Drone Flight Simulation and Optical Flow Computation

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Abstract

This study explores the application of optical flow algorithms to estimate UAV velocity in a simulated environment, aiming to address the limitations of GPS and inertial navigation systems. With the extensive use of UAVs in commercial and military fields, accurate velocity estimation is crucial for tasks such as obstacle avoidance, navigation, and precise landing. This research employs the ROS system and Gazebo to simulate various flight scenarios, integrating the PX4 autopilot system to ensure accurate control and stable flight of the UAV, thereby analyzing the performance of the DIS optical flow algorithm. The algorithm used in this study estimates velocity through downward-facing RGB camera images, balancing computational efficiency and accuracy, making it particularly suitable for real-time applications in dense motion environments.

System Design

In the terminal, launch PX4 and the Gazebo simulator, loading a UAV model equipped with a camera and optical flow module. Start ROS nodes to control the UAV, subscribe to topics to obtain UAV status, RGB camera images, and optical flow data, and publish target position and velocity commands to achieve control.

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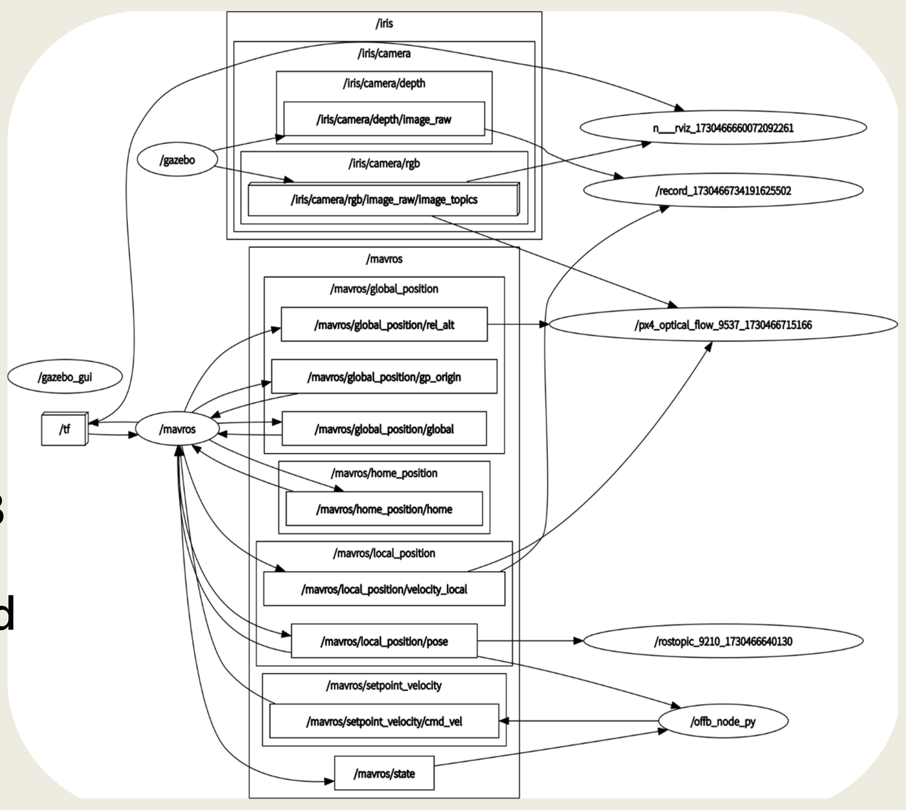
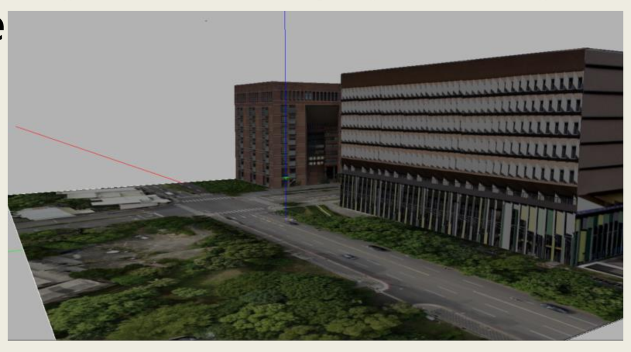


System Implementation

1. Modeling:

A .world file written in SDF (Simulation Description Format) language is used. This code primarily sets up the configuration of the simulation scene and various constraints of the physics engine, including using ODE (Open Dynamics Engine) as the physics engine and setting the simulation update rate To 250 for smoother simulation. Additionally, it creates the scene Environment in the Gazebo simulator , aiming to make the simulated world As realistic as possible.



2. Algorithm:

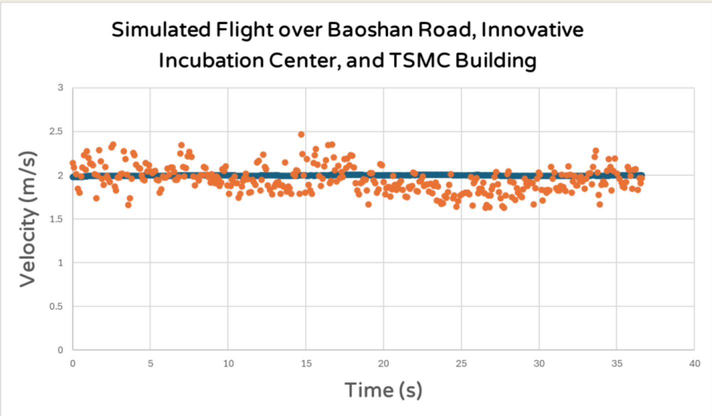
To reduce computational load and ensure the accuracy of optical flow calculations, each frame of the color image is converted to grayscale. This approach focuses on luminance changes, making it suitable for the DIS algorithm's dense pixel matching.We subscribe to the RGB camera data published by the system and convert each frame to grayscale. Each frame is then compared with the previous one to calculate the optical flow between them, generating a motion vector for each pixel.To make it easier to observe the magnitude and direction of the optical flow during testing, we visualize the optical flow on a grid, ensuring that the algorithm is functioning correctly.We compute the average optical flow magnitude for each frame and, referencing the algorithm proposed by Yu Gong and Xiaohong Liu in the literature, multiply the optical flow magnitude by the altitude and divide by a specific parameter to obtain the velocity calculated from the optical flow magnitude.

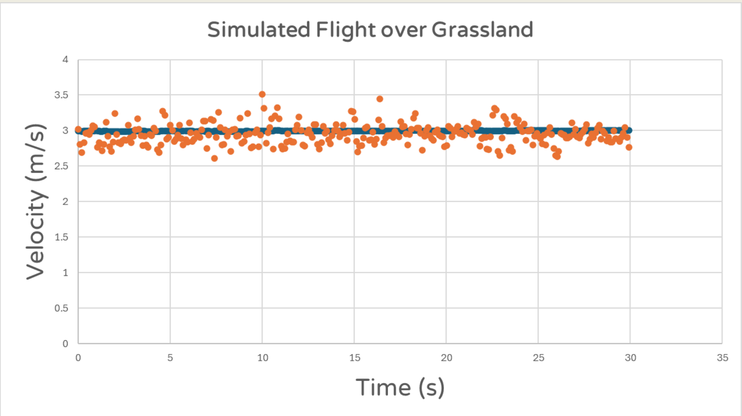
Additionally, we subscribe to the UAV’ s actual flight speed in the simulated environment and compare it with the speed calculated from the optical flow magnitude. The speed computed from the optical flow and the UAV's flight speed in the simulated environment are recorded in real-time in a .txt file, which is later analyzed in Excel.

Experimental Result

Comparison of Optical Flow Computed Velocity with Actual Velocity in Simulated Flight over Baoshan Road, Innovative Incubation Center, and TSMC Building
Flight Altitude: 50.15 meters
Actual Velocity: 1.997 m/s;
Optical Flow Computed Velocity: 1.950 m/s
Error: 2.53%

Simulated Flight over Grassland
Flight Altitude: 50.04 meters
Actual Velocity: 2.995 m/s
Optical Flow Computed Velocity: 2.947 m/s
Error: 1.60%





Results Analysis

1. Due to the presence of buildings up to 36 meters high in the Baoshan Road, Innovation Incubation Center, and TSMC building scenarios, the altitude used by the algorithm does not match the actual height in some parts of the scene. This discrepancy affects speed calculations, so we applied different parameters across these scenarios to address the issue effectively.
2. In this study, we found that the optical flow algorithm may exhibit larger calculation deviations when dealing with environments with significant altitude changes or complex scenes. These errors primarily stem from the effect of camera angle changes on optical flow calculations. The speed calculated from the optical flow data shows oscillations, with individual data points having errors of up to 10-20%. This fluctuation is due to the stop-and-go motion of the UAV when controlled by a PID controller. Additionally, the algorithm can mistakenly match similar points between frames, resulting in inaccuracies.
3. The algorithm used in this study is highly accurate at calculating the UAV's average speed over a given period when the UAV is flying at a constant speed, keeping the error within 2-3%.

Result

In this project, we successfully simulated UAV flights in different scenarios using the ROS system and Gazebo and estimated the UAV's flight speed with the DIS optical flow algorithm. Experimental results showed that the speed calculated by optical flow maintained an error within 2-3% compared to the actual speed in the simulated environment, demonstrating that the DIS algorithm can effectively and accurately estimate speed under specific altitude and stable flight conditions.