MEng Final Year Project Thesis

Topic – Optical Flow Guided Soft-Grasping Aerial Robot

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Keywords – Constant Optical Flow Divergence; Soft Landing; Feedback Control

Summary –

Designed and developed an autonomous aerial robot for collecting surface debris from water bodies. The system used optical flow divergence for altitude control and smooth landings over water. A soft grasper mechanism was integrated and triggered based on time-to-contact information derived from optical flow. The entire drone system was built from the ground up for this specific environmental application.

Figure 18: Hexsoon-650 drone platform customised to house onboard electronics and mechanically actuated soft grasper. Designed and built in-house.

On-board System Details -

Onboard computer: Jetson Nano, Flight Controller: Pixhawk 4 (PX4). Arduino-ROS bridge to interface Teensy 4.0 microcontroller with the optical flow sensors. The Teensy was programmed via the Arduino IDE to extract pixel motion data and compute optical flow divergence in real time. ROS and MAVROS communication links were established using Python and C++ to enable communication between the onboard components.

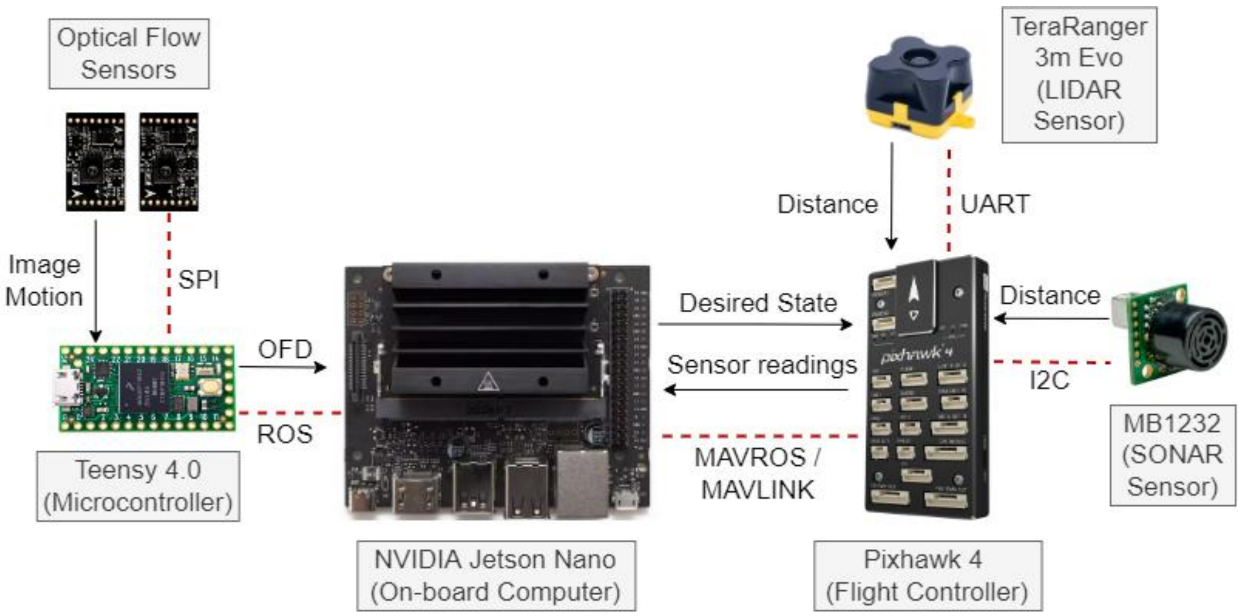
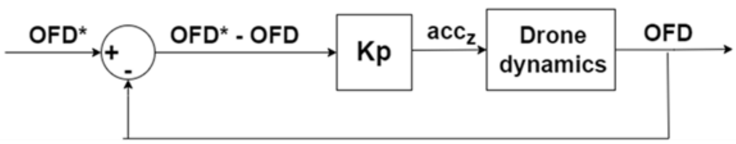


Figure 19: Systems flowchart to show the connections between the different onboard devices. Dashed lines represent the communication protocol. Optical flow used for altitude control. OFD is Optical Flow Divergence. SONAR and LIDAR sensors used for comparison purposes.

Optical Flow Implementation for Altitude Control -

A feedback controller tracks a desired OFD value (OFD*) and adjusts vertical acceleration based on the error between OFD* and the real-time OFD measured by the drone's downward-facing camera. A time-varying gain (k_p), decaying exponentially over time, modulates the controller's responsiveness during descent. This design allows the drone to interpret the onset of optical flow instability as an indicator of ground proximity, enabling it to reduce thrust and land safely without external range sensors. The system was tested indoors over ground and water surfaces, with a Vicon motion capture system used for ground truth and safety validation.



$$\mathbf{acc_z} = \mathbf{k_p}\,(\mathbf{OFD^*} - \mathbf{OFD})$$

$$\mathbf{k_p} = \mathbf{k_{p0}}\ \mathbf{e}^{\mathbf{OFD^*}\,\mathbf{t}}$$

$$k_{p0} = 0.6, \quad OFD^* = -0.3$$

Figure 20: Constant optical flow divergence (COFD) strategy - control loop to turn down the gain until the drone knows that it low enough to land by cutting the thrust.

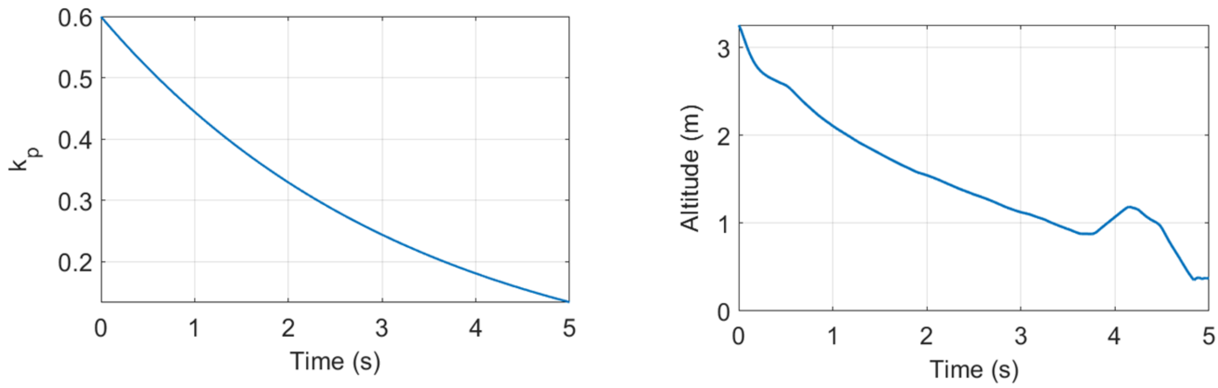


Figure 21: For a given Kp (gain), Onset of instability gives information to the drone about its altitude. Different gain values correspond to oscillations at different altitudes. This information is used to "know" the height during the entire descent.

Grasper Mechanism and Iris Integration –

The grasper used a helical tendon to achieve vertical contraction and radial closure, driven by a motor. A mechanical iris acted as the grasping mouth, enabling smooth, symmetric closure for collecting debris. Expansion occurred passively using gravity, while recoiling was motor-controlled. The grasper was triggered during descent using optical flow-based time-to-contact cues.

Figure 22: 3D printed and assembled mechanical iris for grasping.

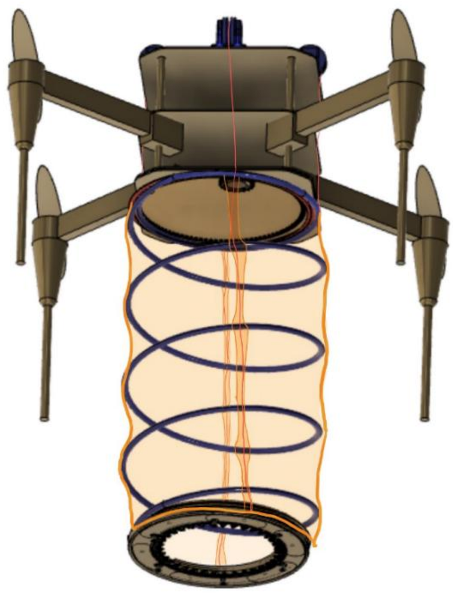


Figure 23: Perspective view of assembled mechanical iris and grasper with drone.