Autonomous Aerial Power Plant Inspection in GPS-denied Environments

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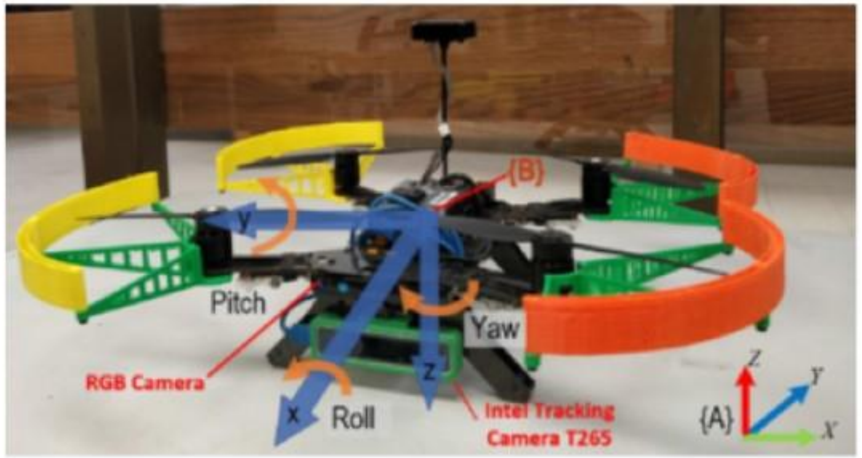
Project Objectives

This project aligns with the DOE interests on using robotic technology to inspect power plant components and maintain good health of their assets. While reducing the risk of the personnel and having the capability of reaching difficult to access spots.

Goal. To enable Unmanned Aerial System (UAS) close quarter inspection within complex over-head and Global Positioning System (GPS)-denied environments of coal-fired power plants, including exterior and interior.

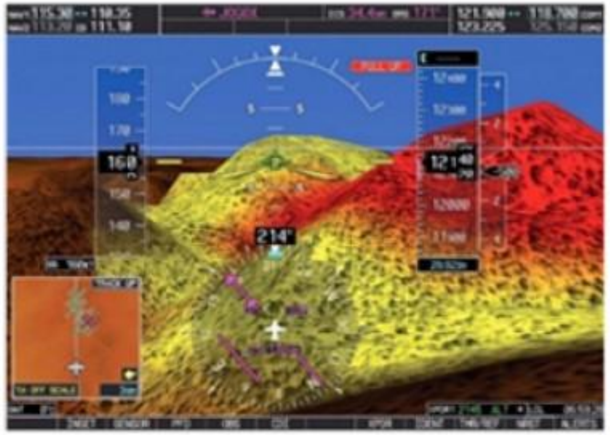
Objective: Develop CAD-based, very close inspection profiles for space-constrained and GPS-denied areas of a power plant (e.g. boiler).

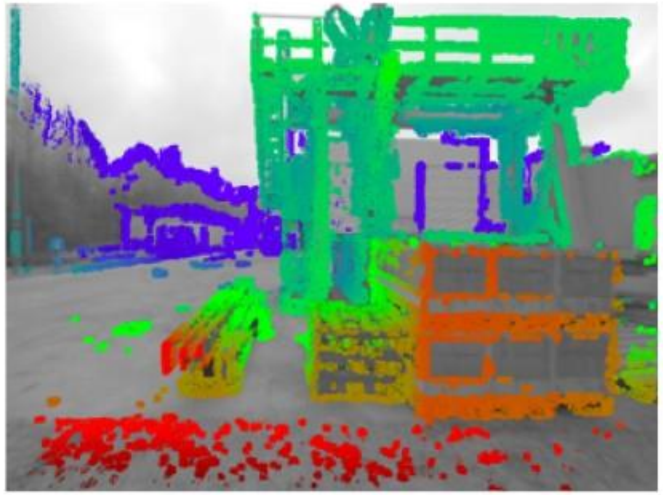


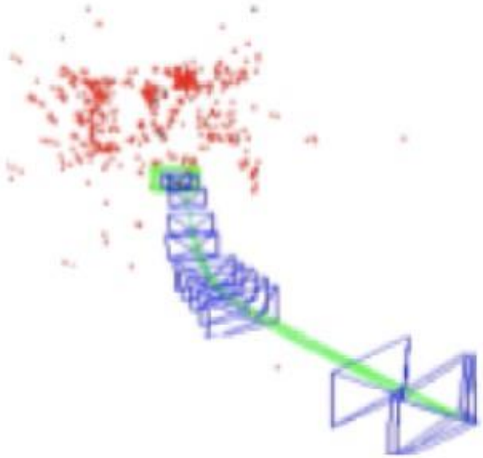
Project Description

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

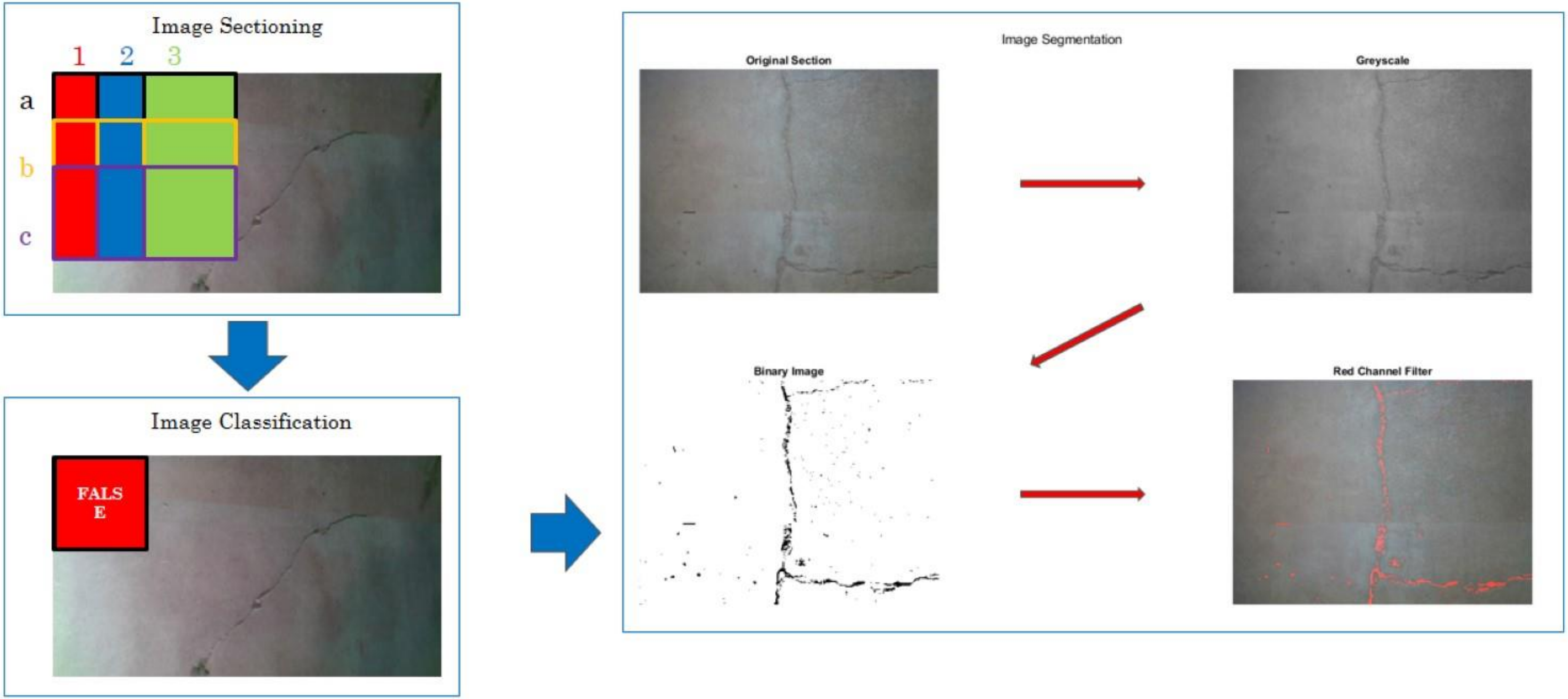
Project update. Damage Detection

- 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.

Image Dataset Used with Neural Network

- Dataset of 564 images
- Camera velocity of 0.1 m/s
- Framerate of 60 fps
- Every 5th image extracted per second

Image Sectioning, Classification & Segmentation



Damage detection: Inspection analysis using Deep Learning

- **Target:** Using Deep Learning (Convolution neural networks) to analyze images taken by the UAV inspection camera i.e. Image Classification to detect faults in powerplant
- **Analysis Mode**: Offline
- **Software and Libraries**: PyTorch & Keras, both open-source neural-network libraries written in Python, with TensorFlow backend.
- **Datasets**: a. Mendeley (40,000), b. Crack Forest (320), c. Project Setup images (333) d. Customized Dataset: All these datasets combined and augmented to cover all image, surface and lightning conditions.
- **Models**: A number of CNN models in Deep Learning (CNN FFN, Sequential, VGG16, VGG19, Resnet34 and ResNet50) has been analyzed with different datasets to find out the best inference results for the specific problem.

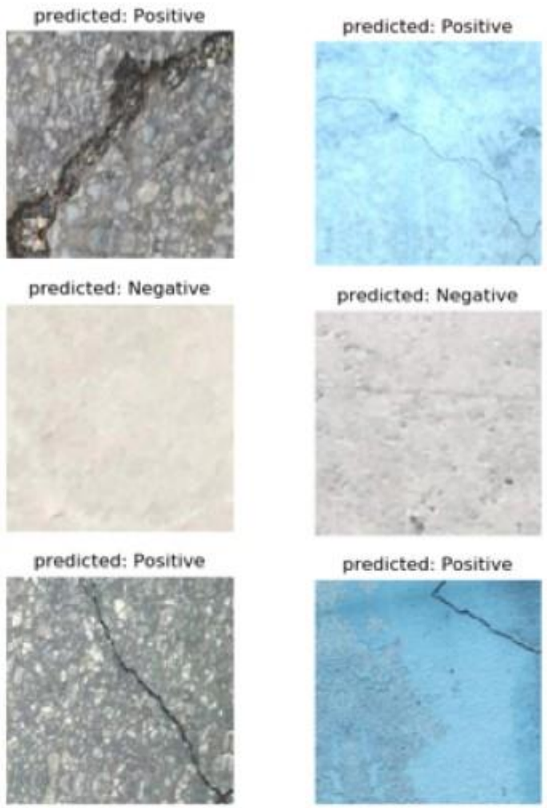


Fig 1: Result/Prediction of images using 'transfer learning' of 'ResNet50' model with customized dataset

Structure-From-Motion

Autonomous Navigation

Updates and Accomplishments

- Two papers published and presented at the 2020 AIAA SciTech Forum
    1. *"A CAM/AM-based Trajectory Generation Method for Aerial Power Plant Inspection in GPS-denied Environments"*
    2. *"Drone Inspection Flight Path Generation from 3D CAD Models: Power Plant Boiler Case Study"*

- UAS assembly was integrated, and autonomous flight tests where conducted

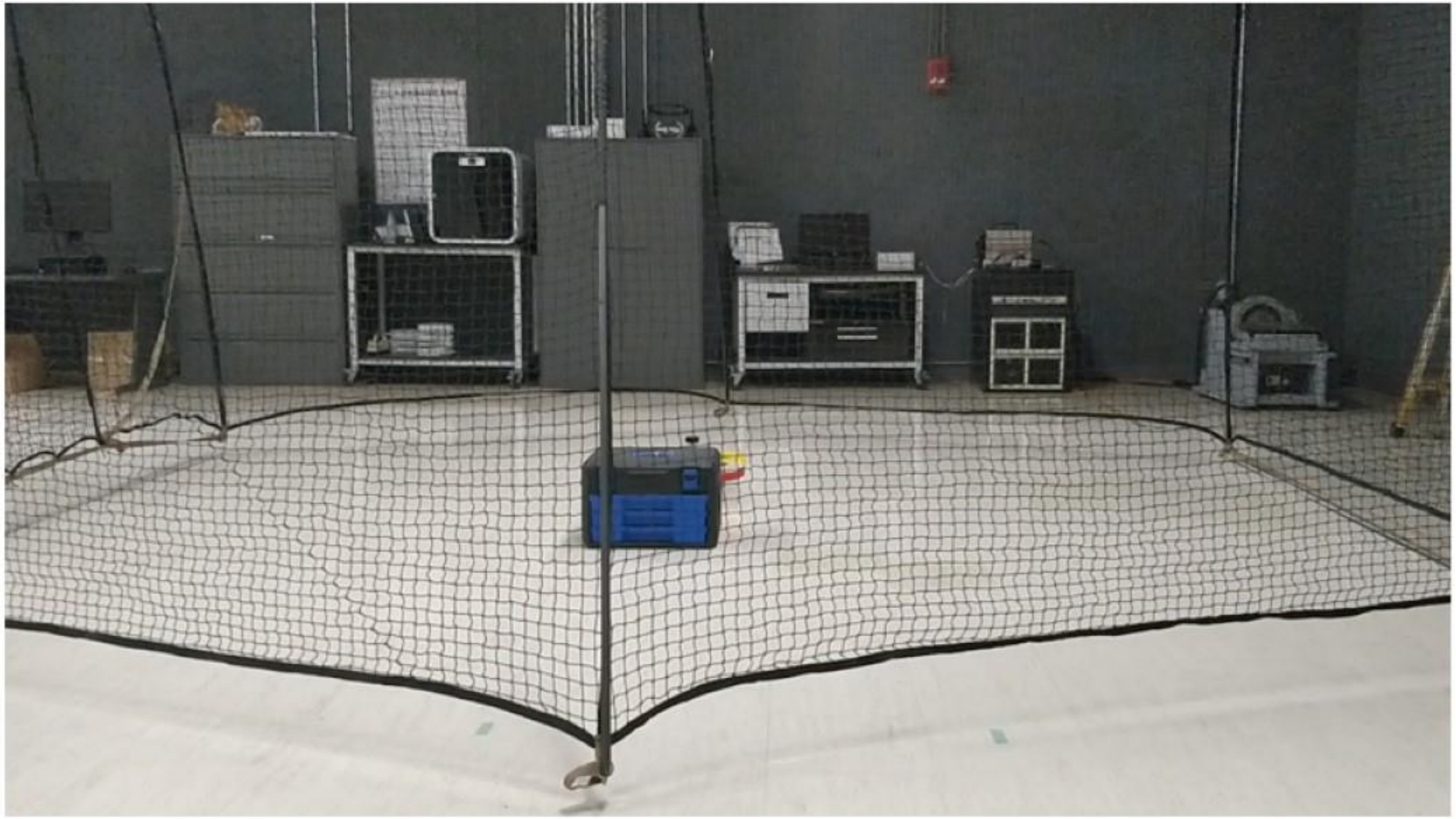
- Inspection data acquisition was successfully integrated into the system

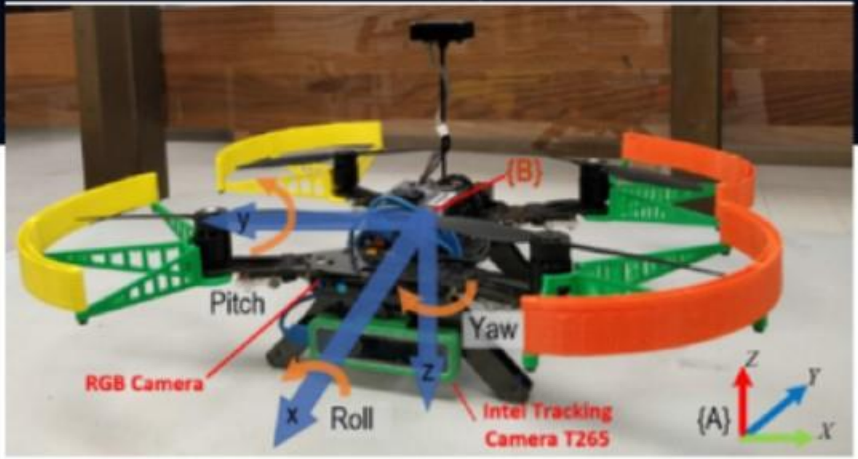
- Ongoing efforts on the design of a database and visualization tool

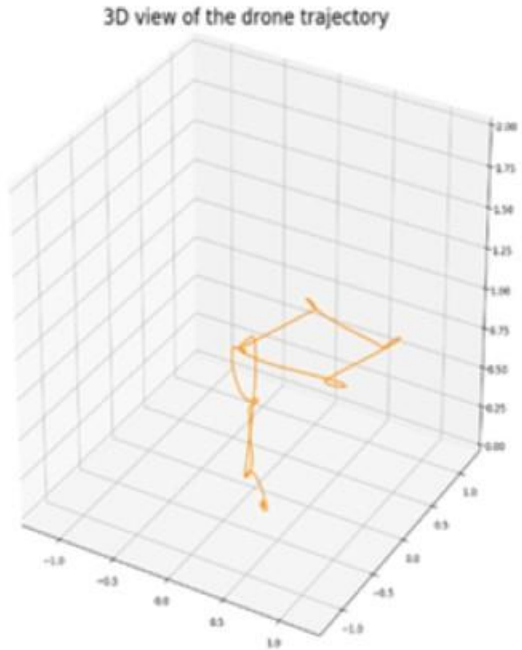
- Integration of a "stitching" stage for mapping the inspected structure

- Improvements on the AI analysis of inspection images for detecting cracks

In-doors autonomous flight test





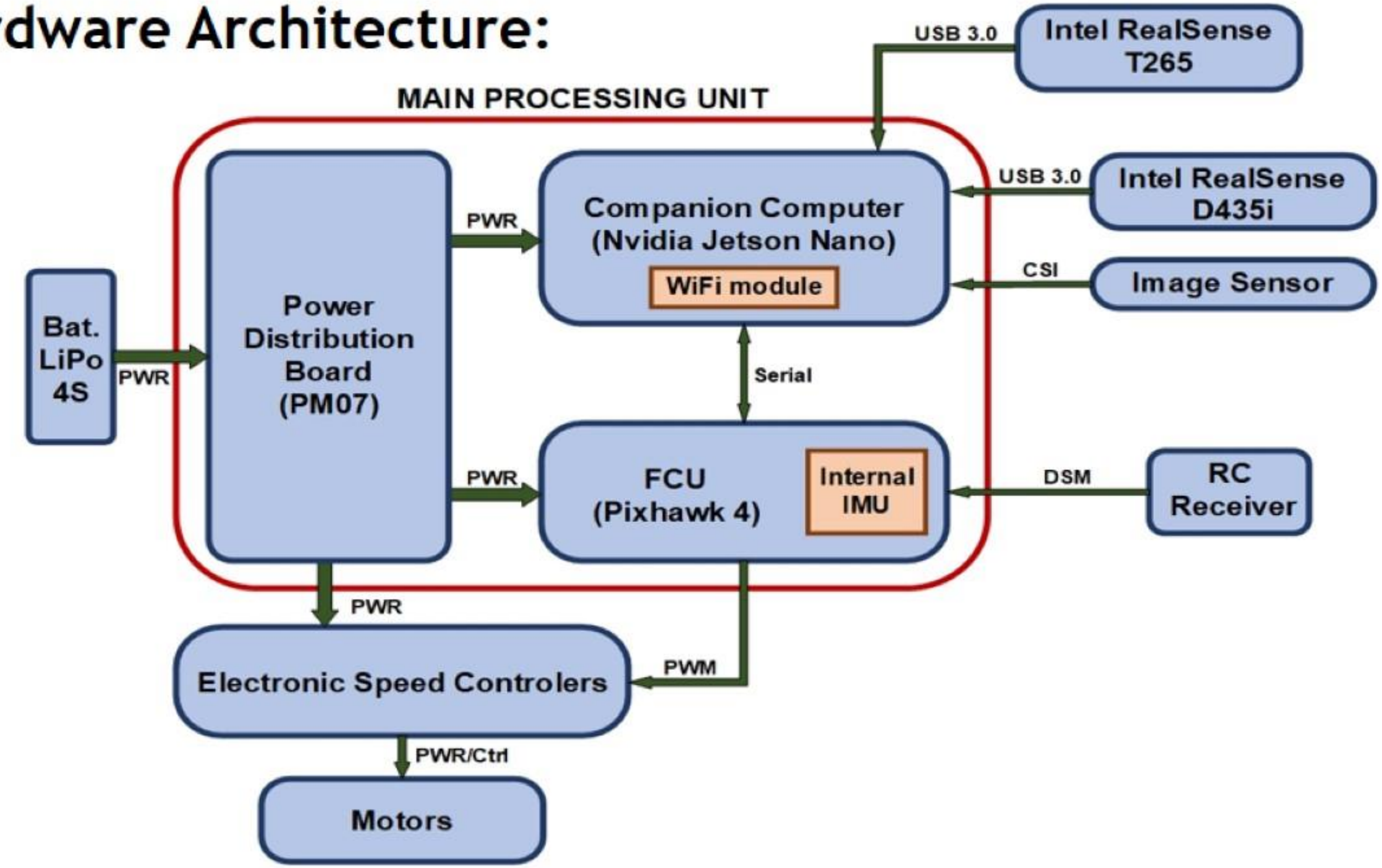


In-doors Test. On-line Obstacle Detection and Avoidance

- The onboard Intel R200 camera was used to collect point cloud data, which was processed by a ROS node in the companion computer.
- The data was filtered, the YZ plane's equation of the obstacle was extracted and used to compute the distance between the drone and the obstacle.
- The drone is hovering at a point, and it goes back to keep a safety distance when an obstacle is detected in front. When the obstacle is removed, the drone goes back to the commanded setpoint.

Autonomous Navigation

UAS Hardware Architecture:



Autonomous Navigation

Setup of a new platform:

- A new platform based on the DJI F450 frame was setup to replace the Intel Aero RTF Drone.
- It is based on the Pixhawk 4 FCU, interfaced with the Nvidia Jetson as companion computer.
- There is no GPS attached to the drone, all the positioning is done through Visual Inertial Odometry (VIO), using the Realsense T265 camera and the internal IMUs.

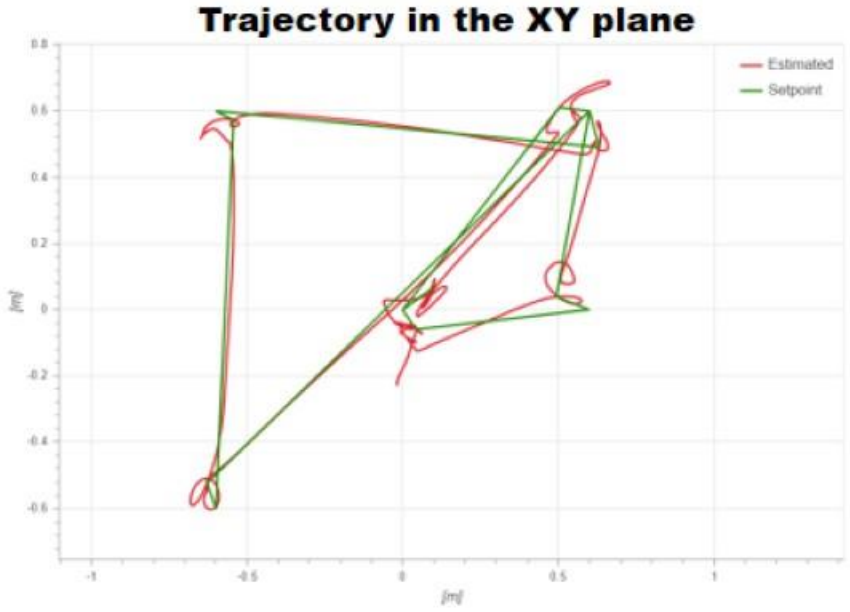
Autonomous Navigation

Platform upgrades and tuning:

- Some upgrades, both in software and hardware where needed to achieve an stable flight.
- The motors, propellers, and ESCs where replaced by better quality ones.
- The placement strategy of the Pixhawk-Jetson payload was modified, and the ESCs were re-positioned.
- The internal controllers where tuned by modifying their gains and running a big set of flight experiments.
- A stable flight was achieved, free of vibrations.

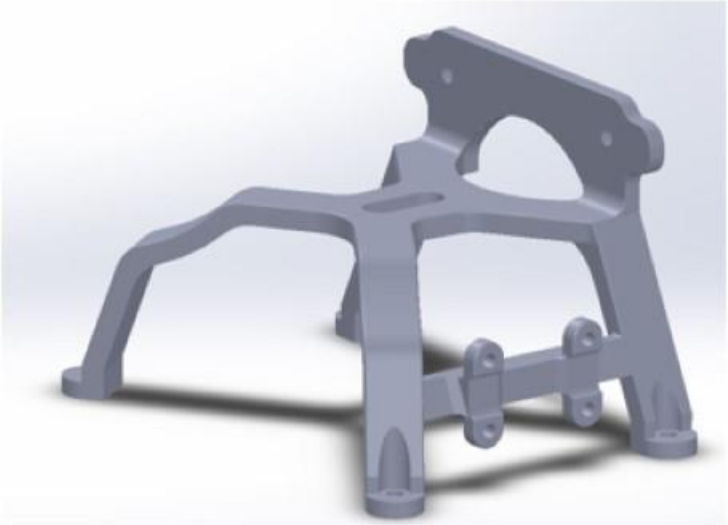
Autonomous Navigation

Complex trajectory in offboard mode



Autonomous Navigation

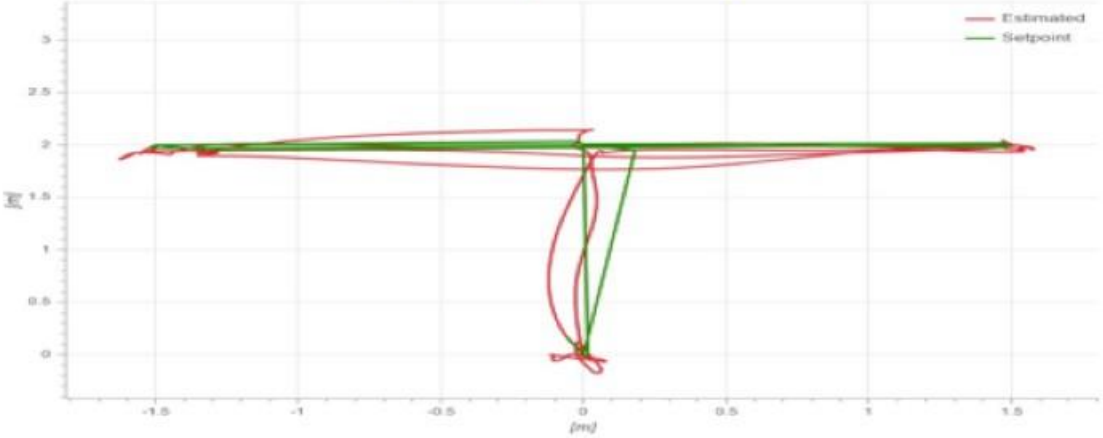
Fully integration of the cameras payload



Autonomous Navigation

Autonomous wall inspection flight test

Trajectory in the XY plane



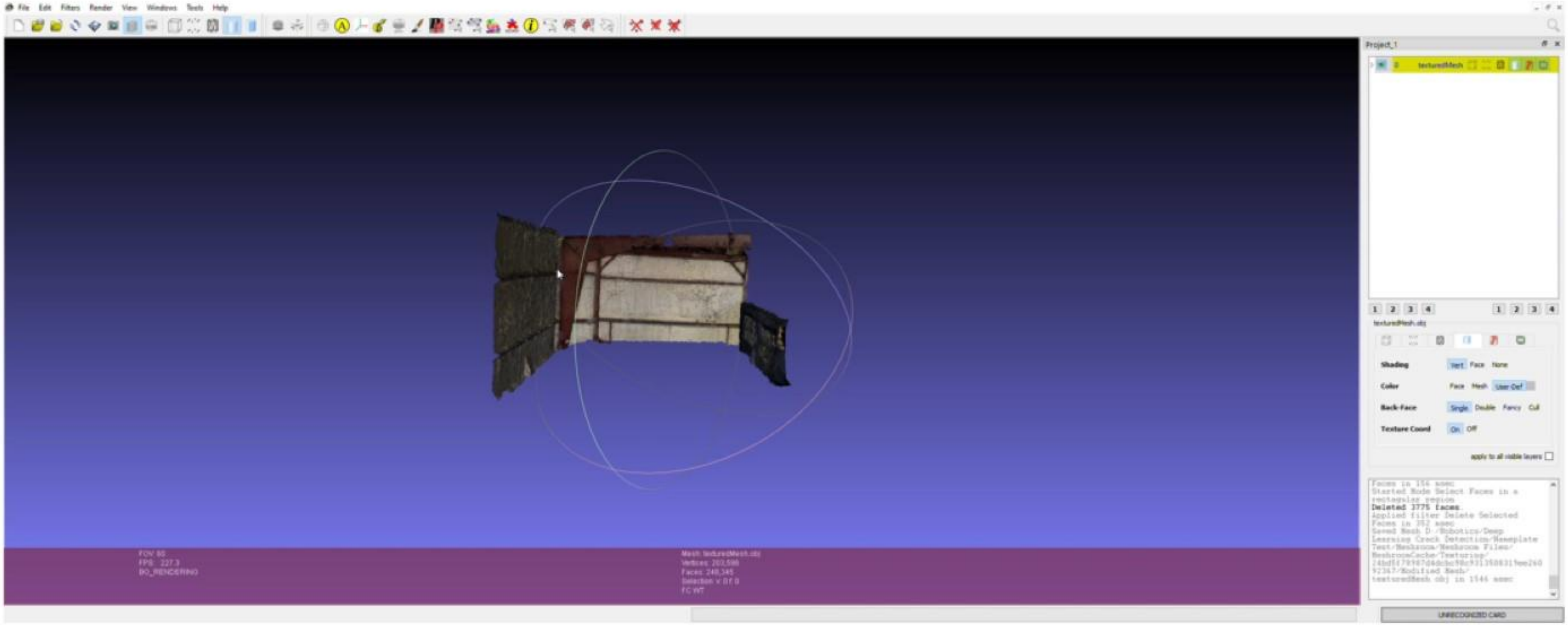
Trajectory in the -Z axis (negative altitude)

Autonomous Navigation

Autonomous Image Acquisition

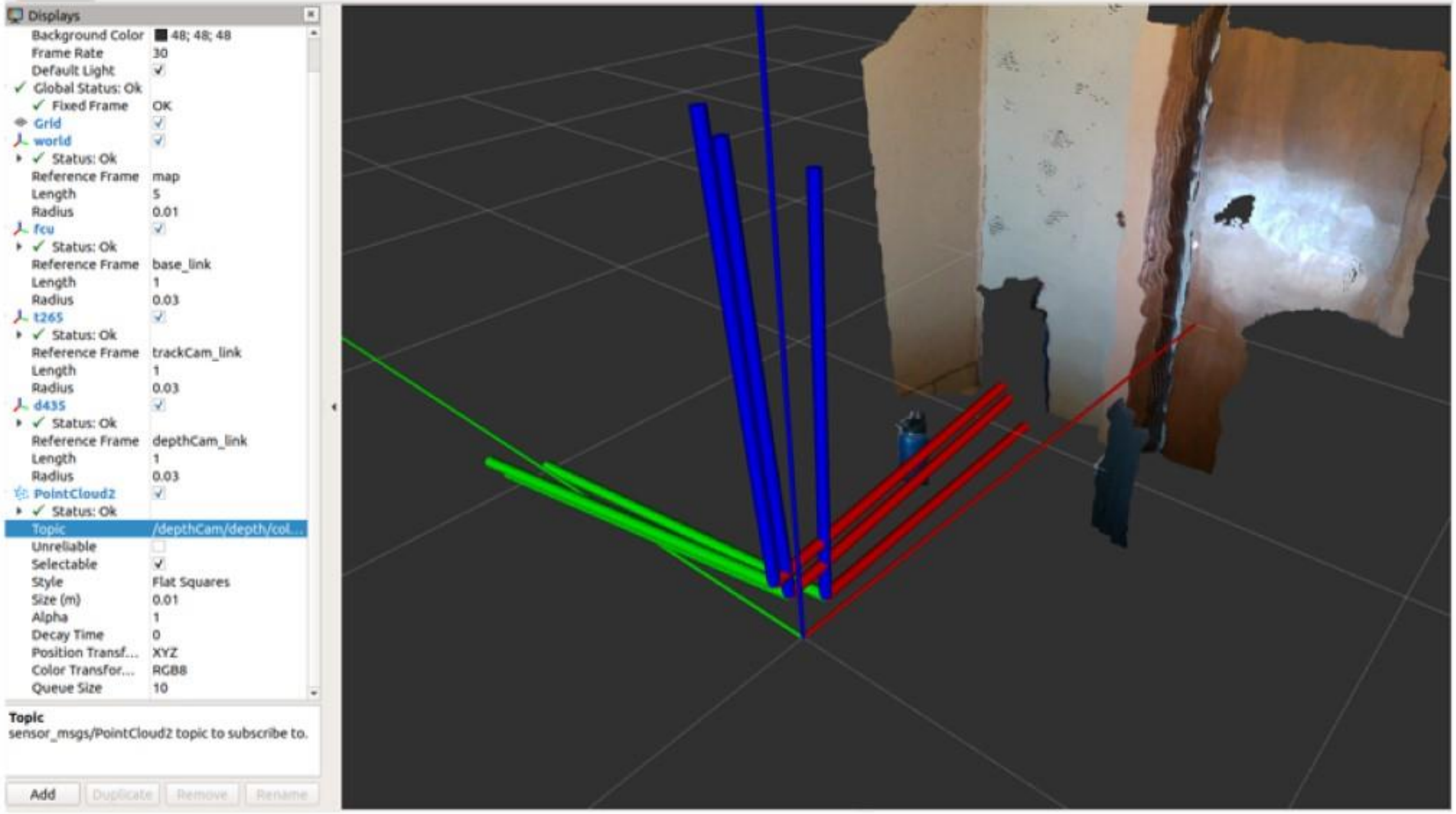
Autonomous Navigation

CAD for future trajectory generation



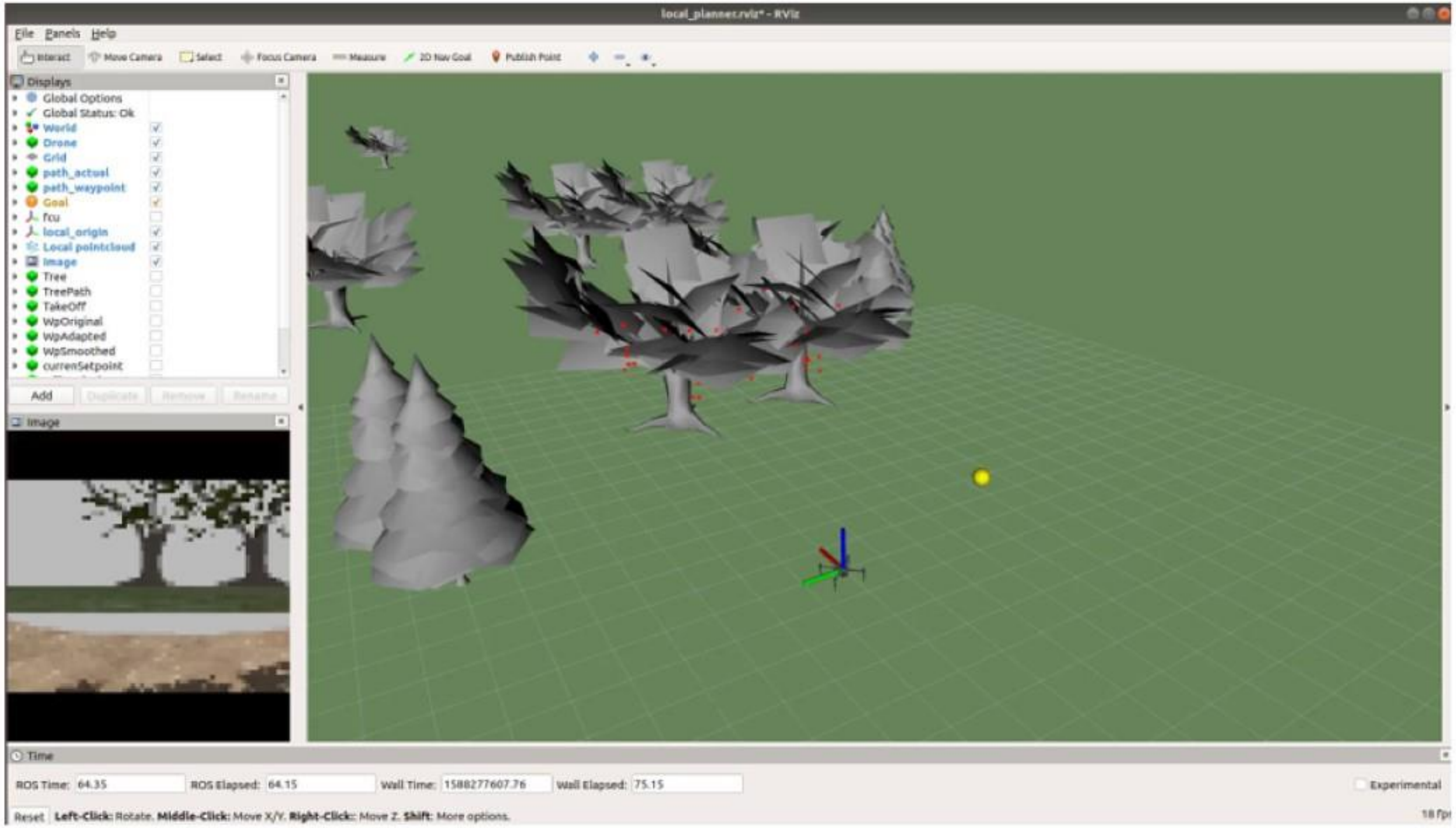
Autonomous Navigation

Reference frames setup and point cloud acquisition using Depth camera



Autonomous Navigation

Local planner test for obstacle avoidance (Simulation):



Market Benefits Assesment

Market gap: Open source platform to perform Close inspection with no GPS and beyond line of sight.

Not open sources.

Open source, not for GPS-denied environments.

Technology to Market Path

Industry Partners:

El Paso Electric

Industry Partners:

Marathon Refinery at El Paso