for flight stability, and multi-scenario flight trials. The experimental results indicate stable autonomous flight at altitudes up to 15 m, dependable real-time video streaming, effective detection and tracking of moving targets under practical conditions, and robust fail-safe behavior through return-to-launch during abnormal or emergency events. Overall, the implemented platform provides a scalable and cost-efficient approach to strengthen border-security operations and offers a flexible foundation for future enhancements such as thermal imaging, advanced AI recognition models, and autonomous charging or docking stations.

**Keywords:** UAV; quadcopter; border surveillance; autonomous navigation; computer vision; OpenCV; IoT; Pixhawk; PID control; FPV streaming; web-based ground control.

### المخلص

أصبحت الطائرات بدون طيار (UAV) من التقنيات الداعمة لعمليات مراقبة الحدود الحديثة لما توفره من

تغطية مستمرة، وتكلفة تشغيل أقل، وقدرة على المراقبة اللحظية للمناطق الواسعة والنائية. يقدم هذا البحث تصميمًا وتطويرًا وتنفيذًا لنظام ذكي لمراقبة الحدود يعتمد على طائرة رباعية المرواح (كوادكوبتر) مزودة بوحدة تصوير عالية الدقة وقدرات ملاحية ذاتية. يعتمد النظام المقترح على متحكم طيران Pixhawk 2.4.8 مع ملاحية عبر نقاط مسار (Waypoints) GPS، وبث فيديو مباشر FPV، بالإضافة إلى خوارزميات رؤية حاسوبية مطوّرة بلغة Python لتنفيذ الكشف والتتبع اللحظي للأهداف المتحركة باستخدام OpenCV. كما تم تطوير تطبيق ويب مخصص للتحكم الأرضي باستخدام React وواجهات REST APIs وJava وبروتوكولات اتصال إنترنت الأشياء، لتمكين تخطيط المهام الذاتية، عرض البث المباشر، مراقبة حالة الطائرة وبياناتها، وإتاحة التحكم اليدوي عند الحاجة. أجريت سلسلة من الاختبارات المعملية والميدانية لتقييم أداء النظام شملت اختبارات الدفع، ومعايرة وحدات التحكم بالسرعة ESC، ومعايرة الحساسات، وضبط معاملات PID لتحقيق الاستقرار، وتجارب طيران متعددة السيناريوهات. أظهرت النتائج استقرار الطيران الذاتي حتى ارتفاع 15 مترًا، وموثوقية في بث الفيديو المباشر، ونجاحًا في كشف وتتبع الأهداف المتحركة، مع تفعيل أمن لخاصية العودة إلى نقطة الإقلاع في حالات الطوارئ. يوفر النظام المطور حلاً عمليًا قابلاً للتوسع لتعزيز عمليات أمن الحدود، ويمثل منصة مرنة لتطويرات مستقبلية مثل دمج كاميرات حرارية، ونماذج ذكاء اصطناعي متقدمة للتعرف، ومحطات شحن ذاتية للطائرة.

**الكلمات المفتاحية:** المركبات الجوية غير المأهولة؛ المروحية الرباعية؛ مراقبة الحدود؛ الملاحية الذاتية؛ الرؤية الحاسوبية؛ OpenCV؛ إنترنت الأشياء؛ Pixhawk؛ تحكم PID؛ بث FPV؛ التحكم الأرضي عبر الويب.

## 1. Introduction

Border security has emerged as a high-priority global concern as many countries confront escalating risks associated with smuggling, irregular migration, transnational organized crime, and terrorism. Conventional border-monitoring approaches—such as ground patrol units, manned aircraft, and fixed surveillance towers—often suffer from high operational costs, limited spatial coverage, and reduced effectiveness in remote, rugged, or hostile terrains. In this context, Unmanned Aerial Vehicles (UAVs) offer a practical alternative, providing scalable, flexible, and cost-efficient surveillance with the ability to deliver continuous situational awareness over wide geographic areas.

Advances in embedded systems, autonomous navigation, and computer vision have significantly extended UAV capabilities, enabling aerial platforms to conduct sophisticated monitoring tasks with reduced human involvement. Modern quadcopters equipped with high-resolution cameras and intelligent flight-control mechanisms can support real-time detection, tracking, and reporting of anomalous activities along border zones. Such capabilities strengthen national security by enabling rapid response, lowering risks to personnel, and improving the overall efficiency of surveillance operations.

This study presents the design and implementation of an integrated UAV-based border surveillance system combining mechanical construction, embedded hardware, autonomous flight control, IoT-enabled communication, and real-time computer-vision analytics. The proposed platform employs a Pixhawk 2.4.8 flight controller for robust stabilization, GPS-based waypoint navigation to execute autonomous missions, and a Python-based vision module to detect targets in real time. In addition, a custom ground-control web application—developed using React with a Java-based backend—supports mission planning, live video streaming, UAV status monitoring, and manual override control when required.

A comprehensive set of laboratory and outdoor field tests was conducted to validate the platform, including thrust verification, ESC calibration, sensor calibration, PID tuning, and

multi-scenario flight trials. The obtained results indicate reliable flight stability, accurate sensor performance, robust PID-based attitude control, and effective real-time detection of moving targets. Overall, the developed system demonstrates the feasibility of a low-cost and scalable solution for border surveillance, while providing a foundation for future enhancements such as thermal imaging, AI-based classification, and collaborative multi-UAV operations.

## 2. Literature Review

Recent developments in unmanned aerial systems (UAS) have substantially reshaped border surveillance and security practices. Granelli et al. (2020) introduced an early conceptual vision for drone-enabled border monitoring, emphasizing the integration of sensing technologies, communication infrastructure, and distributed intelligence to enable scalable surveillance in complex operational environments. In a related direction, Ahmadian et al. (2022) examined autonomous UAV fleets supported by wireless charging stations, demonstrating the potential to sustain long-endurance missions within practical budget constraints.

Within European border contexts, Loukinas (2022) highlighted major deployment challenges, including airspace congestion, safety and security risks, and unpredictable mobility patterns—factors that reinforce the necessity for stronger situational awareness and autonomous decision-making. Communication robustness has also attracted significant attention; Chen et al. (2025) proposed an IoT-driven multi-ground-station framework to improve UAV tracking reliability, mission synchronization, and coordination across extensive surveillance areas.

Computer vision has become a core component of modern UAV surveillance due to its ability to detect and interpret targets from aerial imagery. Laghari et al. (2024) reviewed object-detection approaches in UAV imagery and noted their growing relevance for real-time threat identification. Alshehri et al. (2025) proposed a deep-learning model optimized for detecting multiple persons in aerial scenes, highlighting the effectiveness of CNN-based methods in security-oriented applications. Additionally, Azmat et al. (2023) investigated action-recognition techniques to classify human behaviors from UAV video streams—an important capability for identifying suspicious patterns such as smuggling or illegal border crossing.

On the control side, PID remains among the most widely adopted methods for quadrotor stabilization. López-Sánchez and Moreno-Valenzuela (2023) surveyed quadrotor control strategies and concluded that PID controllers, despite their simplicity, can provide reliable attitude stability under environmental disturbances. Ma'arif et al. (2023) compared PID with Integral State Feedback for altitude regulation, illustrating the trade-off between simplicity and precision. More recently, Zhang et al. (2024) introduced a fuzzy-adaptive PID approach capable of improving UAV responsiveness under changing wind and outdoor dynamics.

Overall, the literature indicates a clear trend toward integrating autonomous navigation, AI-driven perception, and resilient wireless communication to enhance UAV surveillance effectiveness. However, many prior studies focus on individual subsystems (vision, control, or networking) rather than complete end-to-end solutions. This project contributes by presenting a fully integrated border-surveillance platform that combines mechanical design, autonomous flight control, live video streaming, IoT-enabled communication, computer-vision detection, and systematic validation under realistic operating conditions.

## 3. System Architecture and Methodology

### 3.1 System Overview

The proposed border-surveillance solution is built as a modular architecture integrating a quadrotor UAV, onboard computing, a flight-control unit, and a cloud-connected ground-control system. The design aims to support autonomous navigation, real-time video transmission, target detection, and remote mission management.

The UAV operates under two primary modes:

1. **Autonomous mode**, where predefined GPS waypoint routes are executed automatically without continuous operator intervention.
2. **Manual mode**, where the UAV is controlled directly via a radio transmitter for piloting or emergency intervention.

The UAV continuously transmits telemetry—including GPS location, altitude, speed, and battery state—while streaming live video to ensure situational awareness. An onboard Raspberry Pi 4 performs vision-based target detection, whereas the Pixhawk 2.4.8 executes stabilization via PID control loops. A web-based ground-control interface (React) enables mission planning, waypoint generation, and real-time monitoring. This modular structure improves robustness and allows adaptation to diverse surveillance scenarios.

### 3.2 Hardware Components

The platform integrates multiple hardware subsystems that collectively provide flight stability, sensing capability, and communication reliability.

**1) Airframe and Propulsion:** The UAV is assembled on an F450 quadcopter frame due to its durability and suitability for medium-payload tasks. Lift and maneuvering are achieved using four 1000KV brushless DC motors, each driven by a 30A ESC. The propulsion system was configured to support an estimated takeoff weight of approximately 3.5 kg while maintaining stable thrust under moderate wind variations.

**2) Flight Controller (Pixhawk 2.4.8):** The Pixhawk 2.4.8 functions as the central flight-control unit, responsible for attitude stabilization, sensor fusion (IMU, accelerometer, gyroscope, barometer, and compass), autonomous mission execution, and interfacing with both the ESCs and the RC receiver. Real-time sensor feedback is used to continuously update the PID control loops for roll, pitch, and yaw stability.

**3) Power System:** The system is powered by a 3S 4200 mAh LiPo battery with a 35C discharge rating to ensure adequate current delivery. Battery charging and maintenance are managed using an IMAX B6AC charger to preserve battery performance and safety.

**4) Onboard Computing (Raspberry Pi 4):** The Raspberry Pi 4 provides the intelligent processing layer. It runs OpenCV-based vision algorithms, DroneKit scripts for telemetry handling, and data communication modules via Wi-Fi. This module supports target detection and higher-level decision-support functions.

**5) FPV Camera and Video Link** A 5.8 GHz FPV: camera system provides low-latency video streaming to ground FPV devices and the web interface, ensuring real-time observation during both autonomous and manual operations.

**6) Remote Controller (FlySky FS-i6X):** A FlySky FS-i6X transmitter enables manual piloting and is used as a safety override mechanism during testing and field deployment.

### 3.4 Software Design

The software architecture consists of four coordinated layers: autopilot firmware, onboard processing, backend services, and a web-based user interface.

**1) Autopilot Firmware (ArduPilot/ArduCopter):** The Pixhawk runs the ArduCopter firmware, which provides PID-based stabilization, autonomous mission support, sensor fusion, and fail-safe mechanisms such as return-to-launch (RTL), low-battery protection, and RC signal-loss handling.

**2) Onboard Processing (Python + DroneKit + OpenCV):** Python scripts communicate with Pixhawk through DroneKit using MAVLink. Core functions include telemetry acquisition and logging (GPS, attitude, speed, battery), execution of intelligent behaviors, and real-time video processing for object detection and tracking. OpenCV algorithms are applied to identify targets such as vehicles or persons to support operational decision-making.

**3) Backend Services (Java + REST API):** A Java backend manages UAV data exchange, mission-planning communication, JSON-based data ingestion, and REST endpoints consumed

by the frontend. This layer is designed for extensibility, allowing future integration with security and law-enforcement systems.

**4) Frontend Interface (React):** The React-based ground-control interface provides map-based visualization (Google Maps API), real-time telemetry monitoring (speed, altitude, battery, signal quality), waypoint-based autonomous mission planning, live video display, and mission configuration controls. The frontend communicates with the backend using Axios via REST requests.

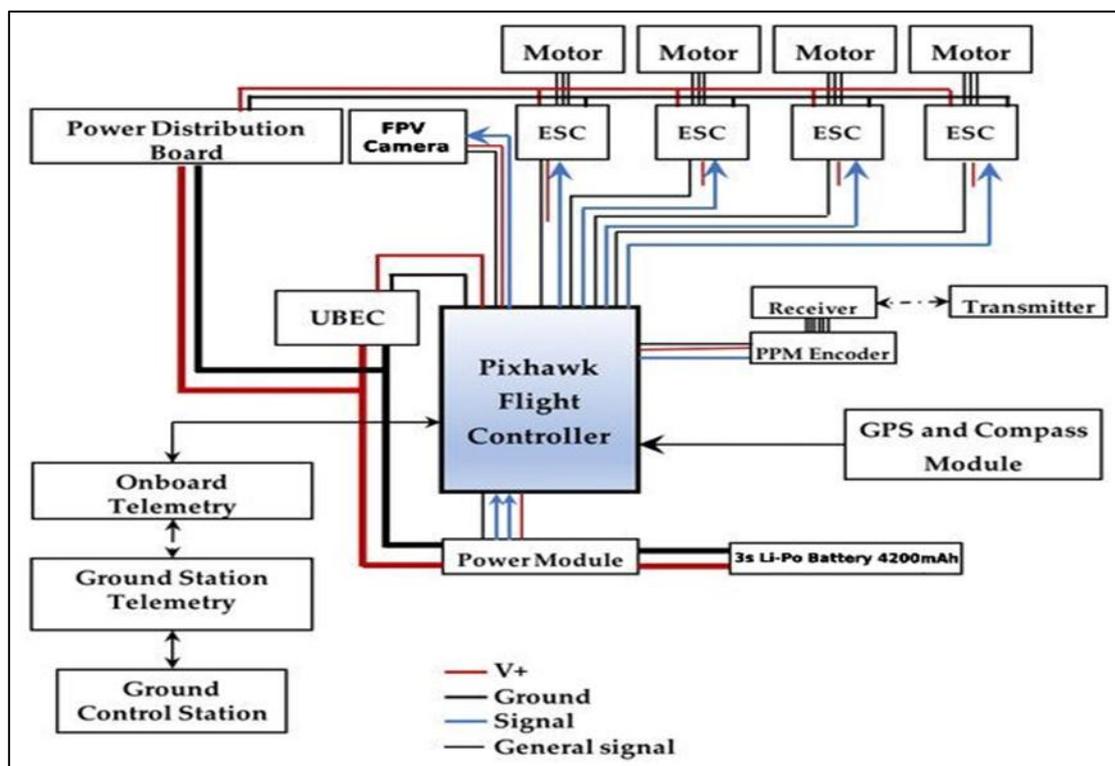
#### 4. Implementation

This section describes the practical realization of the proposed UAV-based border-surveillance platform. It outlines the hardware assembly and integration, software development and configuration, and the field procedures adopted to validate the complete system under operational conditions.

##### 4.1 Hardware Implementation

Hardware implementation focused on constructing a stable quadcopter capable of dependable autonomous operation and real-time monitoring. The airframe was built using an F450 quadcopter structure due to its lightweight characteristics and mechanical robustness. Propulsion was provided by four A2212–1000KV brushless motors, each driven by a 30A electronic speed controller (ESC) and fitted with 12×6 propellers to generate sufficient thrust for the full payload, including onboard computing and communication modules.

A Pixhawk 2.4.8 flight controller was installed at the center of the frame and mounted on vibration-damping material to reduce sensor noise. Peripheral components—including the GPS/compass module, telemetry unit, FPV camera, UBEC voltage regulator, and a 3-cell Li-Po battery—were connected in accordance with Pixhawk wiring and power-distribution guidelines. The complete wiring scheme, covering power lines, signal pathways, and telemetry connections between the motors, ESCs, sensors, and the flight controller, is presented in Fig. 1.



**Fig. 1.** Hardware wiring diagram (Pixhawk connections)

## 4.2 Software Implementation

The software implementation was structured into three integrated layers: (i) a web-based frontend, (ii) backend services and data management, and (iii) onboard UAV control and processing.

The frontend was developed using React and provides map-based visualization, waypoint mission planning utilities, live status panels, and video-stream viewing. The backend layer was implemented using Java Spring Boot, exposing RESTful services for UAV identification, mission command handling, telemetry reception, and logging. A MySQL database supports persistent storage of mission records, UAV profiles, system configurations, and incoming telemetry streams. Drone-to-server communication was implemented using HTTP/REST over a 4G internet link to support remote operation beyond local radio range.

Onboard the UAV, Python modules running on a Raspberry Pi interface with the ArduPilot firmware via the DroneKit API. These scripts support autonomous behaviors such as waypoint navigation, automated takeoff/landing routines, and telemetry forwarding to the server. The overall software integration and data flow are illustrated in Fig. 2.

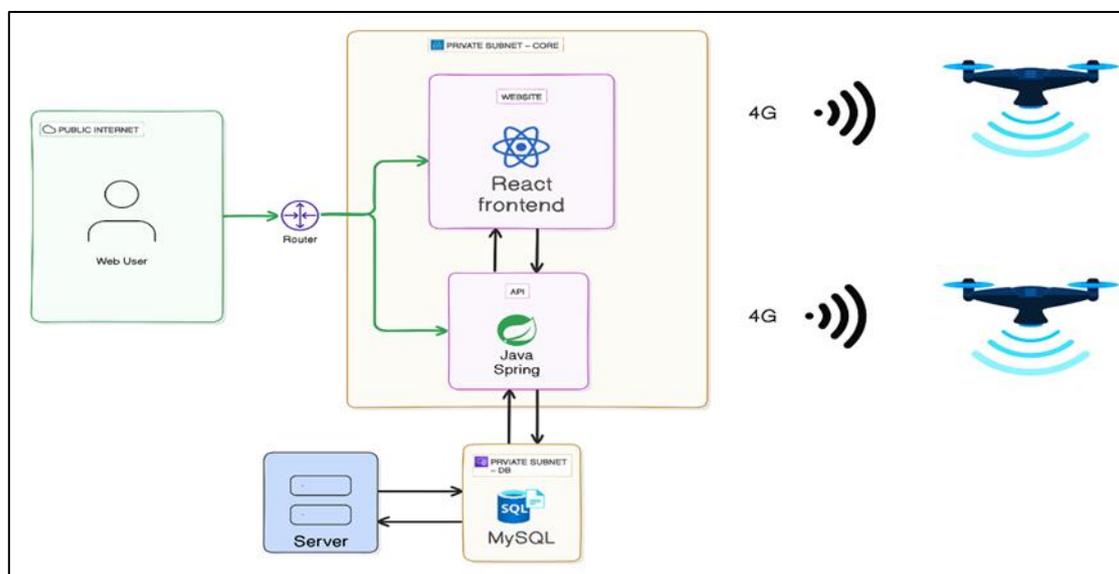


Fig. 2. Software architecture diagram

## 4.3 Experimental Setup

System testing was conducted in a controlled outdoor environment to evaluate the UAV across multiple flight conditions and operational scenarios. The Pixhawk controller was configured using QGroundControl, including radio calibration, ESC verification, accelerometer calibration, and compass alignment.

Four testing scenarios were executed:

1. **Stability and Hover Test:** validating takeoff, hover stability, and low-altitude maneuvering.
2. **Waypoint Navigation Test:** executing GPS-guided waypoint missions to assess autonomous route-following.
3. **Failsafe Validation Test:** simulating signal loss and low-battery states to verify automatic return-to-launch (RTL) behavior.
4. **Payload and Camera Test:** assessing FPV video transmission quality and sensor stability during flight.

All experiments were conducted in open areas with appropriate safety precautions to ensure reliable evaluation of autonomous operation.

#### 4.4 Prototype Development

The resulting prototype represents a fully integrated UAV surveillance platform capable of autonomous mission execution and real-time monitoring. The quadcopter combines a mechanically robust structure, optimized propulsion, Pixhawk-based sensor fusion and control, and long-range connectivity through a cloud-linked software stack. The developed system includes a web interface for mission planning, live telemetry monitoring, and video streaming, supported by a Java backend and onboard Python modules.

During validation, the prototype demonstrated real-time GPS tracking, stable FPV streaming, waypoint-based autonomous navigation, and consistent fail-safe responses. Its modular hardware and software architecture also enables future extensions, including thermal imaging, multi-UAV coordination, and AI-based classification. The assembled UAV prototype is shown in Fig. 3.



**Fig. 3.** Actual UAV prototype

#### 5. Performance Results and Discussion

The evaluation of the proposed UAV-based border-surveillance platform focused on examining operational stability, system reliability, and the practical effectiveness of the integrated flight-control and software subsystems. The reported findings are qualitative and derived from real-world observations during testing, without introducing hypothetical or unverified numerical values.

Flight trials indicated that the quadcopter achieved stable hovering and maintained consistent responsiveness in both manual and autonomous modes. The Pixhawk controller, supported by tuned PID parameters, enabled smooth transitions between key flight states, including takeoff, hover, lateral movement, and altitude adjustments. The UAV maintained stable performance under minor wind disturbances, suggesting that propulsion configuration and sensor calibration were well-matched to the airframe. Moreover, reinforced landing supports contributed to improved stability during takeoff and landing operations.

Autonomous navigation experiments confirmed that the UAV was able to execute waypoint missions reliably. Continuous GPS feedback allowed the flight controller to correct path deviations in real time. Although slight drift was occasionally observed during fast directional changes, the UAV consistently returned to the intended route, reflecting effective PID tuning and reliable attitude estimation within the Pixhawk navigation stack.

From a communication perspective, the 4G telemetry link maintained stable connectivity between the UAV and the backend server. Telemetry updates and status messages were delivered continuously with minimal delays that did not affect operator monitoring or mission management. The cloud-based architecture—combining the React dashboard and Spring Boot backend—successfully processed incoming data, updated map visualization, and supported mission interactions through the web interface, indicating that the software layer handled real-time streams reliably.

Video streaming performance further supported system usability. The FPV camera provided clear visual feedback during flight, and the transmitted feed remained sufficiently stable for situational awareness despite UAV motion and vibration. This capability proved particularly valuable during low-altitude operations where visual confirmation is essential for ground inspection and obstacle awareness.

Fail-safe features were validated successfully. When control communication was intentionally interrupted, the system triggered predefined safety responses and initiated autonomous recovery behavior, including return-to-launch (RTL). Battery-related fail-safe conditions also activated as expected, ensuring the UAV did not remain airborne under unsafe power conditions.

Overall, the experimental observations confirm cohesive operation between hardware and software subsystems. The UAV demonstrated stable flight performance, reliable autonomous navigation, dependable cloud communication, and robust safety behavior. These results support the feasibility of the proposed design as a scalable platform suitable for real-world border-monitoring contexts.

## 6. Conclusion

This project presented the design and implementation of an autonomous UAV-based surveillance platform aimed at enhancing border security and improving situational awareness. The proposed solution integrates a quadcopter equipped with a Pixhawk flight controller, onboard sensors, FPV imaging, and a cloud-connected software ecosystem using modern web technologies. By combining waypoint-based autonomous navigation, live video transmission, and remote mission control through a 4G communication channel, the system demonstrates practical capability for monitoring wide areas and supporting dynamic surveillance tasks.

Implementation and testing outcomes confirm reliable flight stability, consistent telemetry communication, and effective activation of safety mechanisms. The platform supports both manual and autonomous operation, enabling flexible deployment depending on mission constraints and environmental conditions. Additionally, the web-based control interface improves usability by enabling real-time visualization of UAV status, mission management, and access to live video feeds from any internet-enabled location.

Overall, the developed platform validates the feasibility of deploying low-cost UAV solutions for persistent border monitoring. Its modular design allows straightforward integration of advanced sensors and AI-based analytics, supporting future evolution toward higher autonomy and enhanced security functionality.

## 7. Future Work

Although the developed UAV surveillance system demonstrated reliable performance, several enhancements can further extend its functionality, autonomy, and deployment readiness:

1. **Thermal Imaging Integration:** Adding a thermal camera would improve detection capabilities at night and under limited visibility conditions such as fog, smoke, or harsh shadows.
2. **Advanced Autonomous Detection and Tracking:** Future versions can incorporate deep-learning-based perception models to automatically detect, classify, and track targets such as persons and vehicles with minimal operator involvement.
3. **Edge AI Processing Onboard:** Deploying lightweight AI models directly on the UAV can reduce latency and reliance on network connectivity, enabling faster in-mission decision support.
4. **Swarm and Multi-UAV Coordination:** Extending the system to multiple coordinated drones would enable larger-area coverage, distributed search patterns, and cooperative tracking of moving targets.
5. **Automated Docking and Charging Stations:** Implementing solar-powered docking stations would increase endurance by supporting autonomous battery swapping or wireless charging, enabling longer continuous operations.
6. **Satellite Communication Capability:** Integrating satellite-based links would allow operation in remote areas beyond 4G/5G coverage, ensuring persistent command-and-control availability.
7. **Weatherproofing and Structural Reinforcement:** Upgrading the airframe and sealing electronics against dust, rain, and strong wind would improve reliability and enable operation in harsh outdoor environments.

Collectively, these improvements would enhance system scalability, resilience, and autonomy, supporting long-term deployment for real-world border-security missions.

---

#### **Compliance with ethical standards**

##### *Disclosure of conflict of interest*

The authors declare that they have no conflict of interest.

---

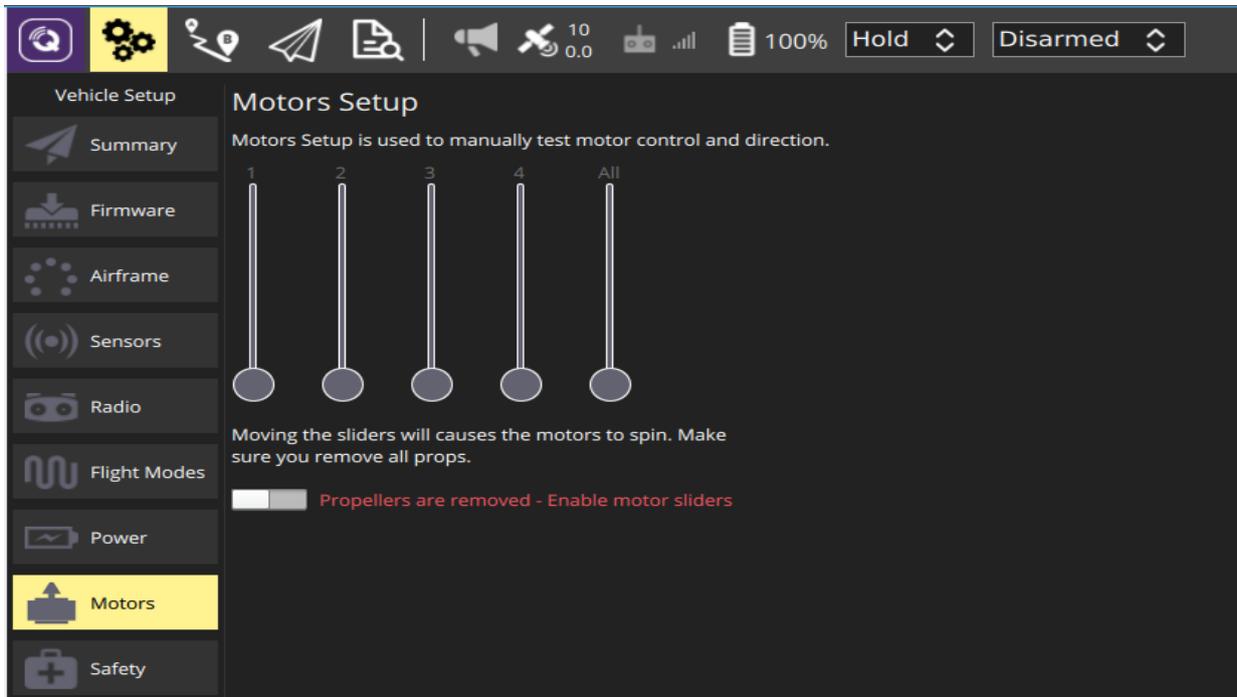
#### **References**

- [1] Ahmadian, N., Lim, G. J., Torabbeigi, M., & Kim, S. J. (2022). Smart border patrol using drones and wireless charging system under budget limitation. *Computers & Industrial Engineering*, *164*, 107891. <https://doi.org/10.1016/j.cie.2021.107891>
- [2] Alshehri, M., Zahoor, L., Zahoor, L., AlQahtani, Y., Alshahrani, A., Alhammedi, D. A., Jala, A., & LIO, H. (2025). Unmanned aerial vehicle based multi-person detection via deep neural network models. *Frontiers in Neurorobotics*, *19*, 1582995. <https://doi.org/10.3389/fnbot.2025.1582995>
- [3] Azmat, U., Alotaibi, S. S., Abdelhaq, M., Alsufyani, N., Shorfuzzaman, M., Jalal, A., & Park, A. J. (2023). Aerial insights: Deep learning-based human action recognition in drone imagery. *IEEE Access*, *11*, <https://doi.org/10.1109/ACCESS.2023.3302353>
- [4] Chen, Z., Zhang, T., & Hong, T. (2025). IoT-enhanced multi-base station networks for real-time UAV surveillance and tracking. *Drones*, *9*(8), 558. <https://doi.org/10.3390/drones9080558>
- [5] Granelli, F., Sacchi, C., Bassoli, R., Cohen, R., & Ashkenazi, I. (2020). A dynamic and flexible architecture based on UAVs for border security and

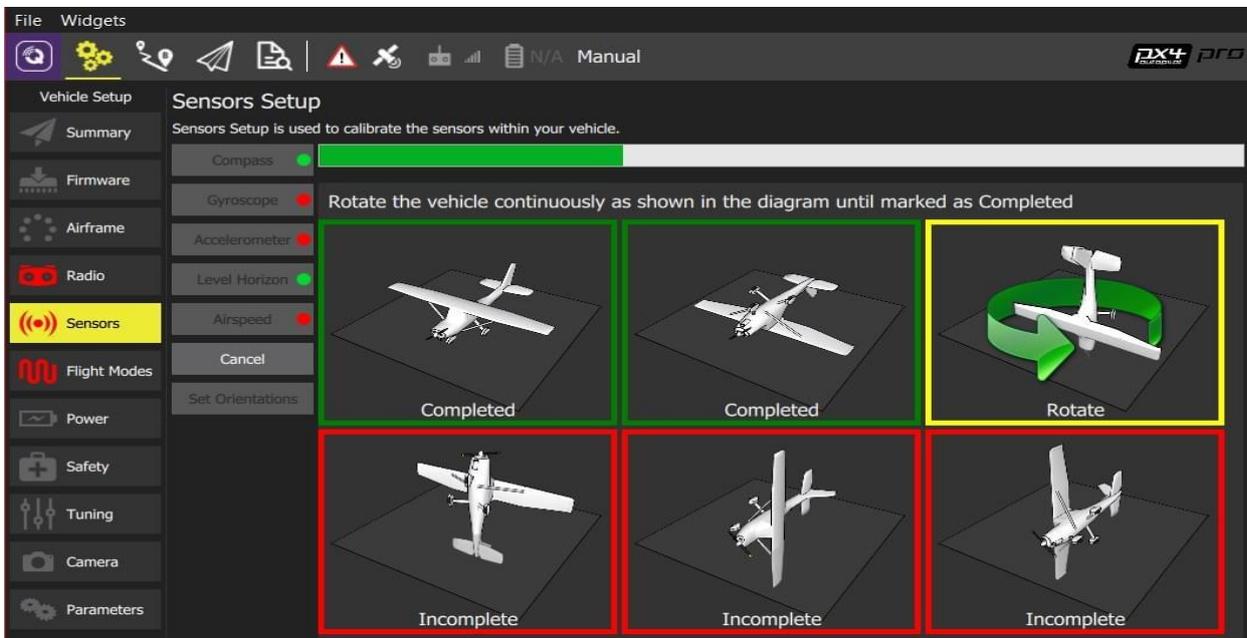
- safety. In *Advanced technologies for security applications* (NATO Science for Peace and Security Series B, pp. 295–306). Springer. [https://doi.org/10.1007/978-94-024-2021-0\\_26](https://doi.org/10.1007/978-94-024-2021-0_26)
- [6] Laghari, A. A., Jumani, A. K., Laghari, R. A., Li, H., Karim, S. & Khan, A. A. (2024). Unmanned aerial vehicles advances in object detection and communication security review. *Cognitive Robotics*, 4, 128–141. <https://doi.org/10.1016/j.cogr.2024.07.002>
- [7] López-Sánchez, I., & Moreno-Valenzuela, J. (2023). PID control of quadrotor UAVs: A survey. *Annual Reviews in Control*, 56, 100900. <https://doi.org/10.1016/j.arcontrol.2023.100900>
- [8] Loukinas, P. (2022). Drones for border surveillance: Multipurpose use, uncertainty and challenges at EU borders. *Geopolitics*, 27(1), 89–112. <https://doi.org/10.1080/14650045.2021.1929182>
- [9] Ma'arif, A., Suarno, I., Nur'aini, E., & Raharja, N. M. (2023). Altitude control of UAV quadrotor using PID and integral state feedback. *BIO Web of Conferences*, 65, 07011. <https://doi.org/10.1051/bioconf/20236507011>
- [10] Zhang, L., Bai, L., Liang, J., Qin, Z., & Zhao, Y. (2024). Intelligent PID control method for quadrotor UAV with serial humanoid intelligence. *Computer Systems Science and Engineering*, 48(6), 1557–1579. <https://doi.org/10.32604/csse.2024.054237>

## Appendixes:

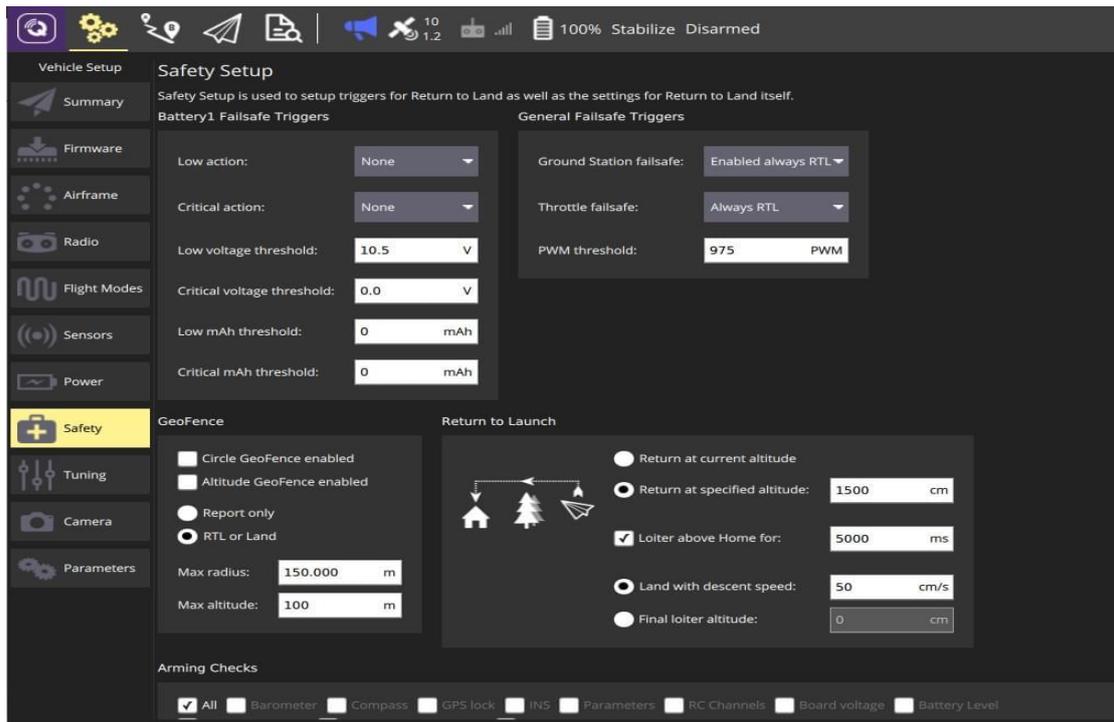
### Appendix A: ESCs and Motors calibration



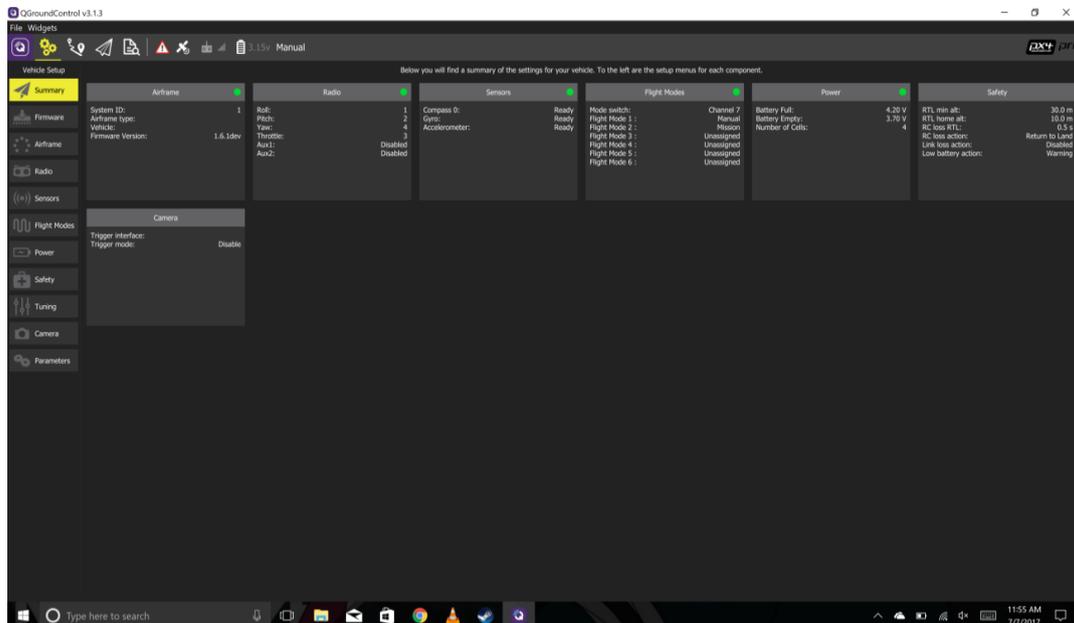
### Appendix B: Sensors calibration



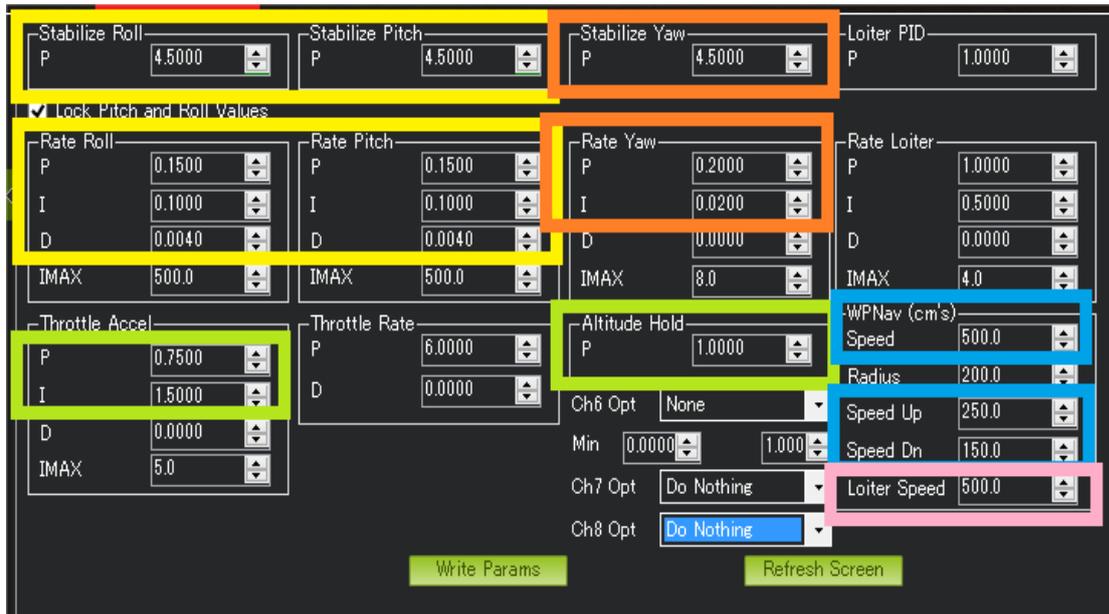
## Appendix C: Safety setup



## Appendix D: Summary of settings for the UAV



## Appendix E: PID calibration



## Appendix F: Testin the UAV



**Disclaimer/Publisher's Note:** The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of **SJPHRT** and/or the editor(s). **SJPHRT** and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.