# A Survey on Mixed Reality-Based Simulator for Drone Pilot Training

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**Abstract:** Unmanned Aerial Vehicles (UAVs), commonly known as drones, are increasingly used in applications such as agriculture, surveying, photography, and disaster management due to their efficiency and versatility. However, effective drone operation requires specialized training, which is often expensive, time-consuming, and associated with operational risks. Flight simulators provide a safe and cost-effective alternative by allowing pilots to practice in a controlled environment. The primary challenge is to develop an immersive simulator that accurately replicates real-world flight dynamics and provides realistic telemetry feedback. The proposed system addresses these challenges by creating a realistic virtual environment using Unity3D and Blender, while drone physics are modeled using RPM data from the ArduPilot flight planner. Multiple viewing modes, including first-person and third-person perspectives, enhance the training experience.

*Keywords: Augmented Reality, Virtual Reality, Mixed Reality, ArduPilot*

## 1 Introduction

This paper presents a Mixed Reality (MR) drone simulator developed to provide a safe, cost-effective, and engaging platform for drone pilot training. The rapid advancement of immersive technologies has transformed the way users interact with digital environments. Virtual Reality (VR) offers complete immersion in computer-generated worlds, while Augmented Reality (AR) overlays digital information onto the physical environment. However, AR often maintains a clear separation between real and virtual elements, which can limit user immersion. Mixed Reality addresses this limitation by seamlessly integrating virtual content with the real world, enabling meaningful interaction between physical and digital objects. Through dynamic visualization and real-time interaction, MR enhances user engagement while preserving awareness of the surrounding environment. Compared to conventional display systems, MR provides a higher level of immersion, improved spatial perception, and a more natural user experience. These advantages make MR a promising technology for realistic and effective drone training applications.

### 1.1 Objectives

**1. Virtual World Modelling**

- Develop a virtual environment replicating real-world scenarios.
- Implement realistic features and landscapes within the virtual space.

**2. Drone Physics Simulation**

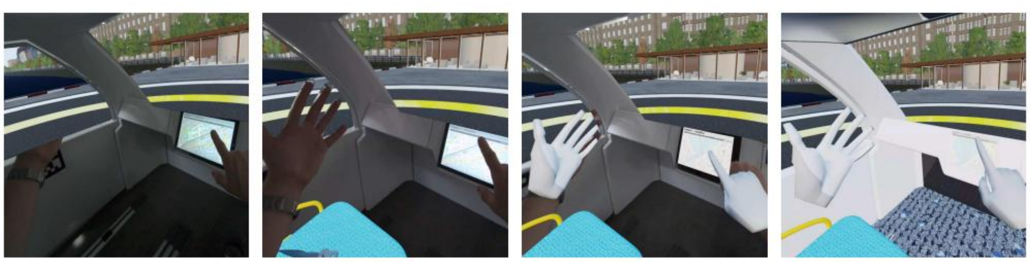
- Construct a comprehensive physics model for an accurate drone simulator.
- Ensure the simulation mirrors the behaviour of real-world drones.

3. Integration with ArduPilot
    - Establish seamless connectivity with ArduPilot for real-time interaction.
    - Enable the virtual drone to mimic the actions and responses of an actual drone.

4. Mixed Reality Implementation
    - Integrate mixed reality features to provide a visual transition between the real and virtual worlds.

## 2 Literature Review

Mixed Reality Training Systems in Aviation enables projector users, remote experts, and drone players to engage in shared virtual flying scenarios. Interestingly, bidirectional communication is made possible by the integration of Ultra-Wideband (UWB) sensors, which gives drone players control over virtual components. Potential uses in a range of sectors, such as entertainment, defence, and firefighting, are envisaged by the study. Subsequent investigations endeavour to appraise the system's usability via user evaluations, tackle detected challenges, and enhance the system according to professional advice [10]. Moving on to air taxi simulation [1] an extensive investigation conducted involved the construction of four different mixed reality environments. The level of immersion varied among these setups, and Varjo's marker tracking technology was essential in keeping the virtual cabin model and the real cabin mock-up in line. The evaluation considered variables like the total rating, user interface interaction, and a comparison of MR setups between virtual and actual cabin scenarios. Notably, compared to the real and mixed setups, participants thought the virtual cabin setup was more immersive. The study offers important insights into the effectiveness and user experience of various MR configurations for air taxi simulation. It made use of the Varjo XR 3 and a custom air taxi mock-up. It sheds light on the benefits and drawbacks of each configuration, especially regarding user interaction, immersion, and the realism of the flight simulation [1].



(a) RC (b) $MC_{RI}$ (c) $MC_{VI}$ (d) VC

Figure: The four different mixed reality setups presented on the HMD. In the RC setup (4a) most of the environment is real and only the out-the-window view is virtual. At the other end of the spectrum, the VC setup (4d) shows a fully virtual environment. MCRI (4b) and MCVI (4c) represent intermediate between these two extrema.[1]

The XR-OOM system was presented by [11] in the field of mixed reality driving simulation. It smoothly combines virtual and physical components to provide realistic driving simulations. A real car, a Varjo XR headset, and metrics on driving behaviour, presence, engagement, and overall satisfaction are all included in this immersive system, which analyses user performance. High levels of user engagement and satisfaction are demonstrated by the XR-OOM system, which also responds quickly to user actions. A performance evaluation of the system reveals robust sensor and XR components, excellent usability, minimal latency, high accuracy, and seamless integration with current tools. Evaluations based on particular situations show how different design approaches work to accomplish goals like increasing safety and decreasing driver distraction [11].With an emphasis on drone flight control, [12] suggested an interactive training system that pairs a remote trainer with a drone player in a dual-role interaction. Without the drone player present, the trainer—which has a head-mounted display (HMD)—conducts remote flight control training scenarios. Drone players can operate first-person-view (FPV) drone flight control in open areas with few obstacles by creating and adjusting training scenarios with ease using the Scenario Timeline & Attention Dock (STnAD) user interface. The drone player and trainer can communicate easily through voice thanks to Photon Unity Networking and Photon Voice. To further enhance mixed reality rendering during the drone player's experience, the system incorporates the ZED software development kit to provide relative drone coordinates, orientation, and 3D depth [12].Examining the possible advantages and disadvantages of extended reality (xR) technology in the context of flight training and aviation [13]. The study uses a Likert scale to measure participants' comfort level with virtual reality (VR) and the environment's applicability to flight training. It collects performance, cognitive load, and eye-tracking data in both virtual and real-world settings. Procedure task completion and altitude and airspeed control performance show notable improvements following 1.5 hours of Virtual Reality Learning Environment (VRLE) training. According to the findings, immersive virtual reality training could be a useful alternative to drone operator training for reskilling and forecasting human performance in real-world flying scenarios [13]. Finally, [8] adds to the conversation by evaluating flight deck training exercises for pilot procedures and skilled drone teleoperation using virtual reality goggles and 2D monitors. Time completion and accuracy are used in the study as performance metrics, and they are graded on a three-point system. In addition, usability and comfort metrics are considered, with mean values displayed next to the student's p-values. The findings show that when using the Head-Mounted Display (HMD) instead of the Desktop Monitor (DM), users were able to locate instruments on the Cessna dashboard more quickly, saving an average of 64% of the time. In addition, the HMD performed with more accuracy than the DM. The checklist took about the same amount of time to finish, but the DM was far more accurate [8].

The cockpit dashboard (Cessna 152) [8]

## 3 Proposed System

This proposed model provides a thorough explanation of the architecture of the system:

### 3.1 Architecture

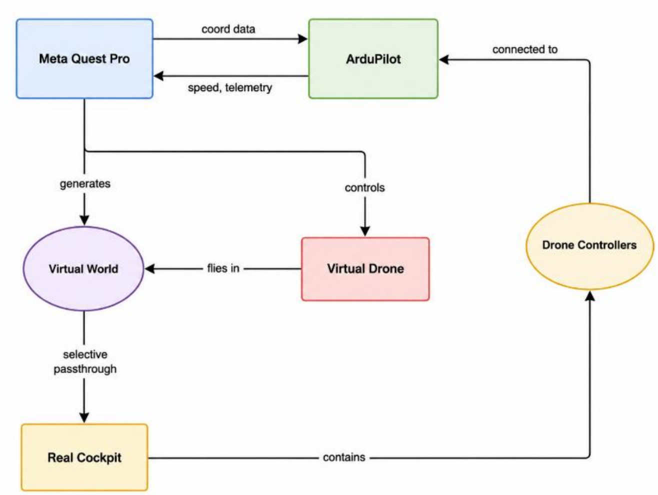



**Figure 3.1**: Architecture of the proposed system

The user is situated inside a fake cockpit that has a drone joystick controller, as shown in Figure 3.1. Through a USB connection, this controller is linked to the ArduPilot Software in the Loop (SITL) that is operating within the Mission Planner application. The RC channels of Mission Planner, which continuously gathers data from the joystick, are mapped to the joystick controls.The Meta Quest Pro headset's Unity program connects wirelessly via UDP to the ArduPilot SITL. This application allows users to fly a virtual drone in a virtual world. Additionally, the headset displays a real-world passthrough of the cockpit. The ArduPilot SITL sends a JSON object to the Unity application. The computed Pulse Width Modulation (PWM) values for each motor are contained in this item. The virtual drone can hover or move in a specific direction when the application applies these values to its four motors.The ArduPilot SITL receives another JSON object from the Unity application in exchange. The position, speed, acceleration, and other characteristics of the virtual drone in flight are all contained in this item. Continuous data interchange between the ArduPilot SITL and the Unity application enables real-time control and feedback of the virtual drone's flight.

## Conclusion

This study demonstrates the significant potential of Mixed Reality (MR) technology in transforming drone pilot training by providing an immersive, realistic, and cost-effective simulation environment. The proposed framework integrates Unity3D, Blender, and ArduPilot Software-in-the-Loop (SITL) to accurately simulate real-world drone dynamics, enabling trainees to gain practical flying experience in a safe and controlled setting. By combining a physical cockpit interface with virtual environments and real-time telemetry, the system overcomes many limitations of conventional VR-based simulators and enhances user engagement and learning outcomes. The progressive training scenarios and realistic flight physics contribute to improved pilot proficiency, confidence, and operational safety while minimizing the risks and costs associated with live drone training. Furthermore, the architecture supports multiple viewing perspectives and seamless interaction between physical and virtual components, making it suitable for academic, industrial, and professional training applications. Future enhancements may include AI-based adaptive learning, haptic feedback, multi-user collaborative training, and autonomous mission simulation to further improve training effectiveness. Overall, the proposed Mixed Reality-based drone simulator presents a promising and scalable solution for next-generation drone pilot training and skill development.

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