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Single Handed Joystick Based Drone System with Gamified Application

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Abstract: *The integration of intuitive control mechanisms with unmanned aerial vehicle (UAV) platforms has become an essential focus in human–machine interface research. This paper surveys the design, implementation, and evaluation of a single-handed joystick-based drone control system that leverages compact hardware architecture and advanced safety algorithms. The system, centered around the ESP32-S2 microcontroller, introduces an accessible, user-friendly, and safe method for drone navigation. It incorporates geofencing, automated return-to-home features, and real-time OLED feedback to enhance operational reliability and user engagement. This survey analyzes the system's hardware and software synergy, performance metrics, safety integration, and user experience outcomes. It also identifies existing research gaps and proposes future directions including wireless interfacing, swarm coordination, AI-assisted safety mechanisms, and adaptive autonomy. The study concludes that simplified control systems with embedded intelligence can significantly lower the learning curve of UAV operation while ensuring precision, safety, and scalability.*

Keywords: *UAV control, Single-handed joystick, Human–machine interface, Embedded systems, Drone navigation, Safety algorithms, Swarm coordination, AI-assisted autonomy, Wireless interfacing, User experience*

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I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have revolutionized applications across surveillance, logistics, entertainment, and research [7]. However, traditional UAV control interfaces demand high coordination and extensive training. The dual-stick control mechanism remains complex, limiting accessibility for beginners and hobbyists [18,4]. Recent research emphasizes the importance of developing ergonomic, low-cost, and safe drone control alternatives that merge intuitive control with advanced automation [9,8,10].

The Single-Handed Joystick-Based Drone Control System addresses these challenges by offering a minimalistic, user-centered design that enables full control using only one hand. This system integrates hardware efficiency with intelligent firmware to enhance maneuverability and operational feedback. The use of the ESP32-S2 microcontroller, OLED displays, and EEPROM- based calibration ensures high accuracy and consistent performance. Safety-critical features such as geofencing and return-to- home automation prevent unintended flyaways and improve flight predictability [1,5,2,6].

By embedding gamification elements like interactive calibration and real-time graphical feedback, the project transforms the drone piloting experience from a purely technical task to an engaging, educational interaction [3,4]. This paper surveys the design principles, methodologies, analytical evaluation, and performance outcomes of this project, highlighting its potential as a scalable model for future UAV control systems.

II. PROPOSED METHODOLOGIES

The development of the joystick-based control system involved a combination of hardware integration, firmware design, and software logic optimized for safety and user engagement. The methodology is divided into hardware configuration, communication logic, control algorithms, and safety implementation.

2.1 Hardware Architecture

The control module employs an ESP32-S2 microcontroller as the central processing unit due to its integrated Wi-Fi capabilities, high processing power, and energy efficiency. The joystick mechanism comprises a five-degree analog input system that maps directional movement to proportional control outputs. Real-time telemetry and status updates are displayed on a compact OLED screen, providing immediate feedback on joystick position, battery levels, and calibration status.

EEPROM storage ensures persistent calibration data, maintaining consistent response characteristics across sessions. On the UAV side, an embedded flight controller interprets the joystick signals, managing thrust, yaw, pitch, and roll through precise pulse-width modulation (PWM) outputs. The USB HID interface ensures minimal latency and high responsiveness [9].

2.2 Communication and Control Logic

The system establishes a bidirectional communication channel between the joystick and drone through a serial interface, later extendable to wireless communication protocols. The controller transmits processed signals based on real-time user input, while the drone acknowledges sensor feedback including position, speed, and proximity data.

An automated geofencing algorithm restricts drone movement to predefined spatial boundaries using GPS coordinates or virtual markers. If boundary conditions are violated, the system triggers corrective maneuvers or initiates an emergency landing sequence. The Return-to-Home (RTH) algorithm automatically directs the drone back to its launch coordinates after 30 seconds of inactivity or disconnection [2,6].

2.3 Safety and User-Centric Design

Safety mechanisms are embedded at multiple layers. Hardware failsafes prevent motor overdrive, while firmware constraints monitor signal integrity and battery health. The OLED-based feedback loop enhances user situational awareness, enabling immediate response to anomalies. Additionally, the gamified interface, through calibration bars and console feedback, transforms control learning into an intuitive, interactive process [6,10,3].

Comparative Analysis of Proposed Methodologies
The aforementioned five approaches differ in terms of operational efficiency, implementation complexity, real-time responsiveness, and scalability when integrated into drone control systems. Each methodology offers unique advantages and trade-offs that influence its suitability for specific UAV configurations and use cases. The proposed single-handed joystick-based approach aims to balance simplicity, precision, and safety while minimizing user training requirements.

The comparative analysis of the existing and proposed methodologies is summarized in Table 1, which outlines their core attributes, benefits, limitations, and practical applicability.

Methodology	**Operational Efficiency**	**Complexity**	**Advantages**	**Limitations**	**Applicability to UAV Systems**
Dual-Stick RC Controller	High real-time control precision	Moderate to High	Widely adopted, standardized, and offers full manual control	Requires high skill; steep learning curve; limited automation	Suitable for expert pilots and manual flight missions
Smartphone-Based Control	Moderate	Low	Portable, accessible, and user-friendly interface	Touchscreen lacks tactile feedback; prone to latency	Ideal for beginner-level UAVs and recreational use
Gesture-Based Control	Moderate	High	Hands-free operation; natural user interaction	Sensor noise; environmental dependency	Emerging use in AR/VR-integrated drone systems
Voice-Controlled Interface	Low to Moderate	High	Enables intuitive, non-contact control	Limited reliability in noisy environments; low response speed	Niche applications requiring accessibility and hands-free operation
Single-Handed Joystick Control (Proposed)	High	Low	Compact, ergonomic design; low latency; embedded safety; intuitive feedback	Wired interface; limited range (can be improved via wireless protocols)	Highly suited for educational, research, and hobbyist UAV platforms

Analysis:

The five control methodologies present distinct variations in terms of responsiveness, usability, technological complexity, and their appropriateness for different UAV applications. The dual-stick RC controller remains the most widely used and technically refined approach, offering excellent real-time precision and complete manual control over the drone's axes. However, its operation requires significant hand coordination and experience, making it challenging for beginners and prone to human error during complex maneuvers. Smartphone-based control, on the other hand, emphasizes accessibility and portability by integrating mobile sensors and touchscreen interfaces, making it suitable for entry-level or recreational drones. Yet, the lack of tactile feedback and potential latency issues often compromise stability during precise movements. Gesture-based control represents a modern, intuitive paradigm by enabling hands-free navigation through motion sensing and computer vision, but its effectiveness depends heavily on environmental conditions such as lighting and sensor calibration, which can reduce reliability in practical applications. Voice-controlled systems introduce a natural interaction model by allowing verbal commands, thereby improving inclusivity and ease of use for users with limited mobility. However, their slower response times, limited multi-axis control, and susceptibility to ambient noise make them less viable for high-speed or real- time drone operations. In contrast, the proposed single-handed joystick-based system effectively bridges the gap between precision control and user accessibility. It provides a tactile and ergonomic interface with low-latency analog response while integrating essential safety features such as geofencing, return-to-home automation, and OLED-based real-time feedback. These elements collectively ensure both operational reliability and ease of use. Additionally, its gamified feedback and persistent calibration contribute to a more engaging learning experience, making it well-suited for educational, research, and training contexts. While its current wired connection limits range, future iterations incorporating wireless protocols and haptic feedback can enhance its mobility and immersion. Overall, this system achieves a balanced integration of simplicity, precision, and safety, establishing it as a robust and scalable model for next- generation UAV control interfaces [1,8,5,18,19,4,9,10,11].

III. RESULTS AND DISCUSSION

The implementation and testing of the system yielded highly successful outcomes, validating both the hardware design and software control architecture of the Single-Handed Joystick-Based Drone Control System. The custom-designed joystick controller exhibited exceptional responsiveness, enabling smooth and intuitive horizontal navigation with minimal latency. Extensive calibration and iterative tuning of the control parameters resulted in precise, real-time drone movement, achieving a command response delay of less than 25 ms. This ensured stable user input translation into consistent drone maneuvering, even during dynamic flight operations.

A significant milestone of the project was the drone's ability to autonomously maintain a hover at a fixed altitude with a vertical deviation of less than ±5 cm. This result confirmed the effectiveness of the simplified control scheme and verified that the onboard feedback loop and sensor fusion algorithms could sustain stable flight without manual correction. The autonomous hovering capability also highlights the robustness of the control logic implemented within the flight firmware, despite relying on a reduced control interface.

The Lighthouse tracking system further reinforced the system's precision and stability by providing sub-centimeter position accuracy across the entire flight arena. Quantitative analysis revealed a mean absolute position error of 0.9 mm along the X-axis and 1.3 mm along the Y-axis, while positional noise during static hover remained below ±0.8 mm RMS. This high-resolution spatial tracking was crucial for evaluating flight consistency and enabled the accurate validation of all safety protocols, including geofencing and automated landing sequences [11,12].

The geofencing mechanism performed exceptionally well, consistently enforcing the predefined virtual flight boundary of ±0.5 meters. Throughout multiple trials, all outbound control commands attempting to breach this boundary were automatically rejected. The drone demonstrated adaptive behavior, halting or redirecting its trajectory in accordance with the programmed safety margins. This functionality effectively eliminated collision risks and unintentional drifts, proving the reliability of software-based containment measures in constrained environments [2].

The Return-to-Home (RTH) function, triggered by the automated 30-second inactivity timer, operated flawlessly across all test scenarios. Upon activation, the drone successfully terminated manual control, navigated autonomously to its initial takeoff point, and executed a smooth, controlled landing. This feature not only strengthened operational safety but also demonstrated the integrity of the autonomous flight algorithms, ensuring a secure failsafe for novice users or unexpected signal interruptions [6].

Furthermore, the gaming subsystem, comprising the Python game script, MQTT broker, and ESP32 game nodes, was fully integrated and validated in conjunction with the drone's control system. The end-to-end communication chain operated seamlessly, confirming that the entire architecture, from physical drone motion to virtual game logic, functioned cohesively. The synchronization between the drone's real-world behavior and the game's virtual scoring and feedback mechanics showcased the project's interdisciplinary potential, bridging embedded systems, IoT communication, and interactive entertainment [3,15].

Overall, these results affirm that the designed system not only achieves technical precision but also successfully merges user-centric control, safety enforcement, and gamified interactivity into a unified framework. The outcomes position the platform as a proof of concept for accessible, intelligent, and educational UAV interfaces, capable of advancing drone usability across academic, research, and recreational domains.

IV. RESEARCH GAPS

While the current prototype demonstrates significant advancements, several opportunities remain for enhancement and scalability. One potential improvement is the integration of wireless communication. Transitioning from USB HID to Wi-Fi or Bluetooth Low Energy would eliminate physical tethering, greatly enhancing portability and flexibility, especially for outdoor applications where mobility is crucial. Another avenue for development lies in gamified learning modules. By expanding the system into an interactive learning platform, users could engage with mission-based challenges and performance scoring, allowing them to train progressively while making the experience more engaging and educational. Future implementations could also explore swarm coordination and multi-drone control. Enabling a single joystick to manage drone swarms would open possibilities in aerial choreography, mapping, and coordinated search operations, significantly broadening the practical applications of the system [2,3,15,16,20].

In addition, incorporating gesture recognition and vibration-based haptic feedback could elevate the human–machine interaction experience. Such enhancements would provide more natural and immersive control, allowing users to feel the environment and respond intuitively to drone behavior. Integrating AI-based autonomy presents another exciting opportunity. Lightweight machine learning models for obstacle prediction and adaptive path correction could improve safety in dynamic environments, allowing drones to navigate more intelligently and autonomously. Coupled with adaptive flight time management, these algorithms could optimize operation duration by adjusting to real-time power and environmental conditions, rather than relying on fixed-duration operation. Mobile companion applications also have the potential to broaden user engagement and functionality. By integrating smartphones for telemetry visualization, flight statistics, and progress tracking, the system could offer users a more comprehensive and interactive experience [1,10,13,16,20,4,5].

Finally, expanding the swarm and Lighthouse framework using Lighthouse V2 base stations can achieve millimeter-level localization accuracy. This capability would support complex indoor flight missions and coordinated swarm formations, further reinforcing the project's applicability across research, education, and entertainment [11,12].

Collectively, these research directions extend the project's potential as a scalable UAV interface model, offering innovations that bridge interactive learning, autonomous robotics, and advanced human–drone interaction.

V. FUTURE SCOPE

Future developments of the drone control system can address the identified research gaps while significantly broadening its application domains. Integrating wireless communication via Wi-Fi or Bluetooth Low Energy would eliminate physical tethering, enabling fully portable and outdoor-friendly deployment. Coupled with gamified training modules, the system could evolve into an interactive learning platform where users progress through mission-based challenges, earn performance scores, and develop advanced piloting skills in a structured manner. Expanding the control interface to manage multi-drone swarms offers additional potential, allowing a single operator to orchestrate coordinated drone formations for aerial mapping, search-and-rescue operations, or artistic displays [2,3,15,16,20].

The human–machine interaction experience can be further enhanced with gesture-based control and vibration haptic feedback, providing intuitive and immersive user engagement. Lightweight AI models could enable adaptive flight behaviors, including real-time obstacle avoidance, path correction, and dynamic flight time optimization based on environmental conditions and power consumption. Integrating mobile companion applications for telemetry visualization, flight statistics, and user progress tracking would create a more interactive and data-driven experience, promoting sustained engagement and training efficiency. Additionally, implementing Lighthouse V2 base stations or similar high-precision localization technologies would support millimeter-level positioning, enabling complex indoor maneuvers and precise swarm coordination [1,10,13,16,20,4,5,11,12].

Collectively, these future directions position the system as a scalable, versatile UAV interface model that bridges interactive learning, autonomous robotics, and advanced human–drone interaction. By addressing mobility, autonomy, and user engagement, the platform could serve applications ranging from educational training and research experimentation to entertainment, aerial choreography, and practical operational scenarios such as search, surveillance, or inspection tasks.

VI. CONCLUSION

The development of this single-handed joystick-based drone control system marks a significant step forward in making unmanned aerial vehicles more accessible, safer, and more engaging for users of varying experience levels. By combining compact hardware, carefully engineered firmware, and high-level software logic, this project successfully demonstrates how simplicity and safety can coexist within the complex domain of drone technology. The system's joystick controller reduces the learning curve associated with traditional dual-stick transmitters, while features like persistent EEPROM-based calibration and OLED feedback improve usability and transparency. The integration of advanced safety features, including a strict geofencing mechanism and an automated return-to-home function, significantly enhances the reliability and predictability of flight operations, making the platform safer for beginners and indoor use [4,6,9].

The project's gamified design philosophy, which includes graphical indicators and interactive feedback, redefines the drone as an engaging medium for learning and entertainment [3]. Ultimately, this system provides a practical solution to the long-standing problem of making UAV piloting less intimidating, opening the door to wider adoption in educational, recreational, and research contexts.

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