Micro-Aerial Vehicle (MAV) for Autonomous Damage Detection

Project Overview

As part of a university research group, I co-developed a semi-autonomous drone system for post-earthquake structural inspection. This included the design and integration of a custom sensor module, featuring a 1D LiDAR and ultrasonic sensors on an ESP32-powered PCB laid on a Parro Anafi to enable precise obstacle avoidance and column standoff distance measurement.

The system automates damage assessment by using computer vision to detect columns, executing an autonomous circular flight path for multi-view image capture, and fusing the results with a worst-case analysis to identify concrete spalling and exposed rebar. This provides more comprehensive structural analysis than single-viewpoint methods. The project successfully combined hardware design, sensor integration, and robotics to create a novel pipeline for rapid, reliable structural inspection.

In addition to contributing to the development of the MAV, its guidance system, and perusing future avenues of the project, I enhanced my technical writing skills by contributing to a conference paper highlighting this work as the 4^{th} author. I preseented results in a clear, succint way, and included areas of futher development and improvement for the project.

Skill Development

Hardware integration, sensor fusion, and PCB design for autonomous systems. Developed GNC algorithms for an MAV. Validated computer vision models for damage detection, and led 3D photogrammetry for structural damage quantification and FEA.

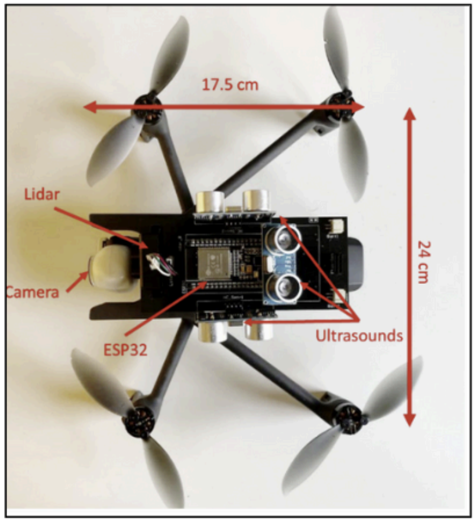


Image of custom PCB upon Parrot Anafi

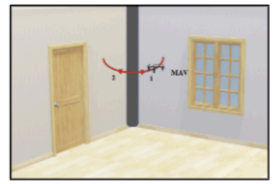
Autonomy & Guidance

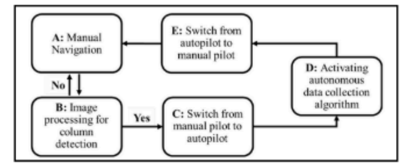
Part of my work focused on the synthesis of perception, guidance, and control to enable robust autonomous inspection in GPS-denied environments.

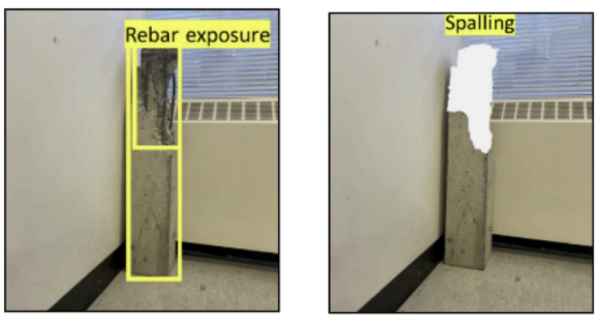
State Machine Architecture: Engineered the high-level autonomy state machine, governing the transition from manual teleoperation to autopilot mode upon positive identification of a structural column via real-time video stream processing.

Reactive Obstacle Avoidance: Implemented a reactive navigation layer using a potential fields-inspired algorithm. This layer interpreted real-time point cloud data from the 1D LiDAR and ultrasonic sensors to generate repulsive vectors, enabling real-time collision avoidance and path replanning during the orbital maneuver.

Guidance, Navigation, and Control (GNC): Developed the guidance logic for the orbital inspection path, calculating desired velocity vectors. Implemented a Proportional-Integral-Derivative (PID) controller to regulate the MAV's yaw rate and lateral velocity, using LiDAR rangefinder feedback as the primary control input for maintaining a constant standoff distance from the target surface.







Rebar and spalling captured and labeled by the MAV

All work outlined in this document makes reference to the following paper:
Tavasoli, S., Pan, X., Yang, T. Y., Gazi, S., & Azimi, M. (2023, June). Autonomous damage assessment of structural columns using low-cost micro aerial vehicles and multi-view computer vision. Canadian-Pacific Conference on Earthquake Engineering, Vancouver, BC, Canada. Paper ID 129.

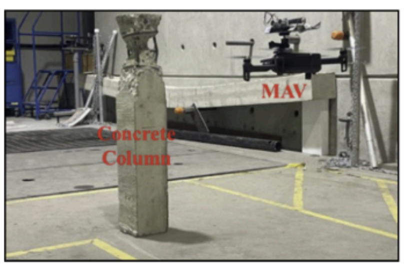
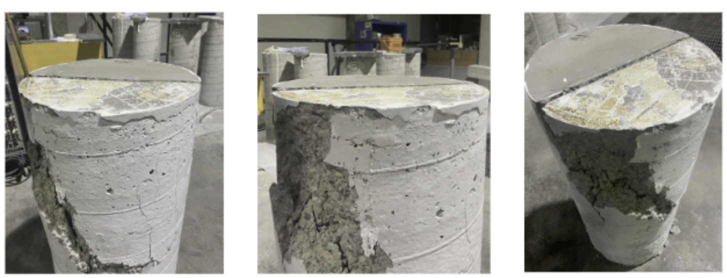


Image of MAV and column interaction



Lab samples of daamage, scanned for model validation

Key Contributions: Validation & Analysis

A. Comprehensive Model Validation & Dataset Curation

I led the data acquisition and validation pipeline critical for the AI's real-world performance.

Multi-Source Data Collection: Curated a extensive image dataset from multiple sources, including my own high-resolution scans of damaged columns in our structural lab and contributions from other research groups' material testing projects, ensuring a diverse set of damage examples. Approximately 200 photos and 5-8 videos were taken of each sample.

Empirical Performance Testing: Meticulously labeled this dataset to match expectations of the detection done by the pre-trained deep learning models (YOLOv2, DeepLabv3+). I quantified its accuracy on our specific use case using standard computer vision metrics (mean Average Precision, Intersection over Union) to compare its detection with my labels.

B. Leading 3D Reconstruction for Quantitative Analysis

Initiated the project's next phase by developing a pipeline to transform multi-view imagery into quantifiable 3D models.

2D Images → 3D Models: Processed the MAV-captured image sets as well as my own scans using photogrammetry (Structure-from-Motion/Multi-View Stereo techniques) to generate 3D point clouds and mesh models of structural components using computers at the university.

Integration with Engineering Analysis: Utilized these 3D reconstructions (exported into CAD files) for advanced structural assessment. I imported models into SOLIDWORKS Simulation (FEA) to perform preliminary analysis, assessing the impact of material loss (spalling) on stress concentrations and structural integrity.