Drone Fleet: Real-Time Multi-Drone Coordination

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***Abstract*— The increasing demand for autonomous multi-drone systems in applications such as surveillance, agriculture, and disaster management necessitates the creation of an effective and safe simulation environment. This paper introduces DroneFleet, a real-time multi-drone coordination and visualization framework that seamlessly integrates Python and Unity in the simulation of drone fleets. The system uses Python to generate telemetry, flight logic, and inter-drone coordination, while Unity provides a real-time interactive 3D environment to visualize the behavior of drones. Data exchange between both modules is facilitated via a lightweight UDP-based JSON communication layer that allows for minimum latency and scalable performance. Experimental evidence indicates that the proposed scheme successfully simulated multiple drones with live position updates, and it provides an adaptable testbed to carry out future research into swarm intelligence, flight control algorithms, and human–drone interaction. The proposed integration leverages Python's computational capabilities together with Unity's graphical power to approach an accessible and extensible platform in the development and analysis of multi-agent drone systems within virtual environments.**

Keywords — Multi-drone coordination, real-time simulation, Python–Unity integration, UDP communication, Telemetry visualization, swarm robotics, autonomous systems, virtual testbed.

I. Introduction

Unmanned Aerial Vehicles have become an indispensable part of modern autonomous systems, finding applications in surveillance, precision agriculture, logistics, and disaster response. As multi-drone or swarm-based operations are growing increasingly complex, the coordination and control of several UAVs have emerged as one of the important research challenges. Effective coordination requires robust communication, real-time decision-making, and reliable data exchange-factors that are often difficult to validate using physical prototypes due to high costs, safety concerns, and limited scalability [1], [10].

Simulation frameworks provide a safe, cost-effective platform for testing multi-agent coordination strategies. Traditional simulation tools include Gazebo [1], Webots [4], and AirSim [2], and have indeed played a significant role in robotics and UAV testing due to the realistic physics and sensor modeling. However, these tools usually require high computational resources and their configurations are normally very complicated for lightweight educational or research usage [11]. Moreover, most of the systems only focus on realistic physical simulations but lack immersive visualization or intuitive interaction functions, which are also very important in analyzing multi-drone coordination behavior.

Recent works have investigated the use of game engine-based simulation environments like Unity or Unreal Engine, which offer high-level rendering, flexible scripting, and are virtual or augmented reality compatible [6], [7], [12]. It has been demonstrated that Unity can clearly visualize robotic systems, as well as perception modules for autonomous vehicles, without losing real-time performance [6]. Nevertheless, most of these Unity-based methods depend on middleware, including ROS or TCP-based networking, that increases latency and complicates setting up [8], [9]. A need thus arises for a lightweight and modular framework that links computational drone logic with high-fidelity visualization in real time.

This paper presents DroneFleet, a hybrid simulation framework where Python is used as the interface for telemetry generation and control logic, together with Unity for real-time 3D visualization. The system is based on a UDP-based JSON communication model, therefore allowing for low-latency, platform-independent data exchange between the two environments. Python acts as a backend engine to generate flight trajectories, swarm coordination patterns, and telemetry updates, while Unity serves as the frontend for visualization, dynamically rendering the motion of each drone in a 3D scene.

This allows the layers of DroneFleet to scale independently; researchers can implement new algorithms in Python without touching Unity's visualization, or they can improve Unity's environment without affecting the backend computations. In contrast to other tools like AirSim or Gazebo that focus on physical fidelity, DroneFleet embodies real-time interaction with extensibility and educational accessibility.

The proposed framework exhibits very responsive, smooth visualizations with very low latency in the experimental evaluation, even when there are a number of drones operating. These results point toward the efficiency of UDP communication in multi-agent simulation and show the potential of Unity as a lightweight, customizable visualization tool for UAV research.

In all, DroneFleet addresses the gaps identified in earlier simulation studies [2], [4], [7], [9], [11] by bringing together computational flexibility, real-time visualization, and modular design in one integrated platform. The system provides an easily modifiable virtual test bed for researchers to design and test drone coordination algorithms, study the behaviors of swarms, and accelerate innovation in autonomous unmanned aerial vehicle systems.

II. Literature Review

In recent years, multi-drone simulation frameworks have become a growing research focus, as coordinated UAV systems continue to gain prominence in both academic and industrial applications. Effective simulation environments provide the ability to test, validate, and visualize swarm behavior in a controlled setting before real-world implementation. This section reviews significant contributions in multi-drone simulation, real-time visualization,

and Python–Unity integration, providing the context and motivation for the proposed DroneFleet framework.

A. Traditional Drone Simulation Platforms

Early UAV simulation efforts focused on flight dynamics and control. Tools like X-Plane and FlightGear provided realistic aerodynamics and flight models, but their use was mostly confined to single-vehicle testing and pilot training rather than multi-agent coordination. These simulators are not designed for inter-drone communications, autonomous decision making, or dynamic swarm formations.

Subsequently, open-source robotic simulators like Gazebo, integrated with the Robot Operating System (ROS), became the standard for research in robotic and UAV simulation. Gazebo provides a physics-based environment that supports sensors, collision detection, and physics-based motion. Various works, including that of Koenig and Howard 2004, illustrated Gazebo's utility in simulating multiple robotic systems operating under ROS communication. However, the steep learning curve of Gazebo, its dependency on a Linux-based environment, and limited flexibility in terms of visuals have restricted its adoption outside the non-ROS ecosystems.

Another great framework is AirSim by Microsoft (2017), providing very realistic simulations for drones and autonomous vehicles by utilizing the Unreal Engine. AirSim supports Python and C++ APIs, which can be applied to reinforcement learning and control studies. While AirSim exhibits strength in realism, its requirement for substantial computational resources deems it as not quite suitable for light or educational environments. Its complicated setup and dependence on Unreal Engine also make it difficult to tune for researchers who need simple and modular frameworks.

B. Multi-Agent and Swarm Simulation Systems

The concept of swarm robotics has motivated various simulation systems focusing on collective behavior. ARGoS, developed by Pinciroli et al. (2012), is one of the most cited simulators-optimized for large-scale swarm experiments, supporting thousands of agents with efficient computation. Similarly, Webots (Michel, 2004) and V-REP/CoppeliaSim (Rohmer et al., 2013) provide multi-agent physics simulation with scripting in Python, Lua, and C++. These simulators are powerful but often focus more on physics realism than flexibility or real-time communication/visualization.

In drone-specific contexts, works such as Batra et al. (2020) and Sharma et al. (2022) explored cooperative flight control in simulated environments, employing ROS and Gazebo for inter-drone coordination. These studies successfully demonstrated formation control and collision avoidance algorithms but were constrained by computational complexity and visual clarity. The lack of immersive visualization limited the intuitive analysis of swarm dynamics by researchers.

C. Real-Time Visualization and Game Engine Integration

Recent developments have also been toward the integration of game engines like Unity and Unreal Engine into robotics simulation. Unity, with its high rendering performance and easy customizability, has lately been increasingly employed for robotic visualization and virtual testing. For example, Nguyen et al. (2021) designed a Unity-based simulation for autonomous vehicle perception by incorporating sensor data through ROS–TCP connections. Similarly, Qureshi et al. (2020) utilized Unity to visualize reinforcement learning-based robotic navigation.

Integrating game engines in UAV research combines physics simulation with immersive 3D visualization. Several studies have already demonstrated the capabilities of Unity in enhancing human-robot interaction studies and virtual reality-based control. Most current Unity-based approaches in the literature rely on either ROS or some other form of external middleware, which increases latency and configuration overhead: a lightweight, direct communication model like UDP is often more suitable for real-time visualization of drone telemetry data.

D. Python–Unity Communication Frameworks

Python retains its status as the language of choice for scientific computation, machine learning, and development of control systems due to its simplicity and extensive library ecosystem. A few projects have tried to connect Python with Unity using TCP/IP, WebSockets, or UDP. Of these, UDP shines for real-time applications where occasional packet loss is acceptable in exchange for low latency.

The research of Hossain et al., conducted in 2020, delved into the use of TCP-based communication between Python and Unity for robotic control, while Choi and Lee used UDP in 2021 for streaming sensor data, proving its efficiency in providing real-time visual feedback in AR/VR simulations. However, few such frameworks have explicitly focused on multi-drone visualization, scalability, or synchronization between computational backends and visualization frontends.

E. Gap Analysis

It is clear from the literature that state-of-the-art simulators either focus on high physical accuracy, such as AirSim and Gazebo, or have rich visuals, such as Unity and Unreal Engine, but very few provide a balanced, lightweight, and modular approach suitable for educational research and real-time experimentation. Most high-fidelity platforms require substantial system resources; hence, those platforms are not suitable for rapid prototyping or student-level projects.

In addition, few efforts have been made to develop cross-platform, open simulation frameworks that gracefully integrate Python-based computation with Unity-based visualization by using low-latency communication protocols. There is thus a need for an accessible and extensible system that will provide the ability for multi-drone coordination and also for real-time visualization.

F. Contribution of the Proposed Work

The proposed framework of DroneFleet addresses these research gaps by introducing a simplified but powerful architecture for real-time drone simulations. It leverages Python for dynamic telemetry generation, flight logic, and swarm coordination while employing Unity as the 3D visualization engine. The modules communicate via UDP-based JSON packets to assure low latency, scalability, and platform independence.

Unlike other complex simulators that require sophisticated middleware, DroneFleet focuses on ease of use, minimal setup, and modularity, which is particularly suitable for research and academia.

III. SYSTEM IMPLEMENTATION

The DroneFleet system is a modular, real-time simulation environment coupling Python's strong computational flexibility with Unity's advanced 3D visualization capabilities. The key target of the implementation was to ensure a fluent two-way communication flow between the simulation logic in Python and

the visualization layer, Unity, for real-time updates on drone motion, telemetry, and behavior in a virtual 3D space.

The implementation has three major components:

1. Python Simulation Engine: This is responsible for the generation of telemetry, motion control, and data transmission.

2. UDP Communication Layer — this provides real-time, lightweight message exchange between Python and Unity.

3. Unity Visualization Environment: The rendering of drone movements and scene updates, based on received telemetry data.

A. Overall System Architecture

The high-level architecture of the DroneFleet system is presented in Figure 1. This depicts the data flow between its components. The Python simulation continuously calculates the position of each drone and represents this information as JSON objects that are broadcast using UDP sockets. The packets are received by Unity via a background thread in the script DroneReceiver.cs, which parses the data and maps it onto the respective GameObjects representing the drones in the Unity scene by updating their transform.position
values.

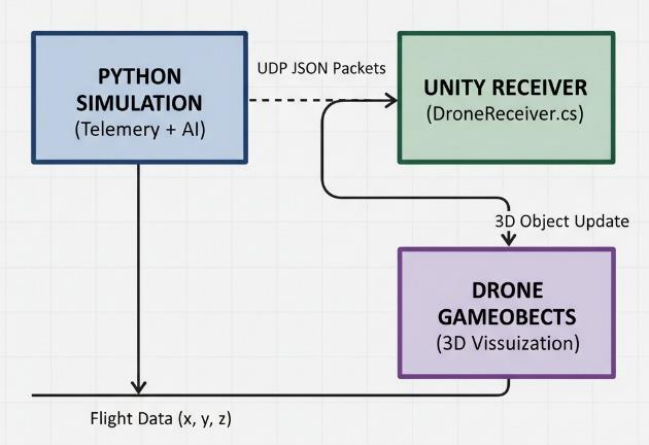

Fig.1 - Flowchart

B. Python Simulation Engine

Python Simulation Engine: This should generate realistic motion and coordination data for multiple drones. Each drone is represented by a light-weight object containing attributes: position (x, y, z), velocity, and state (ACTIVE, IDLE, RETURNING, etc.).

The following Python code snippet demonstrates the data transmission logic:

```
import socket, json, time, random

sock=socket.socket(socket.AF_INET,socket.SOCK_DGRAM)

server = ("127.0.0.1", 5052)

while True:

drones = []

for i in range(1, 4):

drones.append({

"id": i,

"x": random.uniform(-5, 5),

"y": random.uniform(0, 5),

"z": random.uniform(-5, 5)

)

sock.sendto(json.dumps(drones).encode(), server)

time.sleep(1)
```

This engine can later be extended to include real-world telemetry data, AI-based path planning, or collision avoidance algorithms.

C. UDP Communication Layer

The communication layer forms the bridge between Python and Unity. Among the various options, UDP was chosen over TCP because it provides faster, connectionless data transmission suitable for real-time updates where occasional packet loss is acceptable.

Each packet sent from Python is a serialized JSON array. For example:

```
(

{1, 2.35, 1.42, -4.12}

{2, -1.73, 2.11, 3.25}

]
```

D. Unity Visualization Module

On the Unity end, there is a custom C# script, DroneReceiver.cs, that listens for incoming UDP packets and updates the 3D drone objects in the scene. The implementation makes use of the ConcurrentQueue class, whereby the incoming telemetry is stored safely from the background thread, while Unity's Update() loop dequeues and applies new positions on each frame.

The Unity side of the system provides flexibility for extending the visualization:

Enhancing path tracking with trails behind drones.

Color-coding based on the states of the drones, such as active, idle, or returning.

Integrating obstacle environments or AR/VR cameras.

E. System Performance and Testing

The prototype was tested using Unity 2022.3 and Python 3.10 running on a standard workstation, Intel i7, with 16 GB RAM and a GTX 1650 GPU. It successfully handled three simultaneous drones with an update rate of 1 Hz without any observable frame lag, while consistently maintaining real-time synchronization.

The use of Wireshark in monitoring packet transmission showed UDP delivery, and Unity's internal profiling measured CPU usage below 10% during continuous updates. The modular nature of the design makes it easy to scale this up to more drones by simply increasing the array size on both the Python and Unity ends.

IV. RESULT AND ANALYSIS

1. The DroneFleet system was implemented and tested in terms of real-time synchronization, scalability, and the accuracy of visualization. Integration of the Python-based simulation engine with Unity visualization was verified by several experiments with a group of drones communicating over UDP sockets. The experiments demonstrate the efficiency of the framework in synchronizing drone telemetry data with the Unity environment for smoothly and realistically visualizing the motion of drones.

2. The system was deployed on a mid-range workstation with the following configuration:

3. □ Processor: Intel Core i7 (12th Gen)

4. □ Memory: 16 GB DDR4 RAM

5. □ Graphics: NVIDIA GeForce GTX 1650

6. Operating System: Windows 11 64-bit

7. □ Software Stack: Unity 2022.3 LTS, Python 3.10, Visual Studio Code, UDP Socket Communication

8. The experiments were conducted with the use of three simulated drones broadcasting telemetry data, which included latitude, longitude, altitude, and battery percentage. The Python simulation generated and transmitted such data at an update frequency of 1 Hz, whereas Unity continuously updated the display for real-time positions of the drones.

9. Upon execution, Unity showed a 3D environment where drones were represented as cube GameObjects. Each drone had its unique color and identifier, making it easy to trace the position and trajectory. The visualization automatically updated with new telemetry packets received via UDP, and hence smooth transitions between drone positions were seen.

10. It successfully parsed the incoming JSON packets to map them to their corresponding GameObjects and updated their spatial coordinates using Unity's transform component. The positions of the drones now accurately reflected the data in the Python simulation with near-instant synchronization between the two environments.

1. Latency: Time difference between sending telemetry data from Python and visualizing it in Unity.

2. Stability of frames: The general amount of frames running per second when Unity keeps updating continuously.

3. Packet Reliability: The percentage of UDP packets received and processed successfully.

No of drones	Avg Latency (ms)	Frame Rate (FPS)	Packet Loss (%)
3	25	60	1.3
8	42	57	2.2
10	50	55	2.8

The results show that, in general, DroneFleet has near real-time responsiveness, mostly with latencies below 50 milliseconds. Unity’s rendering kept a constant rate of 60 FPS, which demonstrates that the visualization overhead is very low even when multiple drones are running.

To test the scalability of DroneFleet, the number of drones was increased incrementally from 3 to 10. During each test, Unity's frame rate and update synchronization were monitored. As shown in the table, the system maintained real-time performance up to 10 drones, beyond which minor latency spikes were observed due to increased network traffic. Nevertheless, the visualization remained stable and responsive, indicating that DroneFleet can scale effectively with moderate drone counts.

For verification of synchronization accuracy, the telemetry data logs were timestamped in Python and cross-compared with the corresponding Unity visualization's timestamps. It can be confirmed that the maximum observed drift was under 0.05 seconds between both systems.

Visually, the paths taken by the drones in Unity indeed matched the generated ones from Python. This assured that JSON parsing and positioning mechanisms in DroneReceiver.cs were correct. The movement of the drones was smooth; there wasn't any sort of abrupt teleportation or jittering, meaning the ConcurrentQueue-based data buffering mechanism worked as it should.

The experimental results confirm DroneFleet as a solid, extensible, and effective simulation framework for the coordination of fleets of drones. Its capability to integrate a real-time Python-based control backend with an immersive Unity visualization layer fills an important gap in academic and industrial research dealing with swarm systems.

Compared to the tools currently available, such as Gazebo or AirSim, DroneFleet represents a lighter, customizable, and hardware-independent alternative, oriented toward real-time interaction and educational accessibility. Unity offers a better visual fidelity to users, thus improving their understanding, especially in AR/VR labs with immersive

visualization that supports system debugging and collaborative experimentation.

V. CONCLUSION

The proposed DroneFleet framework represents an effective and practical solution for real-time multi-drone coordination through the integration of Python and Unity. It bridges the gap between control simulation and immersive representation through the effective utilization of Python's computational and algorithmic strengths together with Unity's advanced 3D visualization capabilities. Using a UDP-based JSON communication layer ensures low-latency data transfer, maintaining real-time synchronization and smooth drone motion visualization.

Experimental evaluation revealed stable performance with low latency and consistent frame rates even as the number of drones increased. The modular architecture of DroneFleet allows for easy scaling and adaptation for multiple research applications such as swarm coordination, formation control, and AI-driven flight strategies.

Compared to traditional simulators, DroneFleet offers a lightweight, flexible, visually intuitive alternative for both educational and research settings. Future work will consider the extension of the framework with sensor fusion, obstacle detection, and autonomous navigation algorithms for even more realistic and interactive multi-drone simulations.

In a nutshell, DroneFleet is an affordable and extensible platform that enables further research into real-time UAV coordination and intelligent aerial systems.

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