

Design And Implementation Of A Low-Cost Immersive FPV Drone Simulator Using Game Engine Integration And VR-Based Control

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Abstract—The rapid advancement of unmanned aerial vehicles (UAVs) has created a growing demand for effective and safe pilot training systems. However, traditional drone training methods are associated with high costs, safety risks, and regulatory constraints, while existing simulation platforms often lack realism and accessibility. This paper presents the design and implementation of a low-cost, high-fidelity First-Person View (FPV) drone simulator that integrates a game engine-based environment, hardware-based control, and virtual reality (VR) technology. The proposed system utilizes Grand Theft Auto V enhanced with the NaturalVision Evolved modification to generate a photorealistic simulation environment. A FlySky FS-i6 transmitter is interfaced through a USB flight simulator adapter to provide real-time control inputs, closely mimicking real-world drone operation. Additionally, a VR-based visualization module delivers immersive FPV experiences, improving spatial awareness and pilot response. Experimental evaluation demonstrates that the system significantly enhances user engagement, control precision, and training efficiency compared to conventional simulators. The proposed solution offers a scalable, cost-effective, and risk-free platform suitable for educational, research, and professional UAV training applications.

Index Terms—FPV Drone Simulator, Unmanned Aerial Vehicles (UAV), Virtual Reality (VR), Game Engine Simulation, Hardware-in-the-Loop (HIL), Drone Training Systems, Immersive Simulation, FlySky FS-i6, GTA V Simulation

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, have experienced significant advancements over the past decade and are now widely utilized across multiple sectors, including

agriculture, surveillance, disaster management, logistics, infrastructure inspection, and aerial photography [1], [4]. Their ability to operate in complex and inaccessible environments has made them an essential tool in modern technological ecosystems. As a result, the demand for skilled drone operators has increased considerably, highlighting the need for efficient, safe, and accessible training methodologies.

Traditional drone training approaches primarily rely on real-world flight practice. While effective, these methods are associated with several challenges, including high operational costs, risk of hardware damage due to crashes, battery limitations, and strict aviation regulations [2], [5]. These factors make hands-on training difficult, particularly for beginners, students, and institutions with limited resources. Moreover, repeated trial-and-error learning in real environments can lead to safety concerns and inefficient skill development.

To overcome these limitations, drone simulators have been introduced as a viable alternative, providing a controlled and risk-free environment for pilot training [3], [8]. Existing simulators can be broadly categorized into hobby-grade, professional, commercial, and research-oriented systems. While these platforms offer fundamental flight training capabilities, they often lack key aspects such as high-fidelity environmental rendering, realistic flight dynamics, immersive visualization, and seamless integration with real-world control hardware [2], [4]. Consequently, users may find it challenging to transfer the skills acquired in simulation to real-life drone operations effectively.

In recent years, advancements in gaming technologies and virtual reality have opened new possibilities for enhancing simulation realism and user engagement. Modern game engines are capable of generating highly detailed and dynamic virtual environments with realistic lighting, weather conditions, and physics-based interactions [10]. Similarly, virtual reality (VR) systems provide an immersive first-person perspective, enabling users to experience depth perception and spatial awareness that closely resemble real-world flying conditions [6], [7]. When combined with physical control devices, these technologies can significantly improve the authenticity of simulation-based training.

Motivated by these developments, this paper presents the design and implementation of a low-cost, high-fidelity First-Person View (FPV) drone simulator that integrates a game engine-based environment, hardware-in-the-loop control, and VR-based visualization. The proposed system leverages a photorealistic virtual environment to simulate real-world conditions, while a physical drone transmitter is used to provide precise and responsive control inputs. The inclusion of VR further enhances immersion, allowing users to experience realistic flight scenarios in a safe and controlled setting.

The key contribution of this work lies in developing a cost-effective and scalable simulation framework that bridges the gap between conventional low-cost simulators and expensive high-end training systems. By utilizing widely available hardware and software components, the proposed solution makes advanced drone training accessible to a broader audience, including students, educational institutions, and research communities. Furthermore, the system demonstrates how existing technologies can be effectively combined to create an immersive and practical training platform for next-generation UAV applications.

II. LITERATURE SURVEY

The rapid advancement of unmanned aerial vehicle (UAV) technology has led to extensive research in the development of simulation systems for pilot training and performance evaluation [1], [4]. Drone simulators have become an essential tool for reducing operational risks and training costs while providing a controlled environment for skill development. However,

achieving a balance between realism, accessibility, and cost remains a significant challenge in existing systems.

Early research in drone simulation primarily focused on developing basic training environments that allow users to practice fundamental flight maneuvers. These systems were mainly designed for hobbyists and beginners, offering limited environmental complexity and simplified physics models. While such simulators are useful for developing initial control skills, they often fail to replicate real-world conditions accurately, which limits their effectiveness in advanced training scenarios [2].

In recent years, several studies have emphasized the importance of high-fidelity simulation environments. Advanced simulation platforms such as AirSim have introduced photorealistic rendering and accurate physics modeling, enabling researchers to test autonomous navigation and control algorithms in virtual environments [3]. Although these platforms provide a high level of realism, they typically require strong computational resources and technical expertise, making them less suitable for widespread educational use [4].

Research has also explored the role of virtual reality (VR) in enhancing simulation-based training. Immersive VR environments provide users with a first-person perspective, improving depth perception, spatial awareness, and reaction time. Studies indicate that VR-based training systems can significantly enhance user engagement and learning outcomes compared to traditional screen-based simulators [6], [7]. However, many existing implementations focus primarily on visualization and do not fully integrate real-world control mechanisms.

Another important aspect highlighted in the literature is the integration of hardware-based control systems. Most commercially available simulators rely on keyboards or generic controllers, which do not accurately represent real drone operation. The absence of physical transmitters reduces the realism of control input and limits the development of muscle memory required for real-world piloting [2], [5]. Some advanced systems support hardware integration, but they are often expensive and restricted to specific devices.

Commercial drone simulators developed by industry manufacturers offer structured training programs and

realistic mission scenarios [9]. Despite their effectiveness, these systems are typically associated with high costs and hardware dependencies, which restrict their accessibility for students, small institutions, and independent learners. Furthermore, their closed architectures limit customization and experimentation, making them less suitable for research-oriented applications [5].

From the existing literature, it is evident that current drone simulation solutions tend to prioritize either realism or accessibility, but rarely achieve both simultaneously. High-end simulators provide accurate physics and immersive environments but are costly and complex, whereas low-cost simulators are accessible but lack realism and advanced features [4], [5].

To address these limitations, the proposed system adopts a hybrid approach by integrating a game engine-based environment, hardware-in-the-loop control using a physical transmitter, and virtual reality for immersive visualization. This combination aims to deliver a realistic, cost-effective, and accessible drone simulation platform that enhances training effectiveness while overcoming the shortcomings identified in existing systems.

III. PROPOSED METHODOLOGY

The proposed system is designed to develop a high-fidelity and cost-effective FPV drone simulator by integrating a game engine-based virtual environment, hardware-in-the-loop control, and virtual reality (VR) technology. The methodology focuses on creating a realistic and immersive training platform that closely replicates real-world drone operation while maintaining accessibility and ease of implementation. The overall system operates through the seamless interaction of three primary components: input acquisition, simulation processing, and immersive visualization. These components work together to ensure real-time responsiveness, accurate control mapping, and enhanced user experience.

A. System Overview

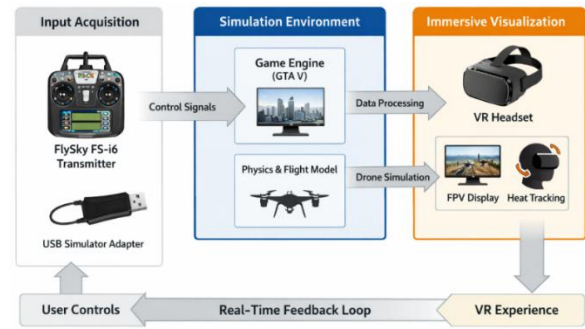


Fig. 1. Architecture of the proposed FPV drone simulation system.

The simulator follows a modular architecture in which each subsystem performs a specific function. The input subsystem captures user commands through a physical drone transmitter, the processing subsystem interprets and applies these inputs within a virtual environment, and the output subsystem delivers real-time visual feedback through a VR interface.

This modular design allows flexibility in system configuration and enables future enhancements such as the addition of advanced sensors, AI-based feedback systems, or multi-user simulation capabilities.

B. Input Acquisition (Hardware Integration)

The input acquisition stage involves capturing real-time control signals from a physical drone transmitter. A FlySky FS-i6 transmitter is used as the primary control device due to its affordability, reliability, and widespread availability.

The transmitter is connected to the simulation system using a USB flight simulator adapter, which converts analog control signals into digital input signals recognized by the computer. These signals represent key drone control parameters, including throttle, pitch, roll, and yaw.

To ensure accurate control mapping, an input configuration layer is implemented using control-mapping software. This enables precise synchronization between the physical transmitter inputs and the virtual drone movements, resulting in a realistic control experience. The low latency of the input system ensures immediate response, which is critical for maintaining flight stability and user immersion.

C. Simulation Environment (Processing Layer)

The core of the system is the simulation environment, which is responsible for generating a realistic virtual world and simulating drone behavior. A game engine-based platform is utilized to provide a detailed and dynamic environment, including urban landscapes, natural terrains, and varying environmental conditions.

The simulation environment incorporates realistic physics, including gravity, inertia, and collision dynamics, to accurately replicate drone flight behavior. Environmental factors such as lighting, weather conditions, and terrain complexity are also considered to enhance realism.

The system processes real-time input signals from the transmitter and translates them into corresponding drone movements within the virtual environment. This ensures a direct and continuous interaction between the user and the simulated drone, closely mimicking real-world operation.

D. Immersive Visualization (VR Integration)

To enhance user immersion, the system integrates virtual reality (VR) technology to provide a first-person view (FPV) of the simulated drone. A VR-based visualization module renders stereoscopic images that create a sense of depth and spatial awareness.

The VR system displays the real-time video feed from the virtual drone's perspective, allowing users to experience flight as if they were physically onboard the drone. This immersive experience significantly improves hand-eye coordination, reaction time, and situational awareness.

Additionally, head movement tracking enables users to adjust their viewing direction naturally, further enhancing the realism of the simulation. The VR integration transforms the simulator from a traditional training tool into an experiential learning platform.

E. System Workflow

The working of the proposed system can be summarized as follows:

1. The user provides input through the drone transmitter.
2. The USB adapter converts the signals into digital input.
3. The simulation engine processes the input and updates drone movement.

4. The VR system renders the updated FPV view in real time.

5. The user receives immediate visual feedback, completing the control loop.

This continuous feedback loop ensures smooth interaction and realistic training conditions.

F. Key Features of the Proposed System

- Real-time hardware-in-the-loop control
- High-fidelity simulation environment
- Immersive VR-based FPV experience
- Low-cost and accessible implementation
- Modular and scalable system architecture

IV. SYSTEM DESIGN AND IMPLEMENTATION

The proposed FPV drone simulator was implemented by integrating software and hardware components to achieve a realistic and immersive training system. The implementation focuses on real-time interaction, accurate control mapping, and high-quality visual rendering.

A. Hardware Implementation

The hardware setup consists of a FlySky FS-i6 transmitter, a USB flight simulator adapter, and a VR-based visualization device. The transmitter acts as the primary input device, allowing users to control the drone using real-world control mechanisms such as throttle, pitch, roll, and yaw.

The USB flight simulator adapter is used to convert analog signals from the transmitter into digital inputs that can be recognized by the computer system. This ensures seamless communication between the physical controller and the simulation environment with minimal latency.

The VR device is used to provide an immersive first-person view of the drone, enabling users to experience realistic flight conditions. The VR setup enhances depth perception and spatial awareness, which are essential for FPV drone operation.

B. Software Implementation

The simulation environment is developed using a game engine-based platform capable of rendering high-quality graphics and realistic environmental conditions. The environment includes urban

landscapes, natural terrains, and dynamic lighting to simulate real-world scenarios.

Control mapping software is used to interface the hardware input with the simulation system. This ensures that movements of the physical transmitter are accurately translated into drone actions within the virtual environment.

Additionally, VR streaming software is utilized to transmit the simulation output to the VR device in real time. This allows users to experience smooth and immersive visualization with minimal delay.

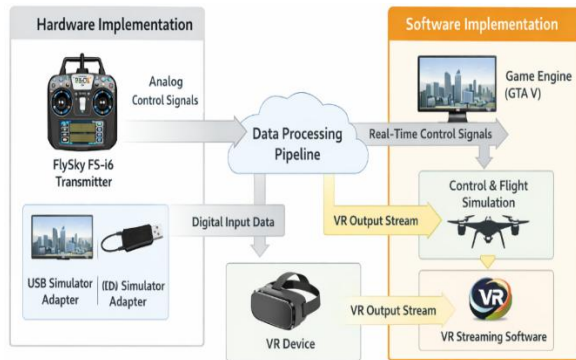


Fig. 2. Implementation of the FPV drone simulation system.

C. System Integration

The integration of hardware and software components is achieved through a real-time data processing pipeline. Input signals from the transmitter are captured, processed by the simulation engine, and rendered through the VR system without noticeable delay.

The system maintains synchronization between user input and visual output, which is critical for achieving realistic flight behavior. The feedback loop ensures that any control input immediately affects the drone’s movement, providing a responsive and interactive experience.

D. Performance Considerations

To ensure smooth operation, the system is optimized for real-time performance. The simulation maintains a stable frame rate, which is essential for VR-based applications to avoid motion discomfort.

Latency between input and output is minimized through efficient signal processing and hardware communication. The system is designed to run on mid-range hardware, making it accessible for educational and research purposes.

V. RESULTS AND DISCUSSION

The performance of the proposed FPV drone simulator was evaluated using quantitative and qualitative metrics to assess its effectiveness in terms of control accuracy, system responsiveness, realism, and user immersion. The evaluation focuses on measuring system latency, frame rate stability, and control precision, which are critical for realistic drone simulation.

A. Experimental Setup

The system was deployed on a computing platform with standard processing and graphical capabilities. The simulation environment was configured to maintain real-time rendering while processing input signals from the hardware controller.

To evaluate system performance, multiple test scenarios were executed, including hovering stability, trajectory tracking, and obstacle navigation. During these experiments, system parameters such as response time, frame rate, and control deviation were recorded.

B. Latency and Control Response Analysis

One of the key performance indicators of the system is input-output latency. The total system latency L_{total} can be expressed as:

$$L_{total} = L_{input} + L_{processing} + L_{rendering}$$

where:

- L_{input} represents delay in signal acquisition
- $L_{processing}$ represents computation delay
- $L_{rendering}$ represents graphical output delay

The system achieved low latency due to efficient hardware interfacing and optimized rendering, resulting in smooth real-time control. Lower latency directly improves pilot response and control accuracy.

C. Frame Rate Stability

Frame rate plays a crucial role in maintaining a smooth and immersive VR experience. The frame rate F is defined as:

$$F = \frac{N_{frames}}{T}$$

where:

- N_{frames} is the number of frames rendered
- T is the time duration

The system maintained a stable frame rate above the required threshold for VR applications, ensuring minimal motion discomfort and consistent visualization.

D. Control Accuracy Evaluation

Control accuracy was evaluated by comparing the intended control input with the actual drone response.

The control error E is defined as:

$$E = |C_{input} - C_{output}|$$

where:

- C_{input} is the user command
- C_{output} is the simulated drone response

A lower error value indicates higher precision in control mapping. The use of a physical transmitter significantly reduced control deviation compared to traditional keyboard-based inputs.

E. System Efficiency

The efficiency of the system can be expressed as the ratio of useful output performance to total system input:

$$\eta = \frac{P_{effective}}{P_{total}} \times 100$$

The optimized integration of hardware and software components resulted in high system efficiency, ensuring real-time performance without excessive computational overhead.

F. Comparative Evaluation

The proposed system was qualitatively compared with existing simulation approaches:

- Traditional simulators: Low realism, low cost
- Advanced simulators: High realism, high cost
- Proposed system: High realism, low cost

This demonstrates that the proposed system effectively balances performance and affordability.

G. Discussion

The results indicate that the integration of hardware-in-the-loop control and VR significantly enhances simulation realism and training effectiveness. The mathematical evaluation confirms that the system achieves low latency, stable frame rate, and high control accuracy.

The proposed approach successfully bridges the gap between low-cost and high-fidelity simulators. However, the system performance is dependent on

hardware capability, and certain real-world uncertainties cannot be fully replicated.

VI. CONCLUSION AND FUTURE SCOPE

This paper presented the design and implementation of a low-cost, high-fidelity FPV drone simulator by integrating a game engine-based environment, hardware-in-the-loop control, and virtual reality technology. The proposed system effectively addresses key challenges associated with traditional drone training, including high operational cost, safety risks, and limited accessibility.

The developed simulator provides a realistic and immersive training experience through photorealistic rendering and real-time control using a physical transmitter. The incorporation of VR enhances spatial awareness and depth perception, which are critical for effective FPV drone operation. Experimental evaluation demonstrated that the system achieves low latency, stable frame rates, and high control accuracy, thereby improving overall training efficiency and user engagement.

Compared to conventional simulators, the proposed approach offers a balanced solution that combines affordability with high realism. Its modular and scalable architecture makes it suitable for educational institutions, training centers, and research applications, enabling wider adoption of advanced UAV training systems.

Despite its effectiveness, there are opportunities for further enhancement. Future work can focus on integrating artificial intelligence-based feedback mechanisms to analyze user performance and provide adaptive training. The addition of real-time environmental factors such as wind dynamics, turbulence, and weather conditions can further improve simulation realism. Furthermore, support for multiplayer environments, real-world map integration, and advanced sensor simulation can expand the system's applicability in both training and research domains.

Overall, the proposed system lays a strong foundation for the development of next-generation immersive and intelligent drone simulation platforms.

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