2021 - Crosscutting Research and Advanced Energy Systems Project Review Meeting

Autonomous Aerial Power Plant Inspection in GPS-denied Environments

The University of Texas at El Paso
Aerospace Center (cSETR)

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May 18, 2021

NATIONAL ENERGY TECHNOLOGY LABORATORY

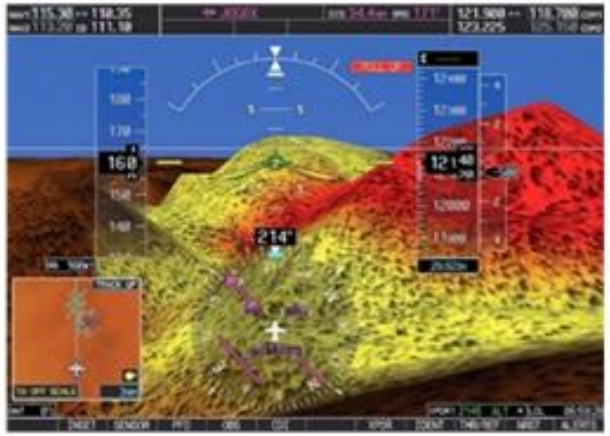
Outline

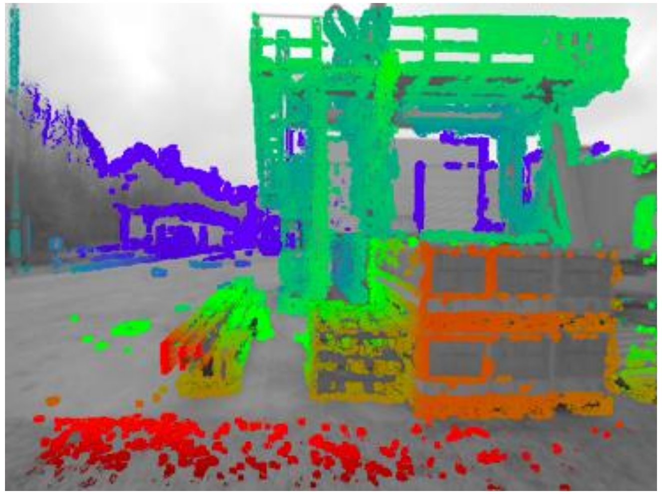
- Project Description
- Autonomous Drone Platform Updates
- Flight Path Generator
- Autonomous Navigation in GPS-denied environments
- Inspection Payload
- System Interface

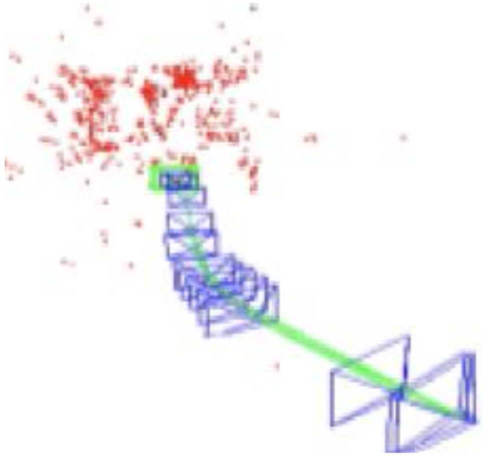
Project Description

Global planning layer: inspired by synthetic vision. Here a 3D CAD model will act as the synthetic vision system

Local-reacting layer: consists of stereoscopic vision sensors that cover all three axis of the vehicle.







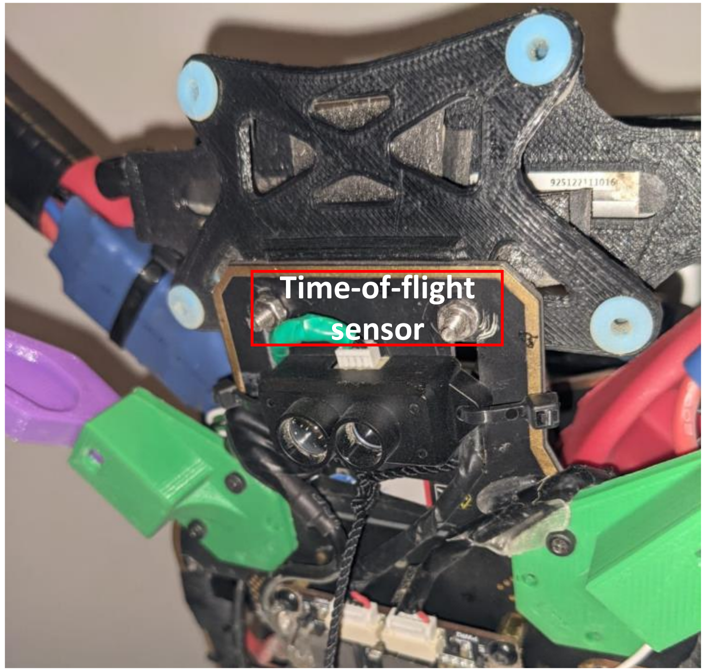
Technology Status and Bench marketing

Features:

- Autonomous
- GPS-denied areas
- Close range within 1 ft.
- Can Inspect inside-outside
- Dusty and ashy environments

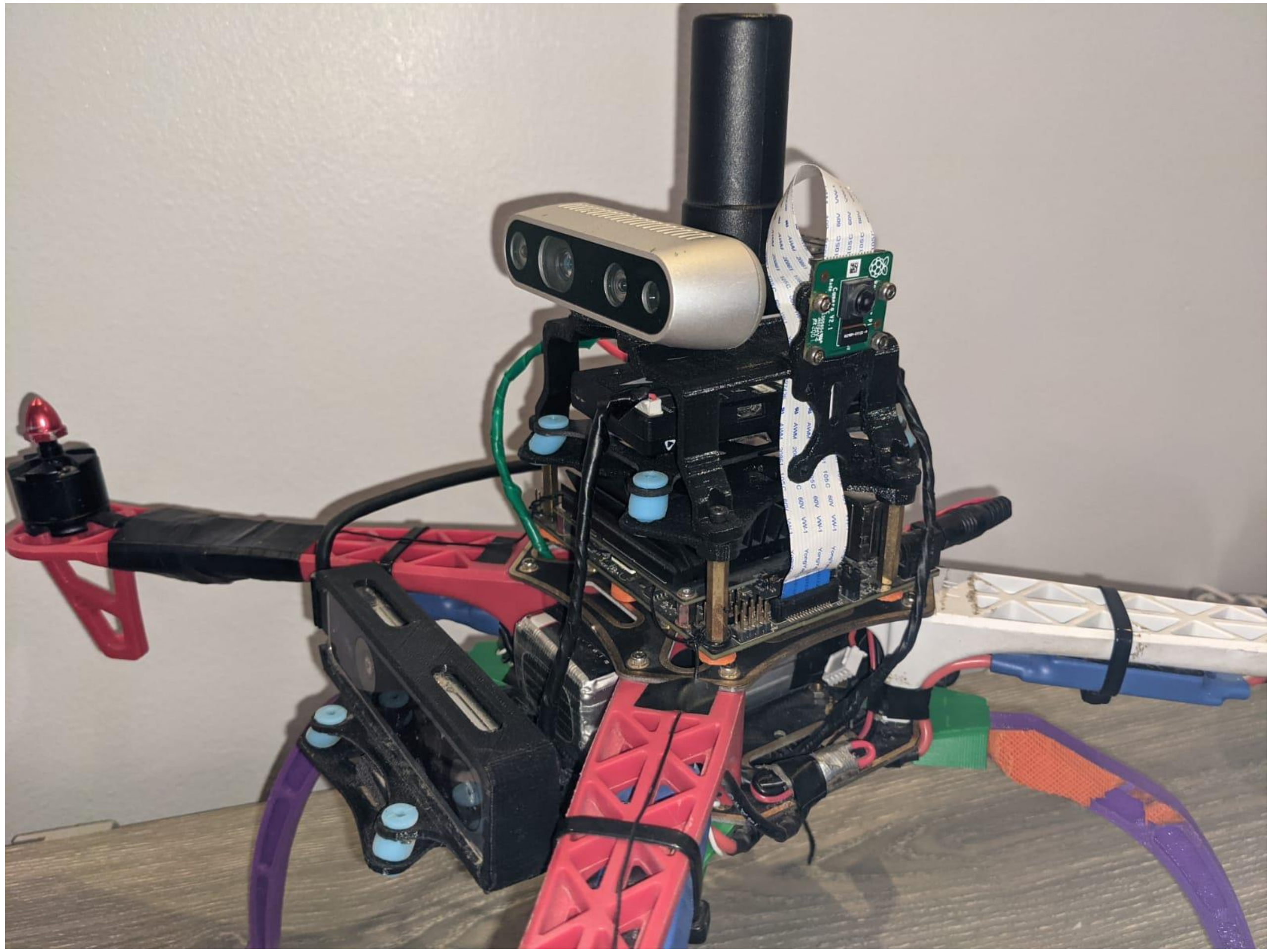
Intel® Falcon™ 8+ Drone

Autonomous Drone Platform Updates

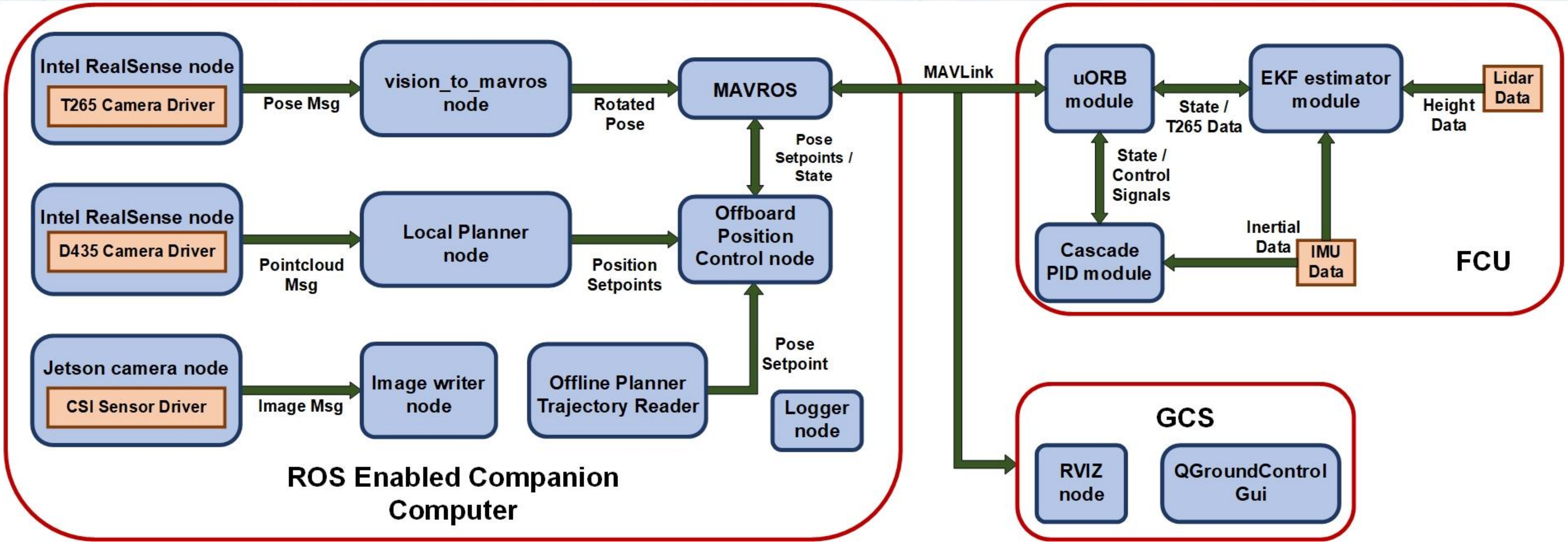


The altitude data is fused with the visual estimation using the EKF implemented in PX4.

-New mounting parts - Vibrations reduction - Stable flight



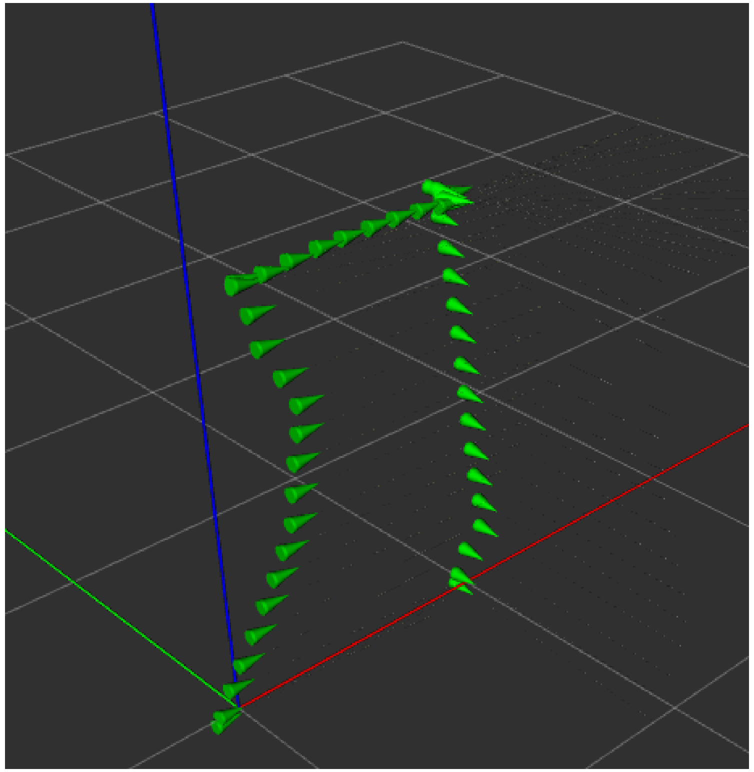
Autonomous Navigation
- Current software architecture



- The software architecture has a modular design with processes running in three different computer. Two of them onboard and one offboard.
- The communication is achieved through the MAVLink protocol running over TCP/IP and UART.

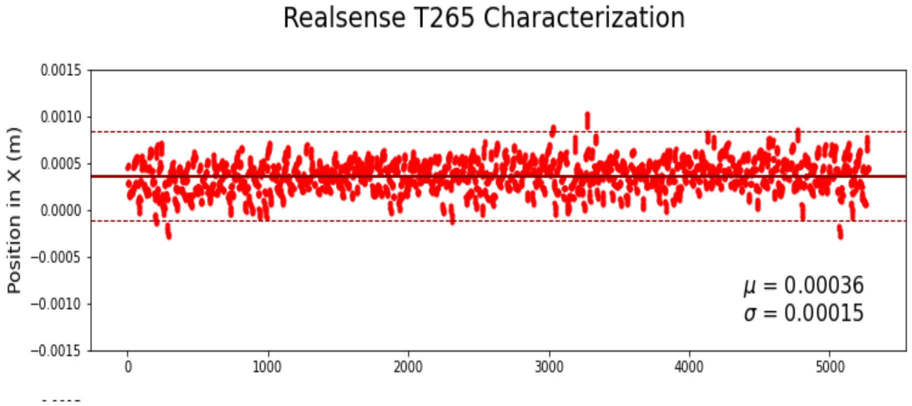
Autonomous Navigation

-Implementation of heading setpoints: Yaw angle control

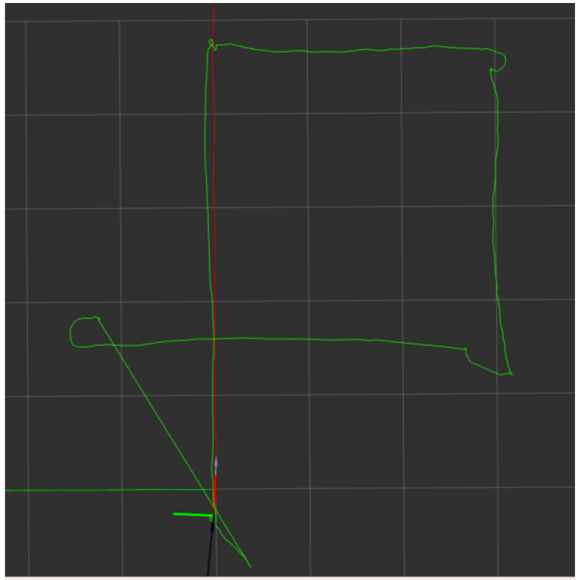


The inspection cameras are pointing normal to the surface of interest.

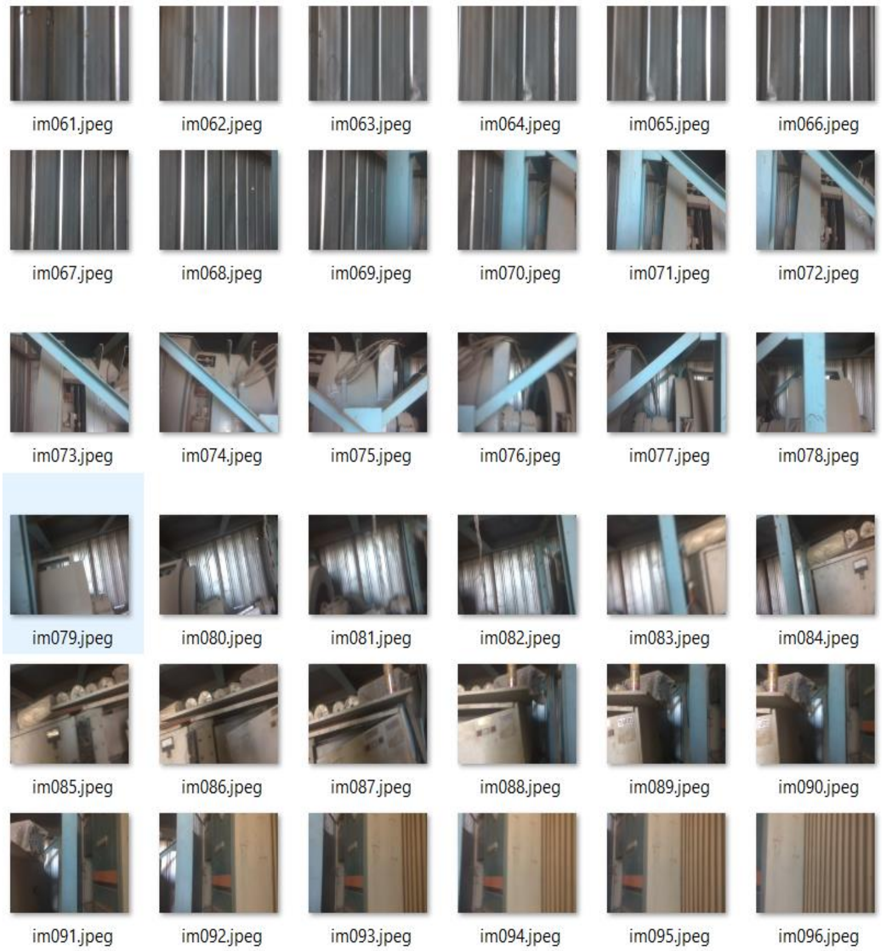
Bias and variance characterization



Light filtering did not improve 3D tracking.



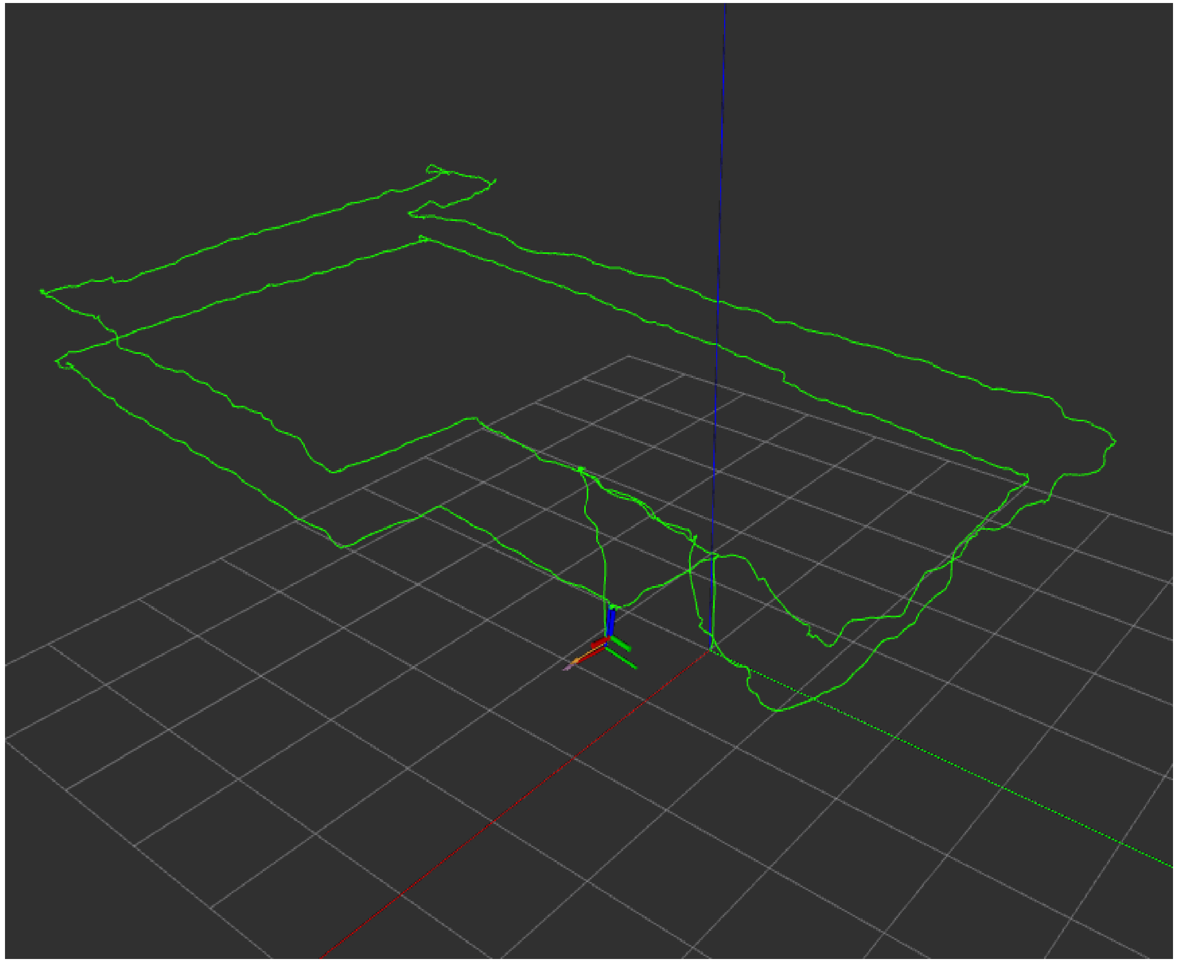
Autonomous Navigation
-Data acquisition in an industrial environment



- Flight tests were conducted in a real industrial environment. The left image shows the output of the image acquisition system.

Autonomous Navigation

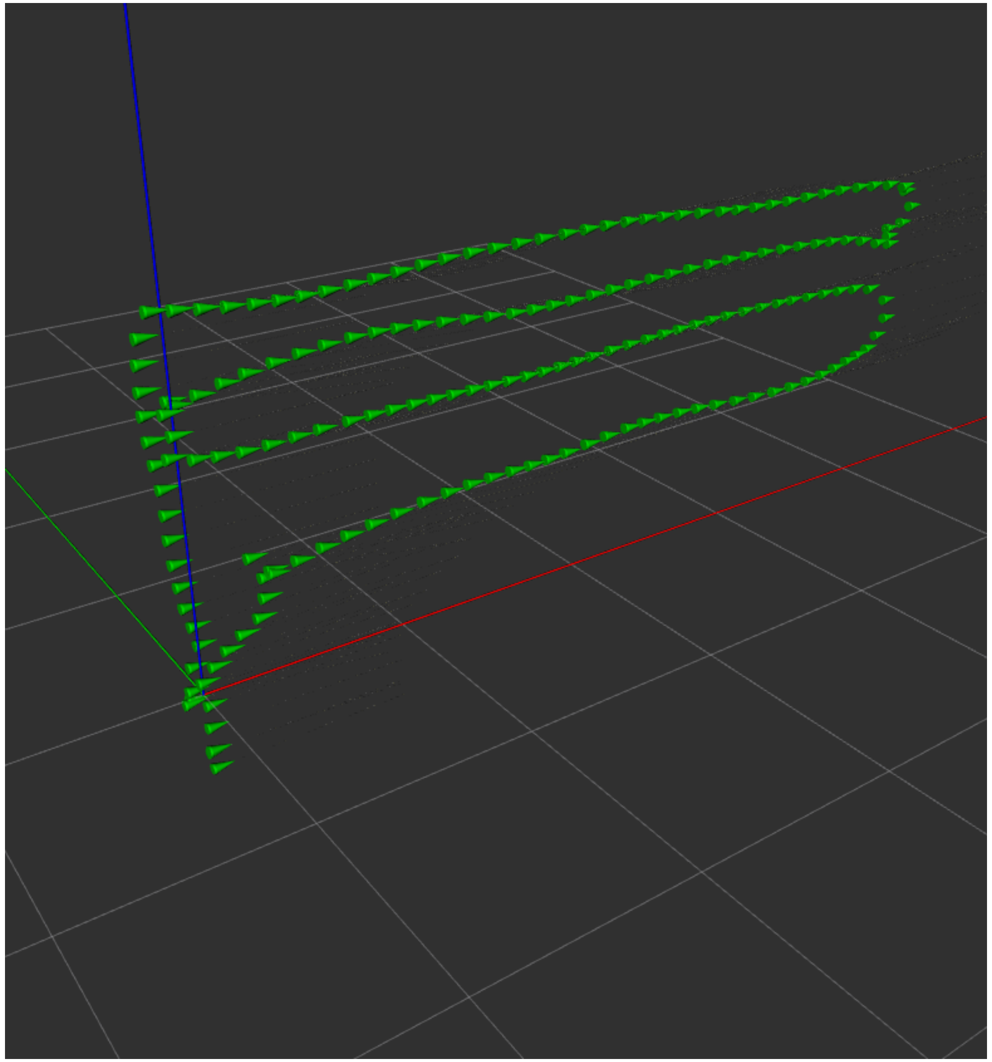
-Trajectory estimation tests in an industrial environment



- The initial tests consisted in manually moving the system around the structure of interest for validating an accurate position estimation.

- The trajectory estimation was acceptable for proceeding with autonomous flights.

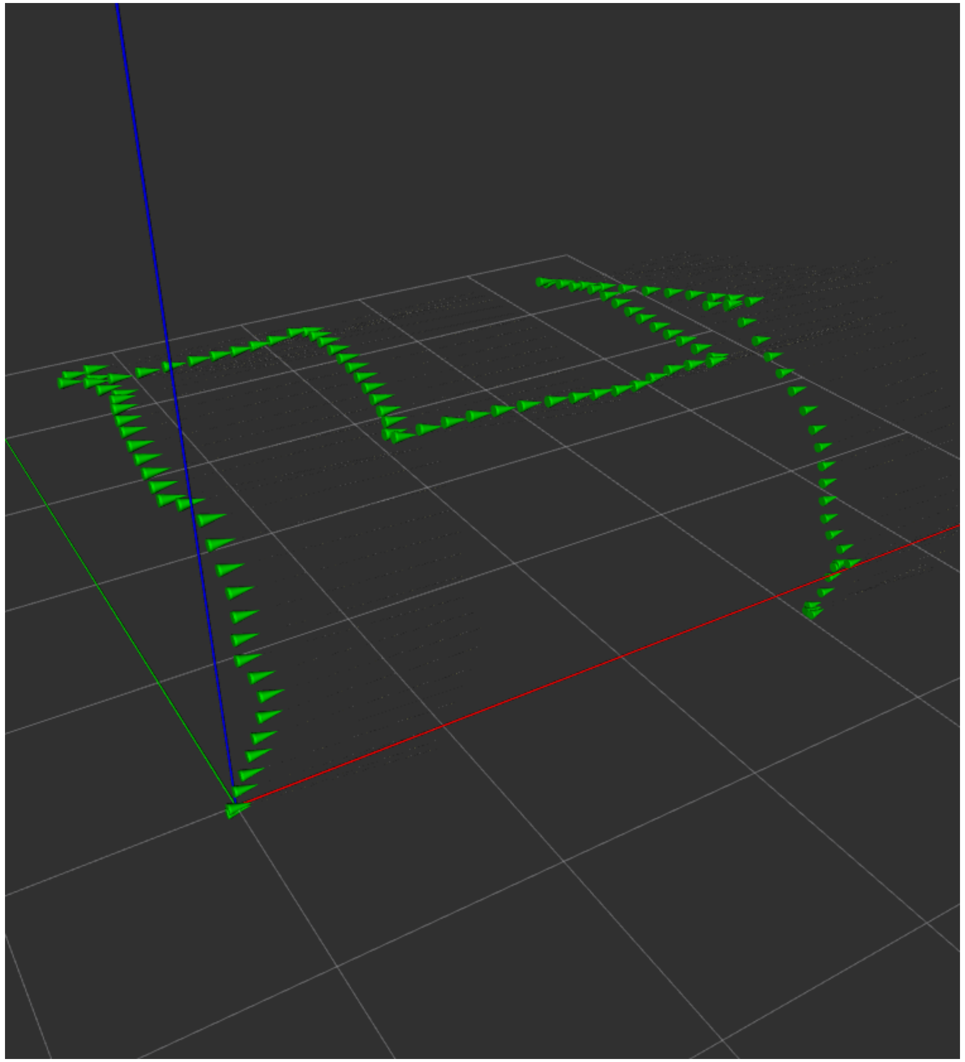
Autonomous Navigation
-Autonomous wall scanning in an industrial setting



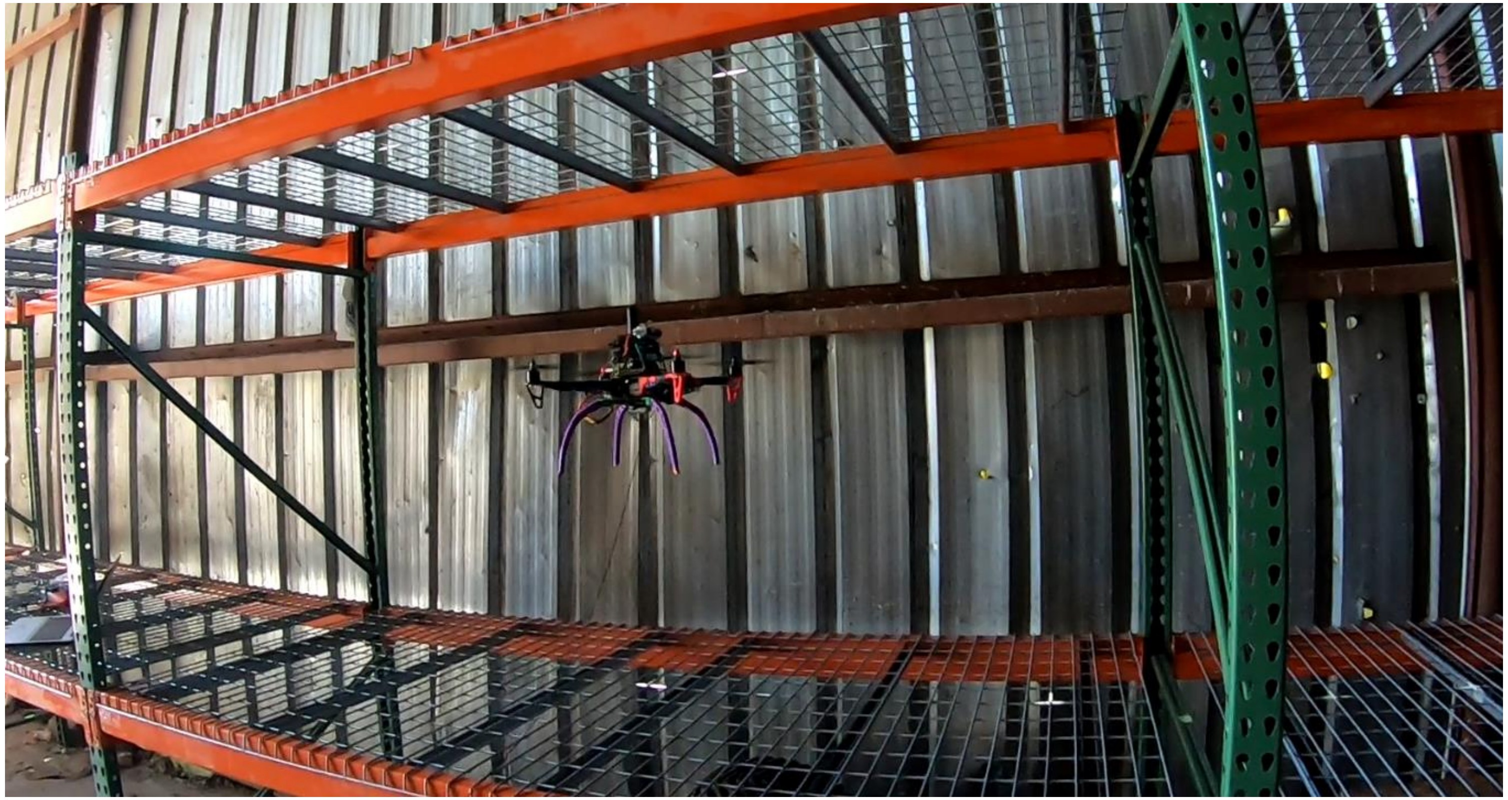
- An autonomous scanning mission was executed along one of the walls, going from side to side at four different altitude levels.

Autonomous Navigation

-Autonomous flight tests inside a constrained space

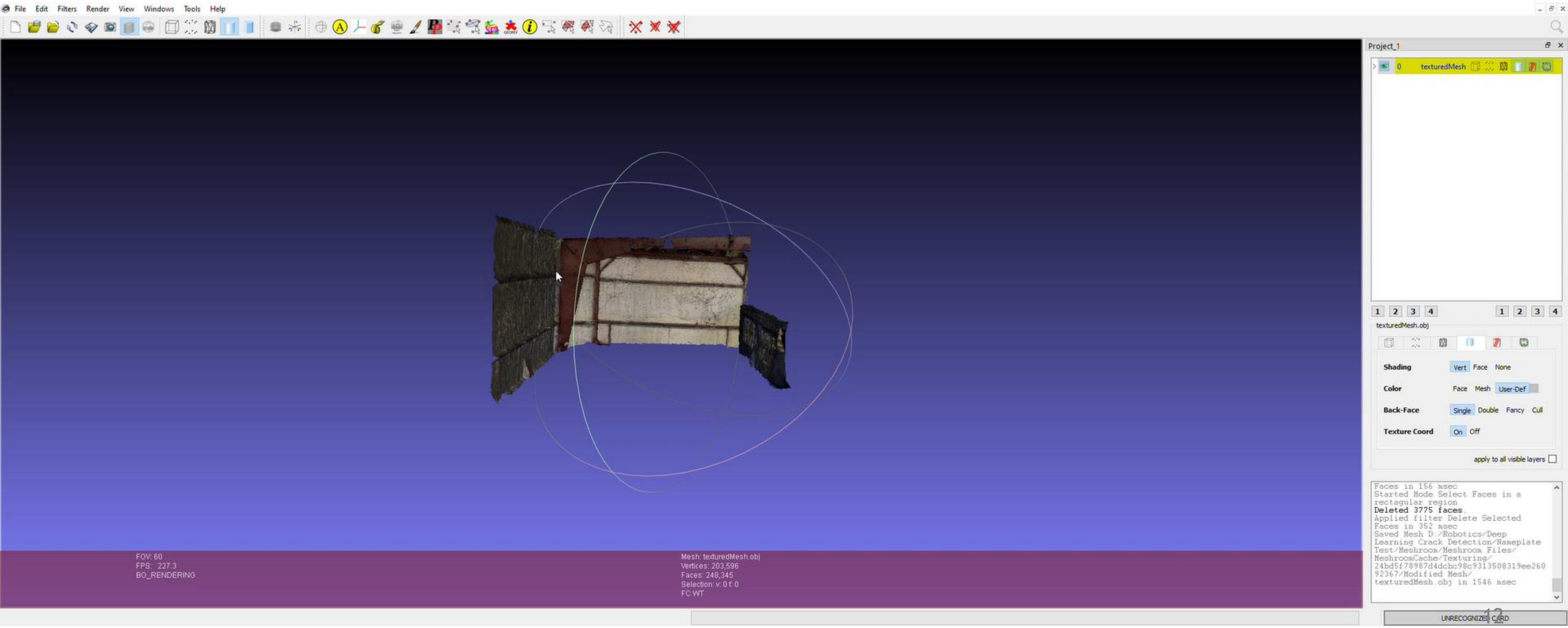


- The system was finally tested in a constrained environment by executing an autonomous mission inside a storage rack.



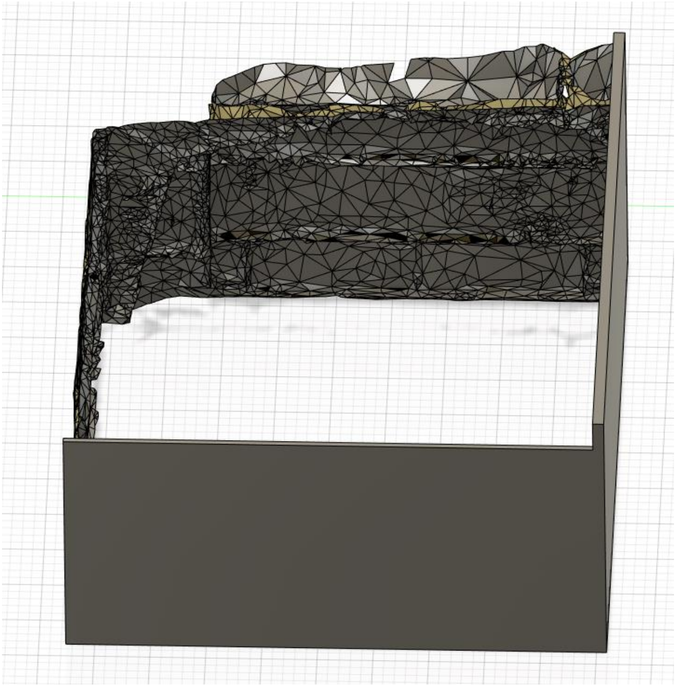
Photogrammetric Reconstruction

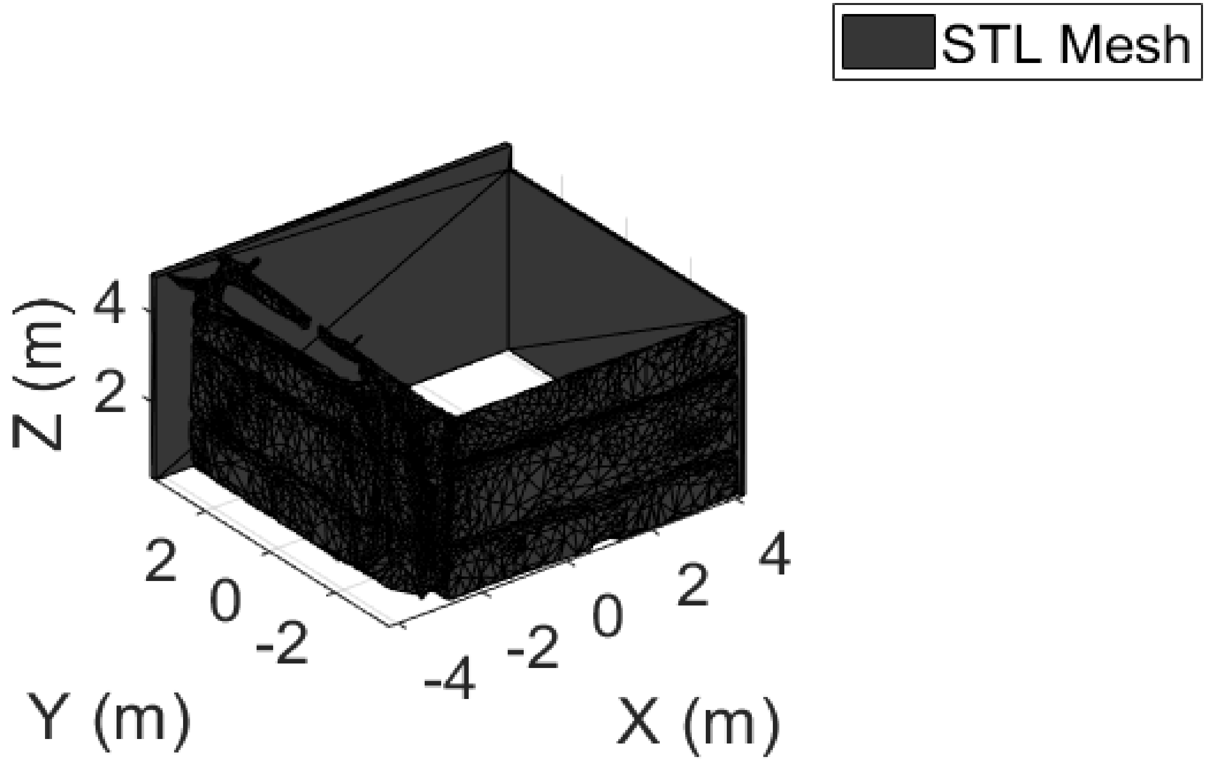
Acceleration Park Hangar (Fabens, TX)



Photogrammetric Reconstruction/STL

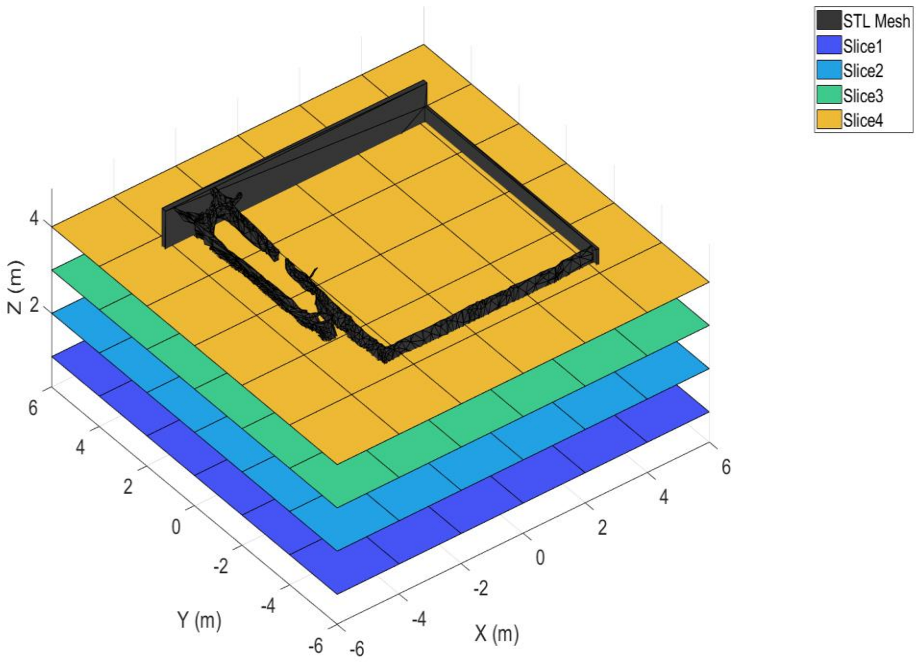
Acceleration Park Hangar (Fabens, TX)

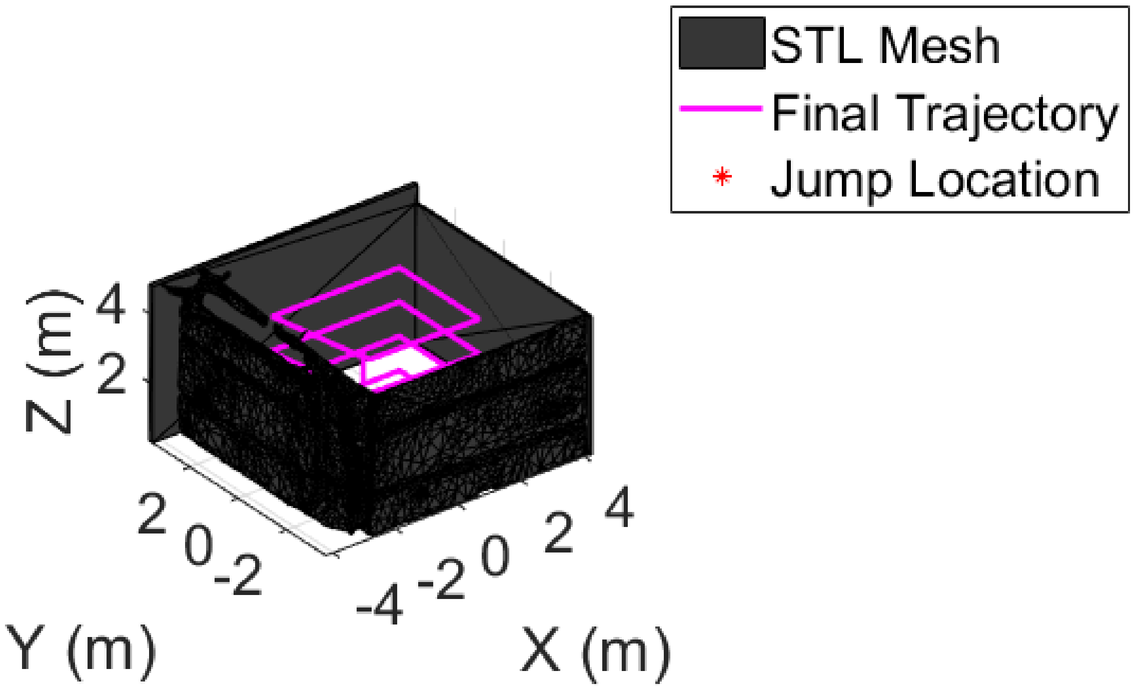




Trajectory Generation

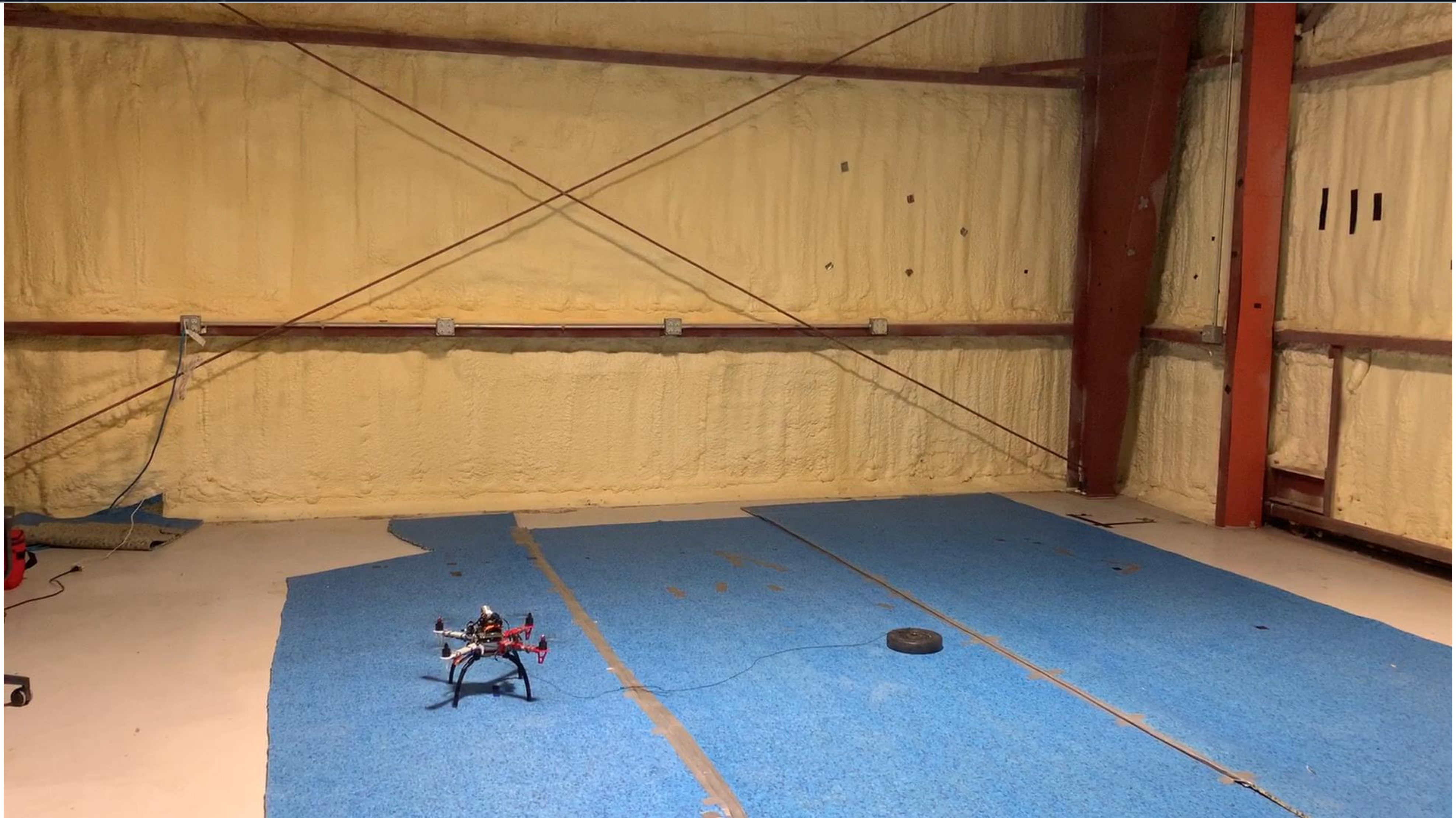
Acceleration Park Hangar (Fabens, TX)





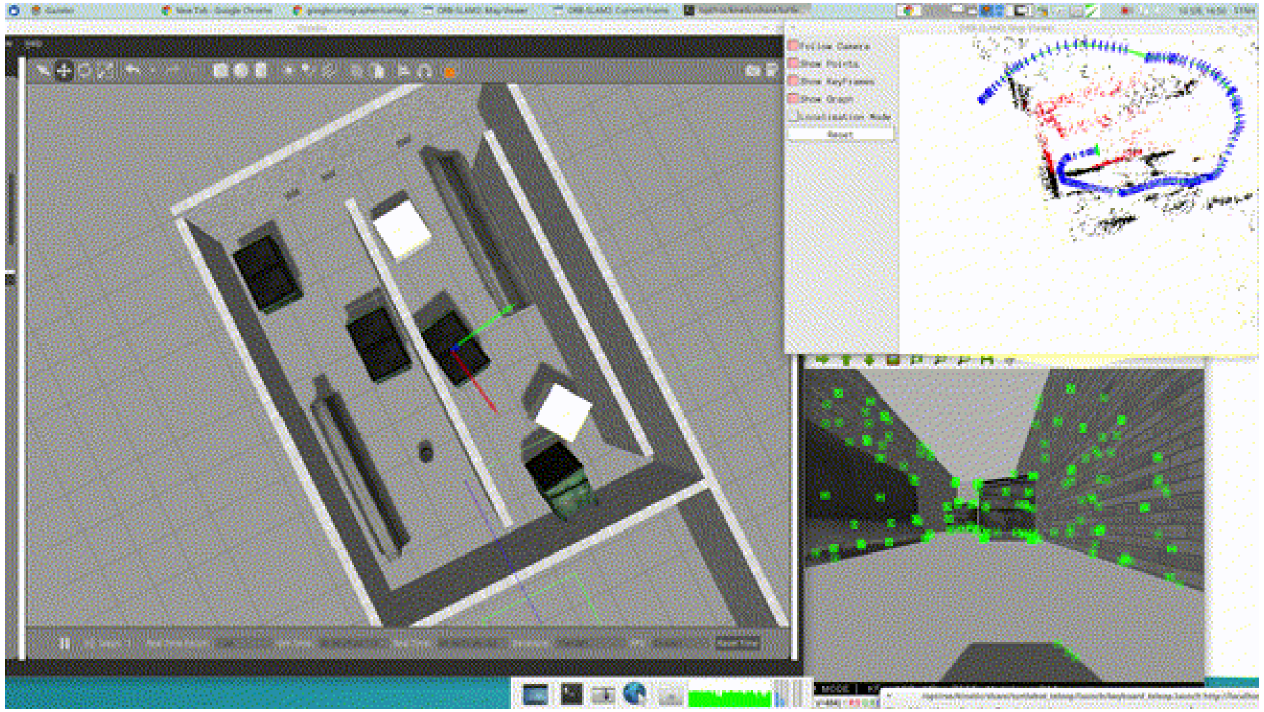
Offline Trajectory Flight Mission

Acceleration Park Hangar (Fabens, TX)



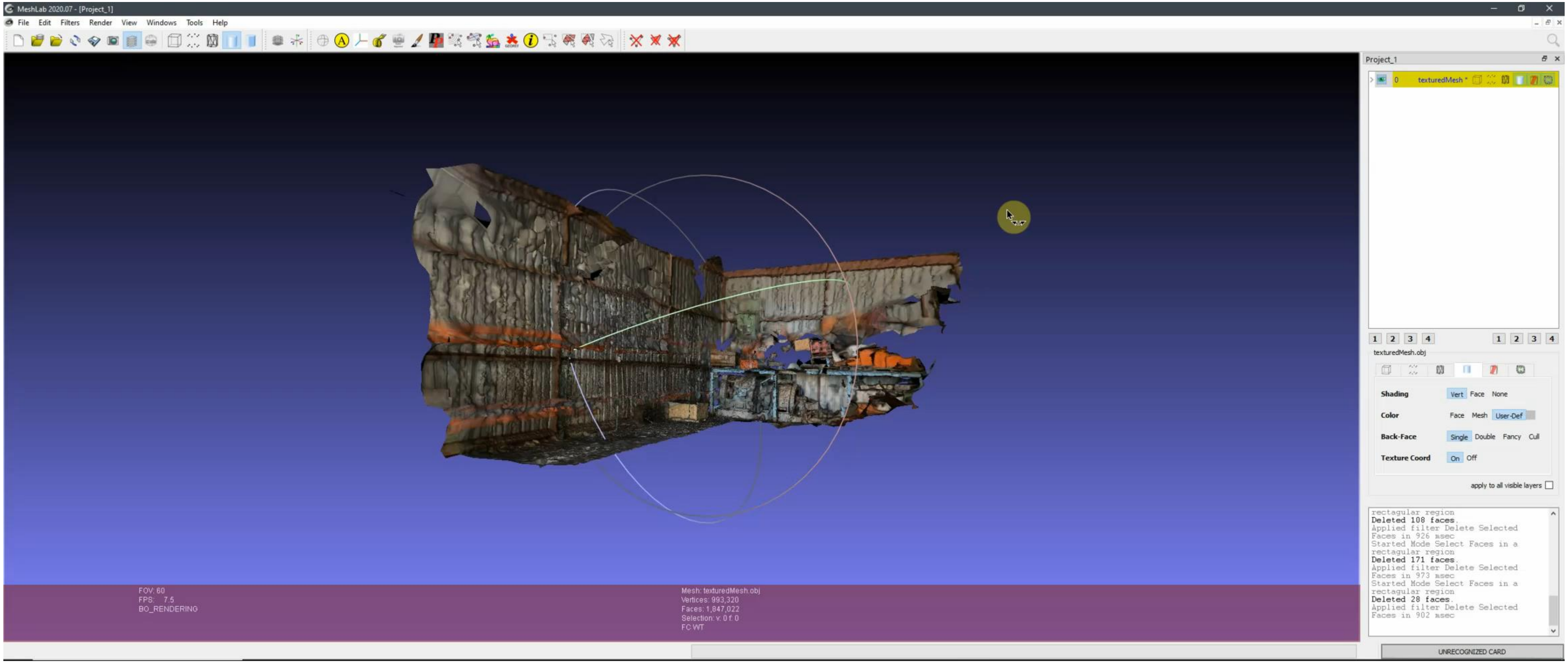
Enhancing Localization by Combining SLAM and CAD Model

1. ORB-SLAM2 Library
2. RealSense Depth Camera D435 for RGB-D Mode
3. Exploring the use of Localization Mode to initialize drone in CAD/STL environment and trajectory
4. Save Map using existing extensions
5. Working on generating a mesh (STL or the like) from PointCloud data.
6. Aim to enhance/replace CAD with SLAM and Photogrammetric Reconstruction



Photogrammetric Reconstruction

Vinton Steel Factory (Vinton, TX)



SLAM Reconstruction Setup

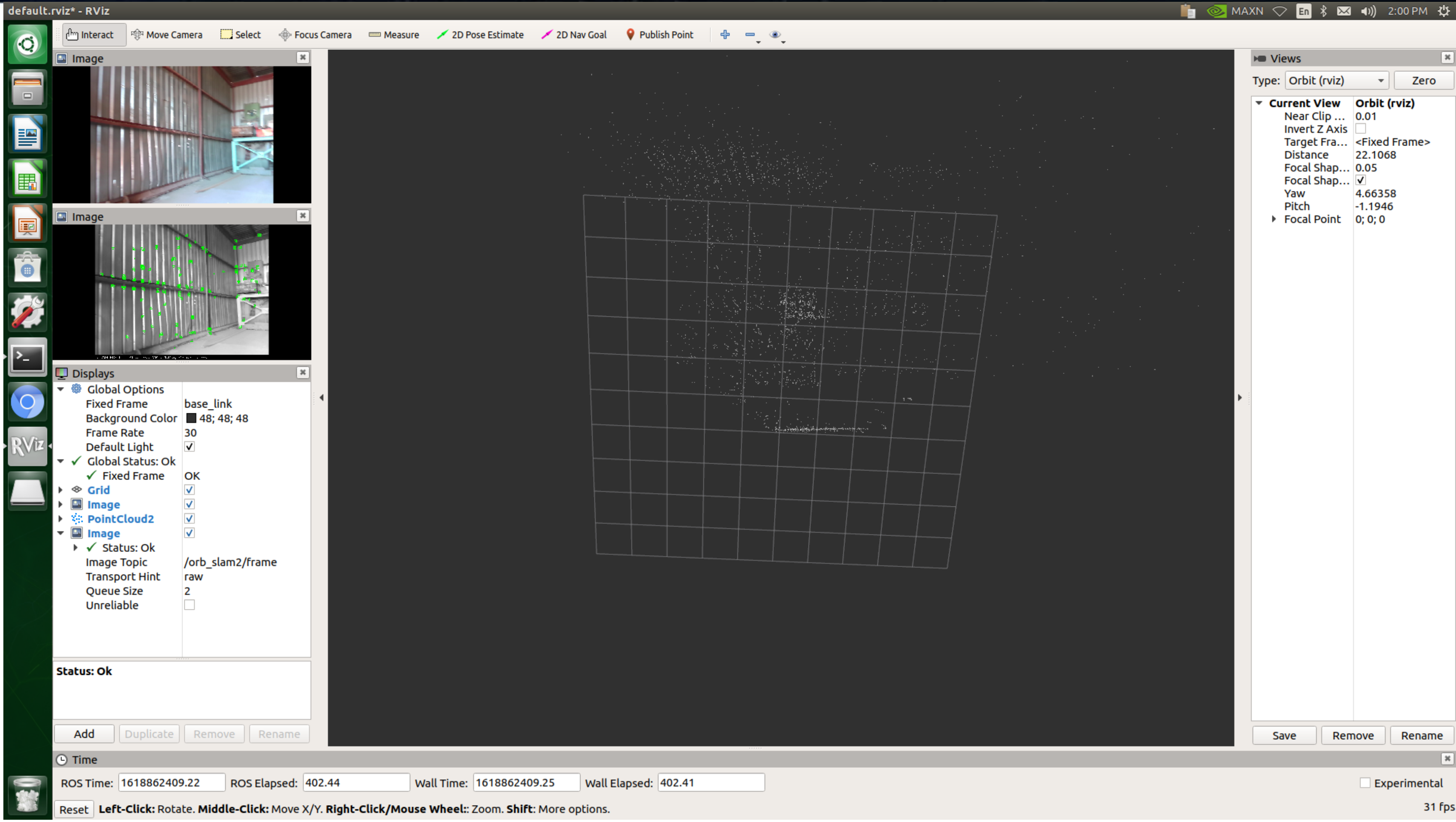
Vinton Steel Factory (Vinton, TX)

1. Handheld device to achieve full control that employs same components as the UAV.
2. Need for a faster approach that is not as computationally expensive as Photogrammetric Reconstruction.
3. Semi-Dynamic environments (Static during inspection but dynamic over days or weeks).
4. Arises from the need to have most current CAD model.
5. Control over features detected in live image acquisition vs static RGB images that might fail in Photogrammetry.

SLAM Reconstruction Results

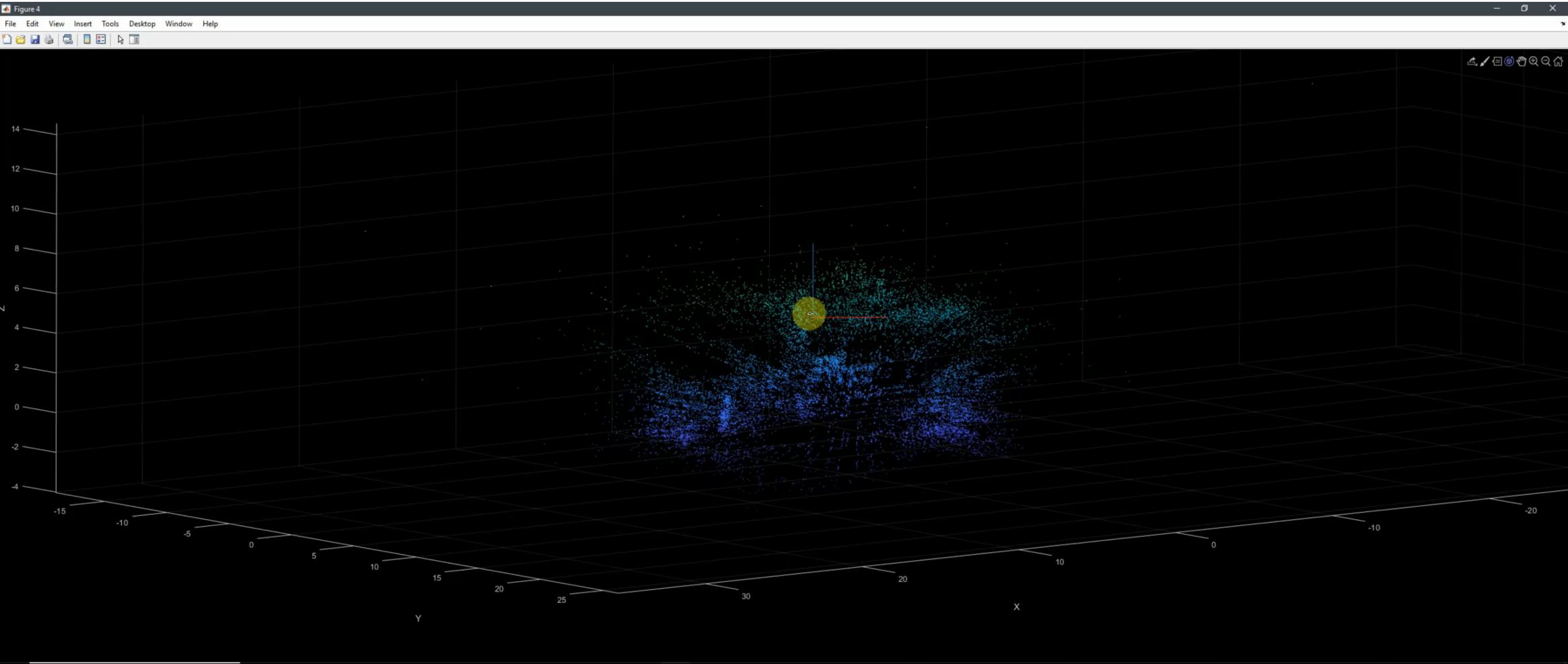
Vinton Steel Factory (Vinton, TX)

1. Original RGB feed from D435 (Top-Left).
2. Modified feed with Feature Detection (Under Previous).
3. 3D Point Cloud of features being mapped.

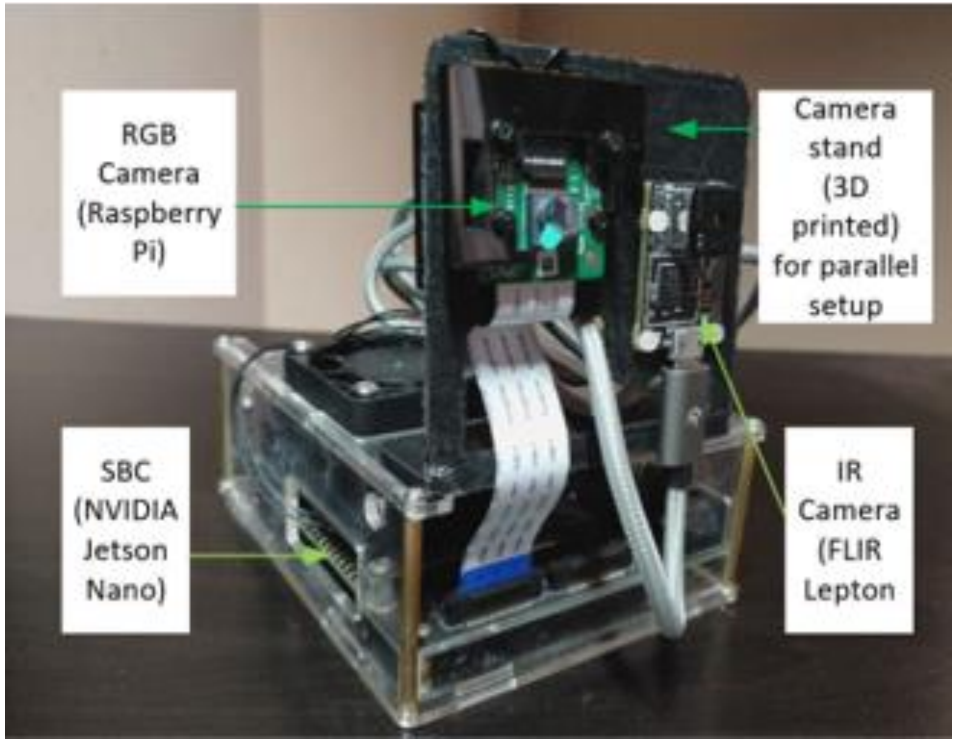


SLAM Reconstruction Results

Vinton Steel Factory (Vinton, TX)



Inspection Payload



1. **RGB Camera**: Raspberry Pi (Sony IMX219 Sensor)
   - 8 Megapixel
   - Focal length: 3.04 mm
   - Vertical FOV: 48.8, Horizontal FOV: 62.2
   - Works with Gstreamer Pipeline on Jetson Nano, coded with Python.
2. **IR Camera**: FLIR Lepton 3.5 camera, Purethermal 2.0
   - LWIR camera temp range up to 400°C (752°F)
3. **Platform/SBC**: NVIDIA Jetson Nano
   - GPU: 128-core NVIDIA Maxwell™
   - CPU: Quad-core ARM® A57.
   - Low power requirement considering UAV power limitation.

o Coding Language: Python

Defect analysis: AI/DNN Object Detection model in Python (Tensorflow) - Offline

- **Models**:
- Dataset: created with crack and corrosion together. About 300 images.

1. DNN model YOLOv4-tiny (Precision vs inference speed restriction), customized by transfer learning and trained on Google Colab (training time over 6 hours)

Classes: Crack

Evaluation: e.g. mAP@0.5) = 0.379753 only

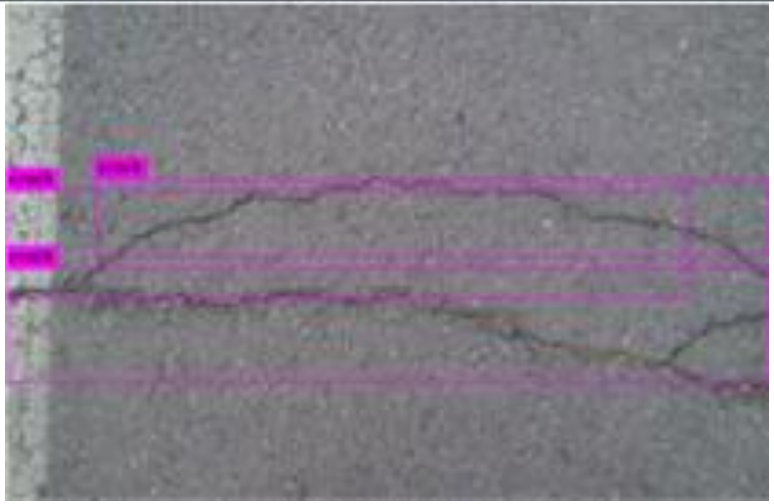
2. DNN model YOLOv4, customized by transfer learning and trained on Google Colab (training time over 12 hours)

Classes: Crack & Corrosion

Evaluation: e.g. mAP@0.5 = 0.55

Tools:

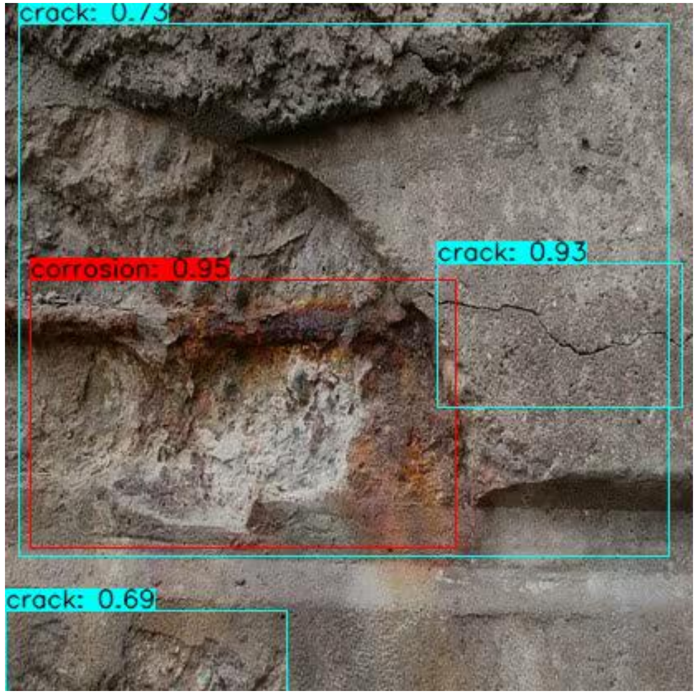
Keras & Tensorflow, both open-source neural-network libraries written in Python, with TensorFlow backend.



Payolad Inspection: Intelligent Inspection

I. **Offline Inspection** using Deep Learning: Inference using 2 quantized models on saved videos (source: online)

(a) Custom TensorRT model



(b) Custom TensorFlowLite model

Media 01. Inference on Saved Videos

Intelligent Inspection on Edge

II. Inspection using AI on Edge: Inference of TensorRT models using SBC onboard camera (Raspberry Pi)

(a) Indoor test in ambient (natural) lighting

(b) Outdoor test in Shaded area in ambient (natural) lighting

Media 02. Real-time Custom TensorRT model Inference

Intelligent Inspection

II. Inspection using AI on Edge: Inference of TensorRT models using SBC onboard camera (Raspberry Pi)

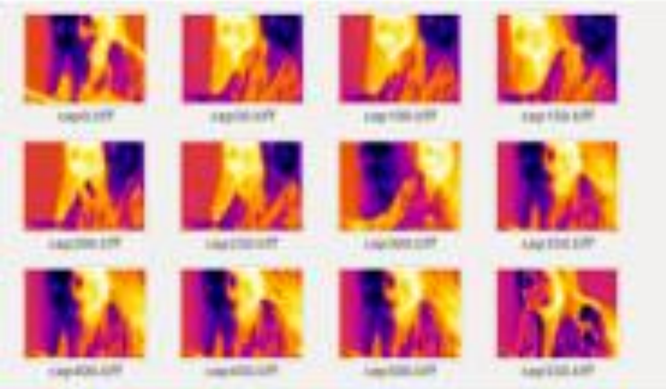
(c) Outdoor test under direct sunlight

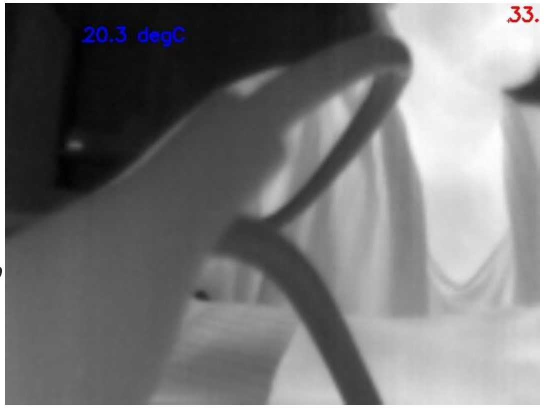
(d) Outdoor test under direct sunlight

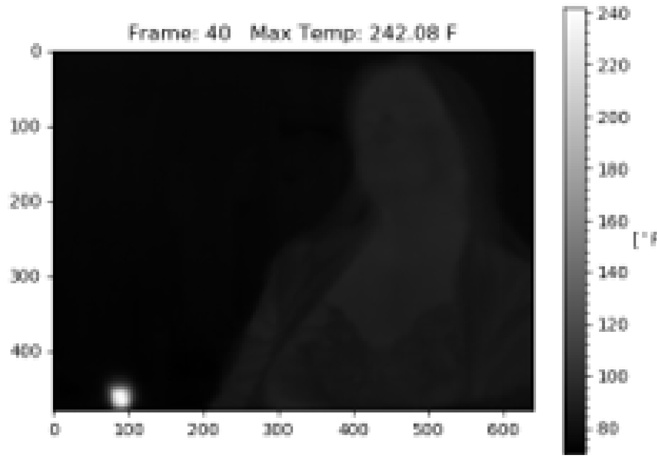
Media 03. Real-time Custom TensorRT model Inference

IR analysis

- Progress:
  - Setup FLIR Lepton 3.5 camera with Purethermal 2.0
    - Installation and compilation of needed libraries e.g. libuvc etc
  - Python code
    - to capture/acquire image with **pseudo color** (.jpeg format, legible but looses temperature data)
    - to capture/acquire image without colormap (.tiff/.png format), keeping temperature data, but not discernable)
    - To normalize temperature image to **radiometric** feed (.tiff/.png format) to make discernible and image saving in .hdf5 format
  - RGB and IR camera parallel video feed sync (Python, OpenCV, with inference running on RGB display/feed) in Jetson Nano
  - Python code to obtain pixelwise temperature, minimum, maximum etc from IR images







IR analysis

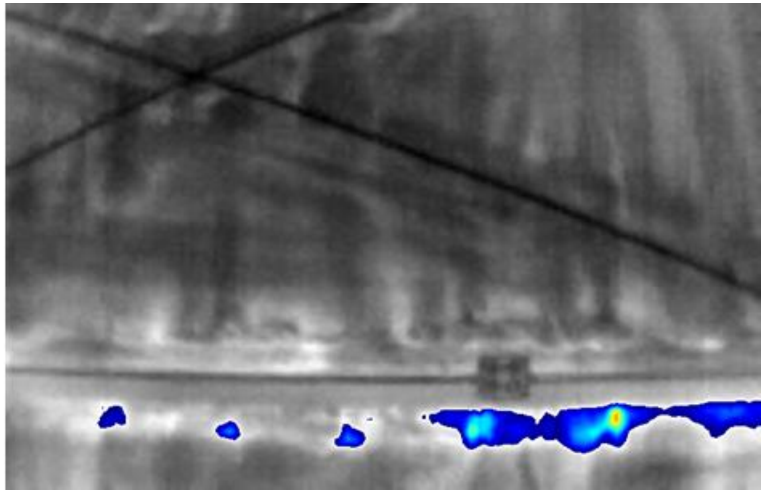


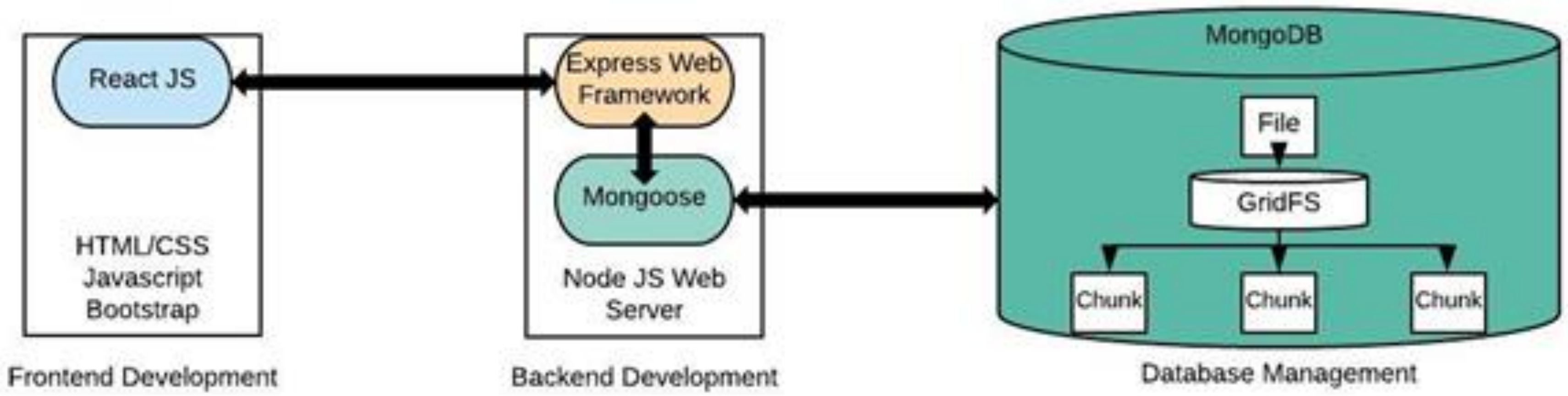
Fig. Synchronized Visual and Infrared image acquisition and thermal thresholding

Progress:

- Synchronized IR thresholding (fig above) and 'Thermal spot-meter' (reading temperature at a pre-selected pixel coordinate)

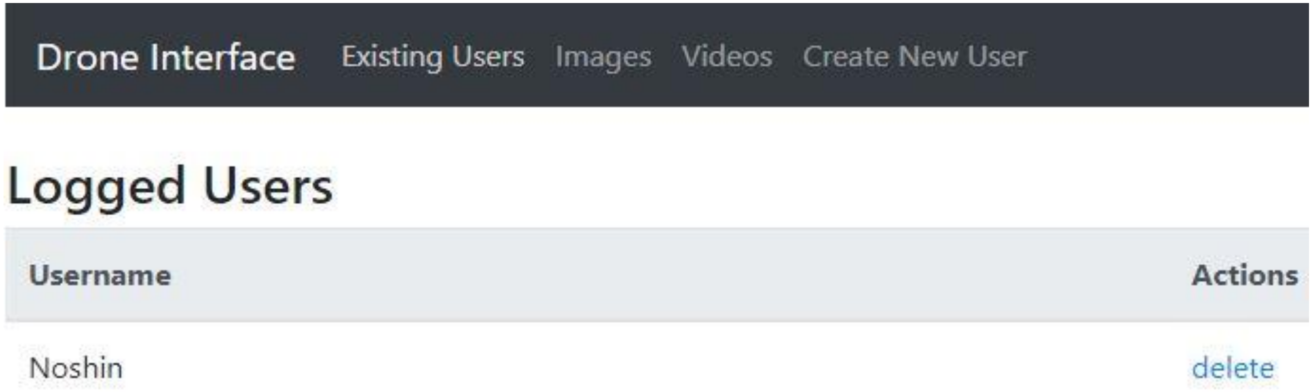
Drone Interface Architecture

- MongoDB – NoSQL database with flexibility in data type storage
- Express – Backend framework supporting various middleware with a robust API
- React – Javascript library for building user interface
- Node.js – Javascript runtime environment with node package managers to create modules



Drone Interface Frontend

- Allows specific users to upload images and videos
- User IP addresses must be added when creating the user but is not publicly stored
- Stores images and videos into the MongoDB database
- Can be accessed through the URL: https://droneinterface.herokuapp.com/



Drone Interface Frontend

Drone Interface Existing Users Images Videos Create New User

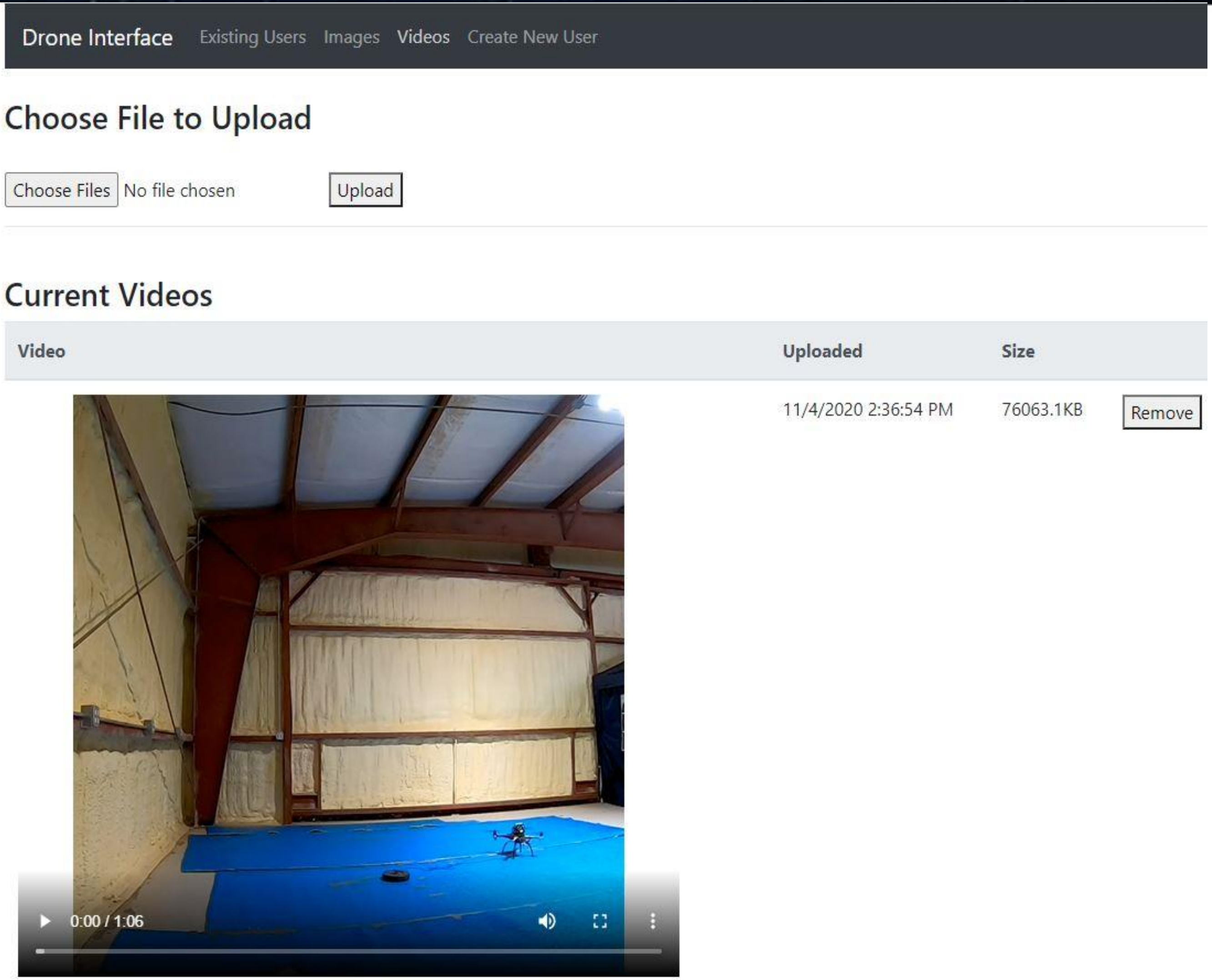
Choose File to Upload

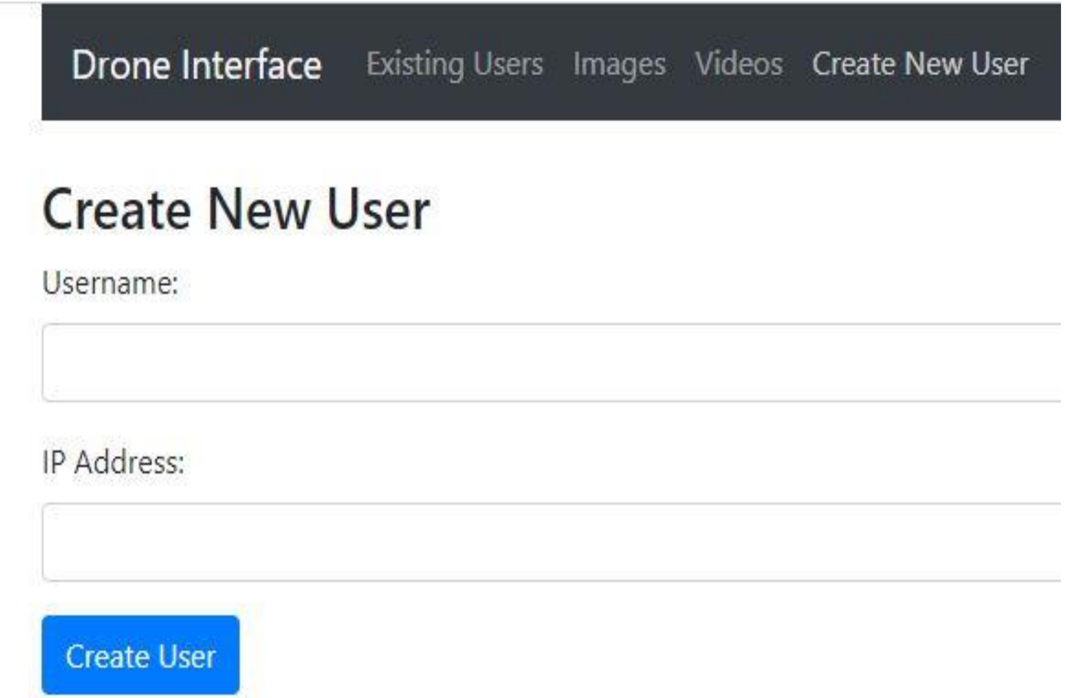
Choose Files No file chosen Upload

Current Images

Image	Uploaded	Size	
	10/20/2020 7:26:31 PM	200.5KB	Remove

Drone Interface Frontend





Technology to Market Path
Industry partners: El Paso Electric

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Acknowledgment and Disclaimer

Acknowledgment: "This material is based upon work supported by the Department of Energy Award Number DE-FE0031655."