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Industry Day
Autonomous Robots for Mining and Forestry: Navigating rough terrain
Stellenbosch University
2026

Purpose of our research

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- High accurate 2D and 3D maps
- Fully autonomous systems
- Develop algorithms and sensor packs for rugged robots
- Monitor environments
  - Tree growth
  - Mine shaft progress
  - Safety inspection

- Navigate extreme rough conditions
  - Off the shelf algorithms and platforms do not work
- Navigate open areas
  - No path to follow
  - Current research focuses on tunnels and roads
- Develop platforms and algorithms
- Target environments that require full automation
  - No GPS
  - No communication
- Validate in forests and mines

From Left: Johan Fourie, Francisco Baudrand, Dr. Callen Fisher, Ruben Olivier

Enaex Africa Announces A Strategic Partnership With Stellenbosch University To Revolutionise Mining Safety Through AI And Robotics

Enaex Africa Research chair in mining robotics

- Aim:
  - Upskill students
  - Develop an autonomous inspection robot
  - Improve AI capabilities in mining robotics
  - Improve safety of underground mines
- Project duration:
  - January 2024 to December 2026

- Current team:
  - 2x PhD students
  - 6x MEng students
  - 3x 4th year students

Enaex Africa

Trends in the mining industry in SA

- Improve the safety of the mine
  - ENAEX: Humanize mining
  - DOK-ING: Don’t send a human to do a machines job
- Avoid mine disasters (disasters management)
- Keep humans away from dangerous areas
  - Extremely hazardous environments
  - Determine hazardous areas
- Continuously changing environment
  - Blasting nightly
  - Continuous monitoring
- Need to detect:
  - Loose rocks
  - Sagging walls
  - Fall of ground
  - Collapse
  - Gas build up
- Mapping and inspection:
  - Labor intensive (visual inspection)
  - Manual process
  - Remote (static) sensors
  - Conventional (manned) inspection vehicles

Environment challenges: Cluttered

From Underground Mines to Forests: Similar Robotics Challenges

Parallel environments

Mining	Forestry
Narrow tunnels	Dense vegetation
Uneven terrain	Uneven terrain
Low light / darkness	Heavy canopy shadows
Dust	Fog, rain, debris
GPS-denied	GPS degraded under canopy
Hazardous for humans	Hazardous for humans

Both environments are **unstructured, harsh, and dynamic**, which makes them ideal use cases for autonomous robotic systems.

Collaboration with Forestry and EucXylo

- **IMPACT OAL**
  - Intensive Monitoring of Planted And Competing Trees Open Air Laboratory
  - A state-of-the-art, flagship research plantation.
- The idea behind IMPACT OAL:
  - Build on the knowledge that we gained from the small- to medium-scale experimental studies
  - Examining how *Eucalyptus* responds to the environment through intensive, long-term monitoring.
  - Monitor the growth and responses of eucalypts from root to canopy
    - When planted at different levels of competition
- The plantation:
  - Area of about 9 hectares
  - Planted with *Eucalyptus* or *Pinus*
  - At Lourensford Wine Estate, near Somerset-West
- Requirements:
  - Constant monitoring and mapping -> Autonomous robots
  - Detect tree trunk thickness from 3D maps of the area
- https://eucxylo.sun.ac.za/open-air-lab/

What mining requires from us

2D and 3D maps of mine

Changes in map

- Estimate advance after blast
- If fall of earth, assist search and rescue

Safety inspection

- Identify hazards
- Identify potential fall of earth
- Identify discarded equipment

Mine management virtual walk through of mine

What forestry require from us

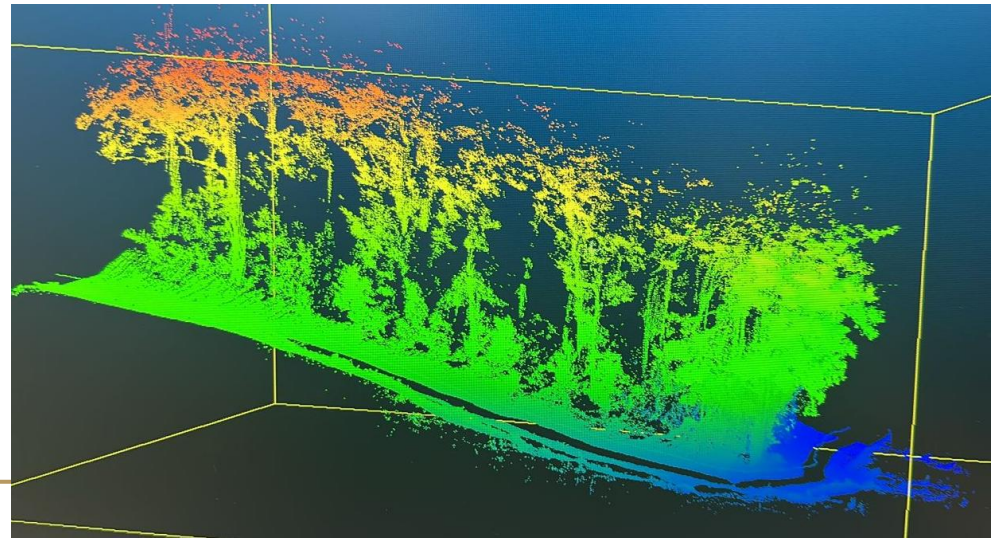
3D map of forest

Images of selected trees

Leaf samples

Width of tree stump

Estimated volume of canopy



Vehicle challenges

- Wear and tear
- No paths to follow
  - Open areas
- Steep slopes
- Narrow and closed passages
- Small areas
- Sensor degradation

Environment challenges

- Terrain
  - Rough
  - Steep slopes
  - Irregular
  - Unstructured
  - Slippery
  - Soft ground
- Water
- Poor illumination
- Dusty
- Cluttered environment

Other challenges

- Communication problems
  - Conductive ore
  - Large distances
- Map keeps changing

Due to these shared challenges,
we are exploring autonomous vehicles

Our approach

New project:

- Start date: January 2024
- End date: December 2026

More focused on the algorithms then the platforms

Problem: Cannot apply common algorithms to this environment

Not focused on exploration

- more on the safety and detailed mapping to facilitate mining operations

- Develop AI capabilities in mining robotics
- Form local industry and academic ties
- Develop an autonomous inspection robot for hazardous subterranean environments
- Develop Robotic Engineers for mining applications
- Based on a funding proposal for man-power not capital expenditure

ClearPath Robotics: Husky A200

Purchased base platform

Modified for sensor attachments

Added additional batteries for on board computers

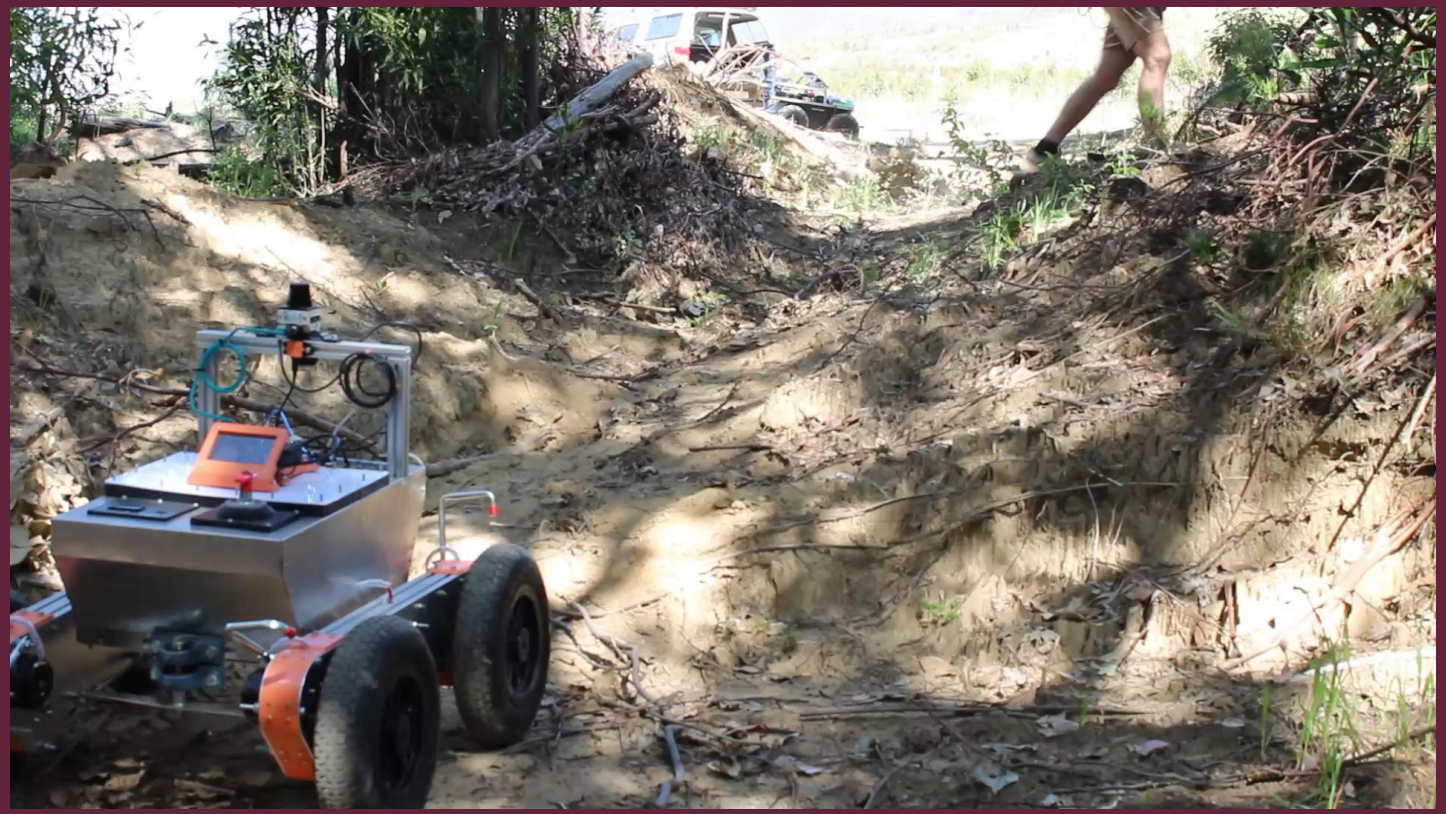
UGV development: InspectionBot

In parallel developed another UGV

Rocker-bogie suspension system

- Better for rough terrain
- 4-wheel drive

Stress Testing



Improved visual odometry and 3D mapping

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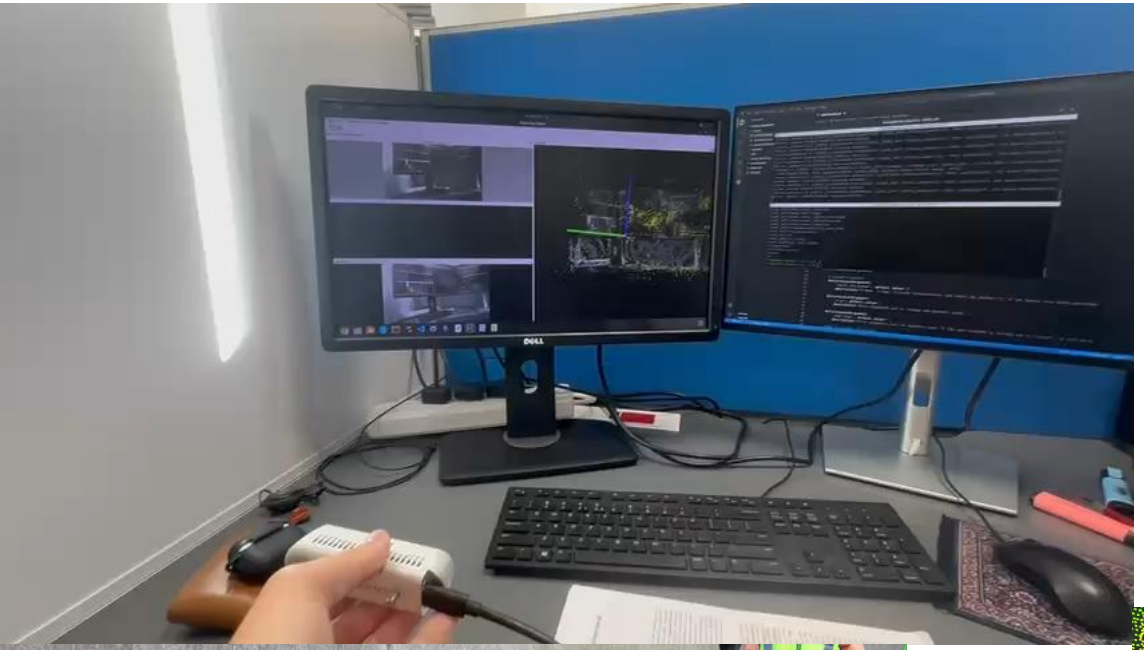
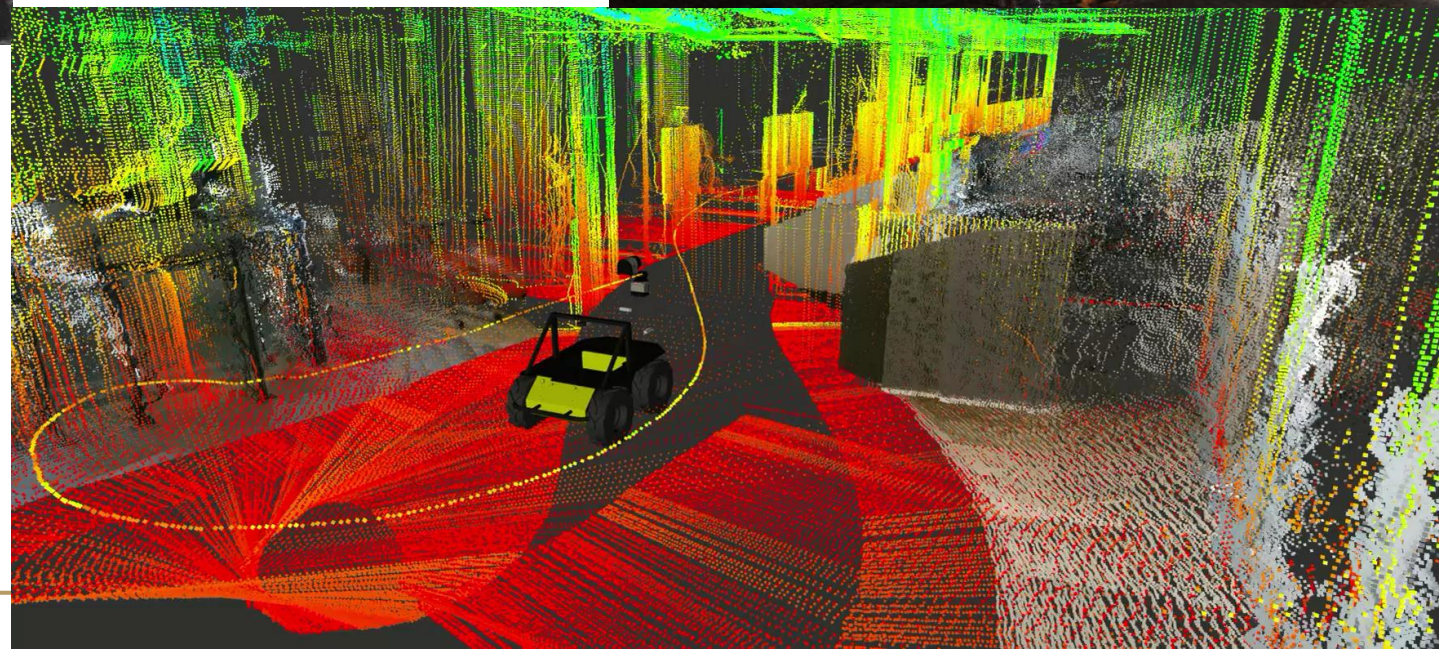
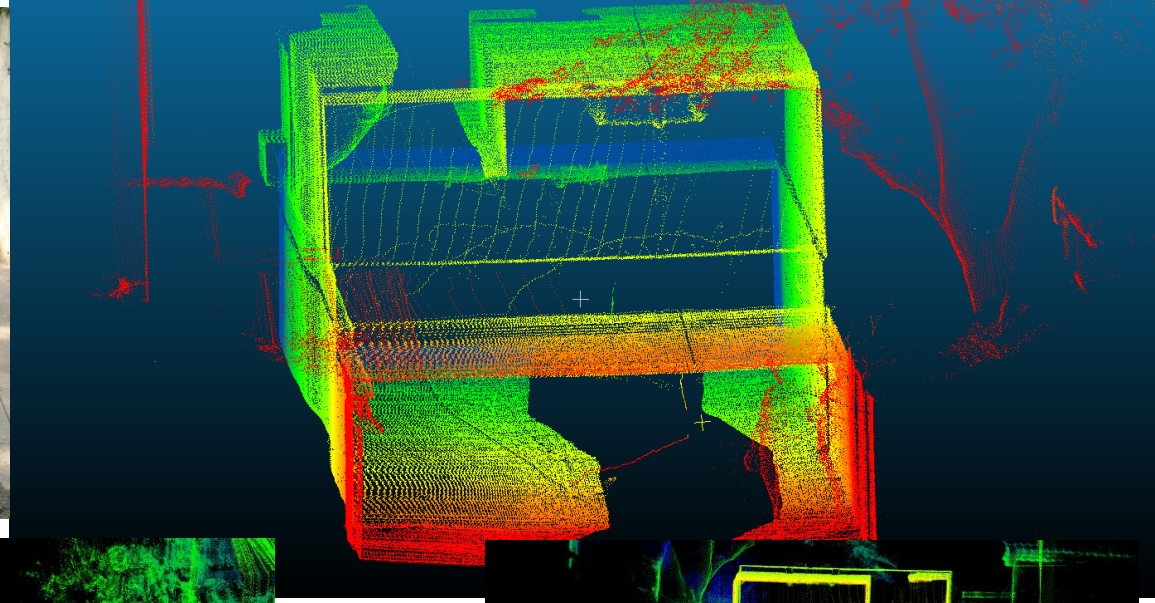
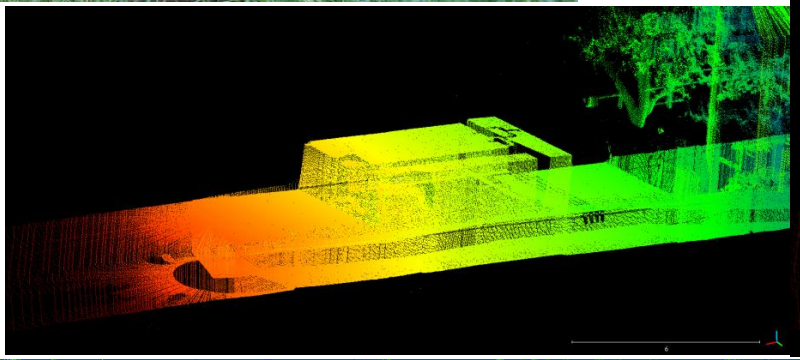
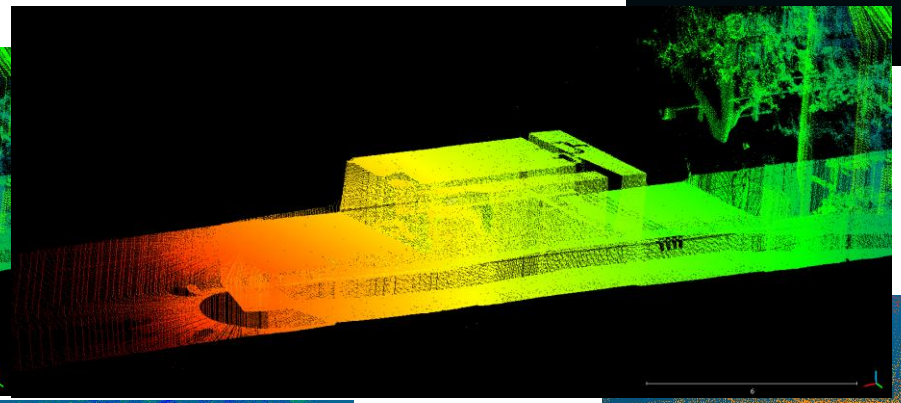


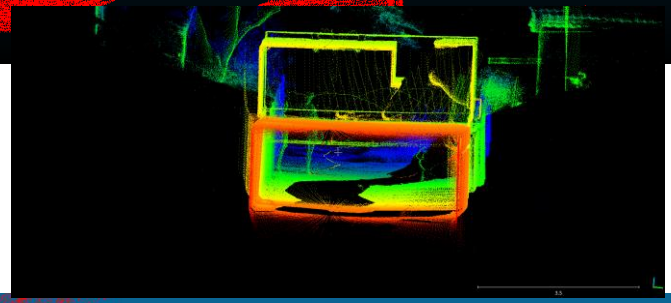


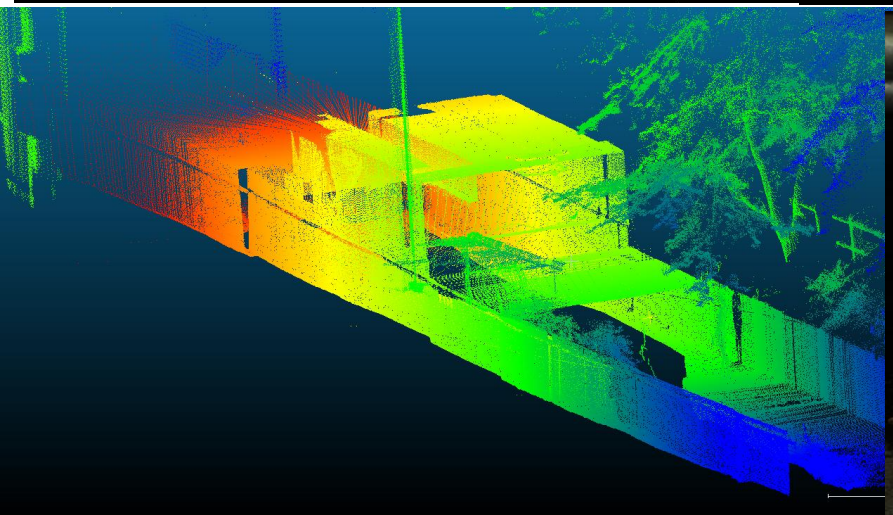
Canal test

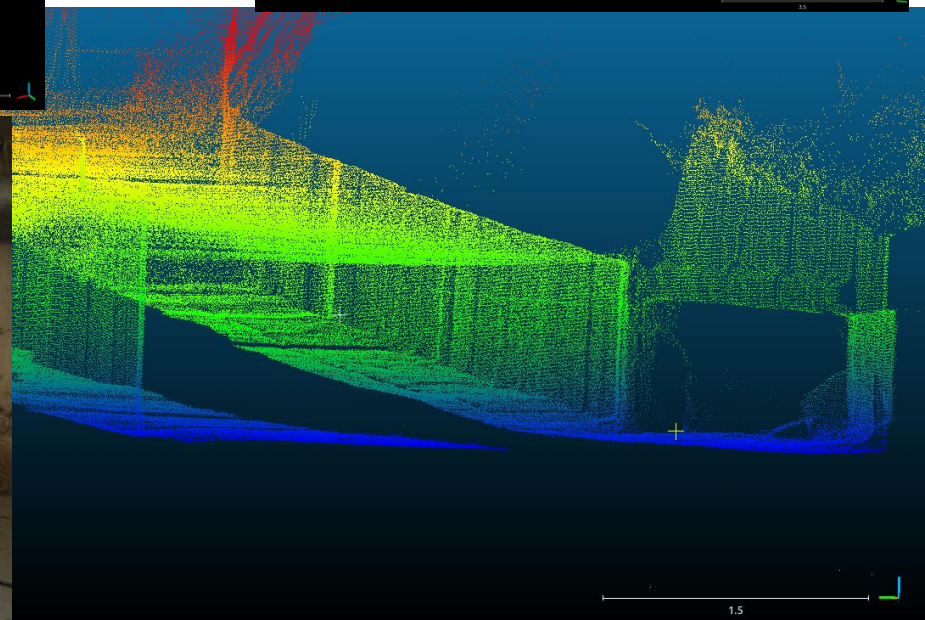


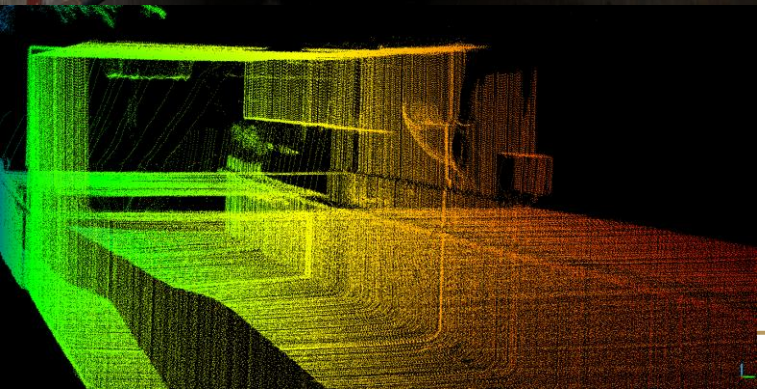


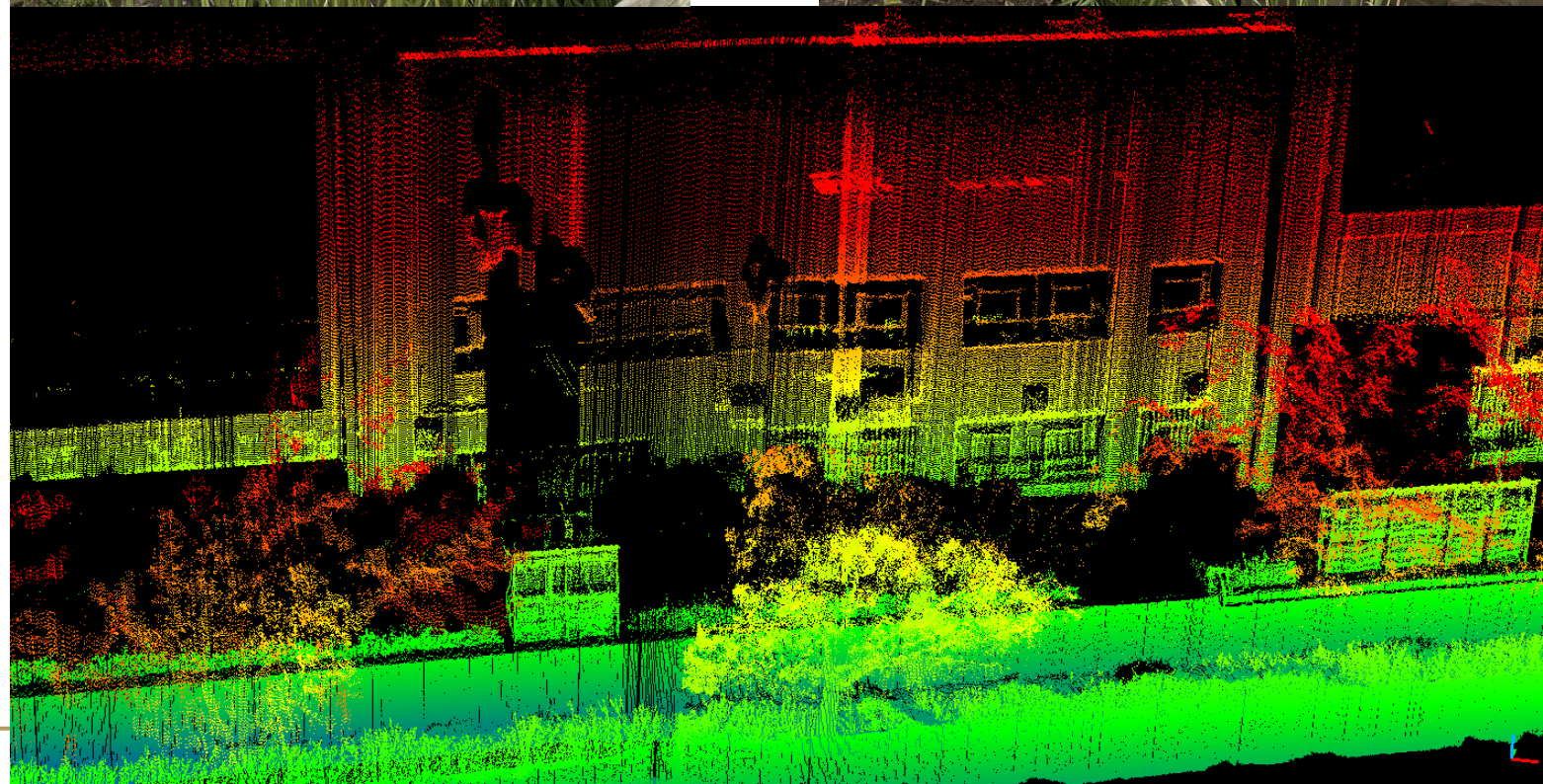


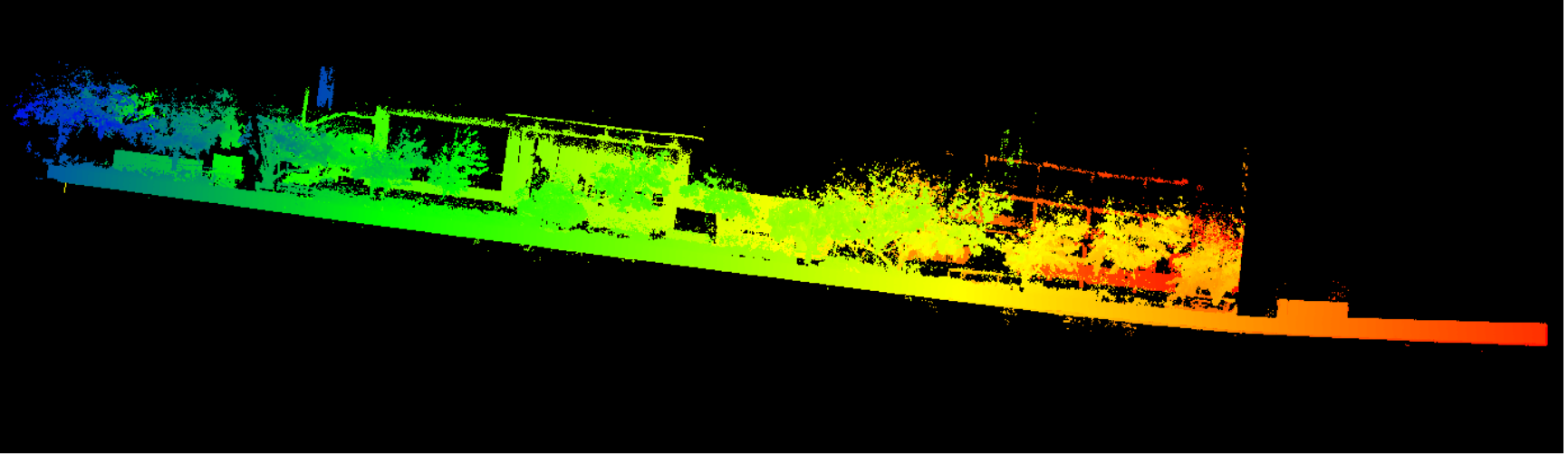


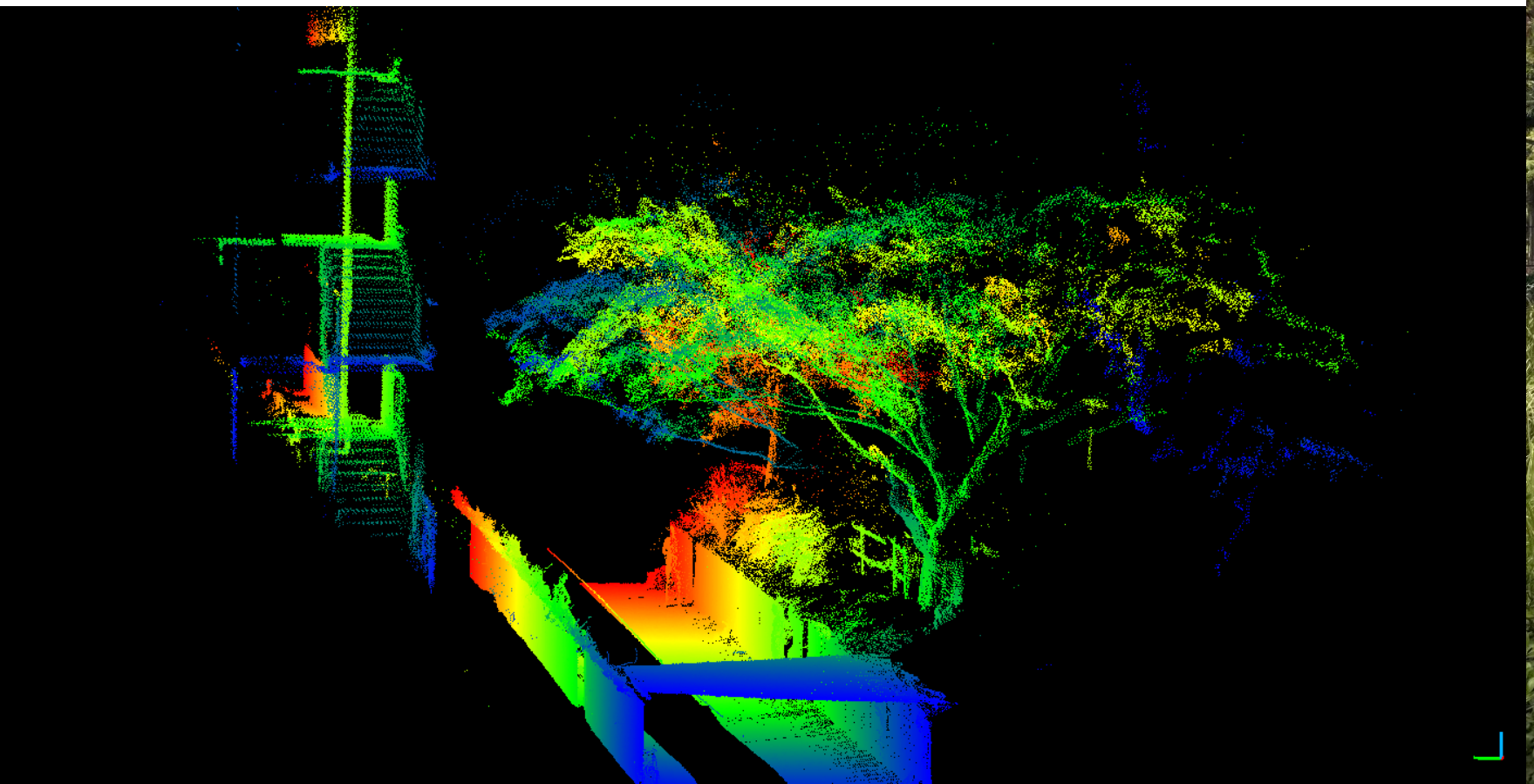












Forestry/Vineyard mapping

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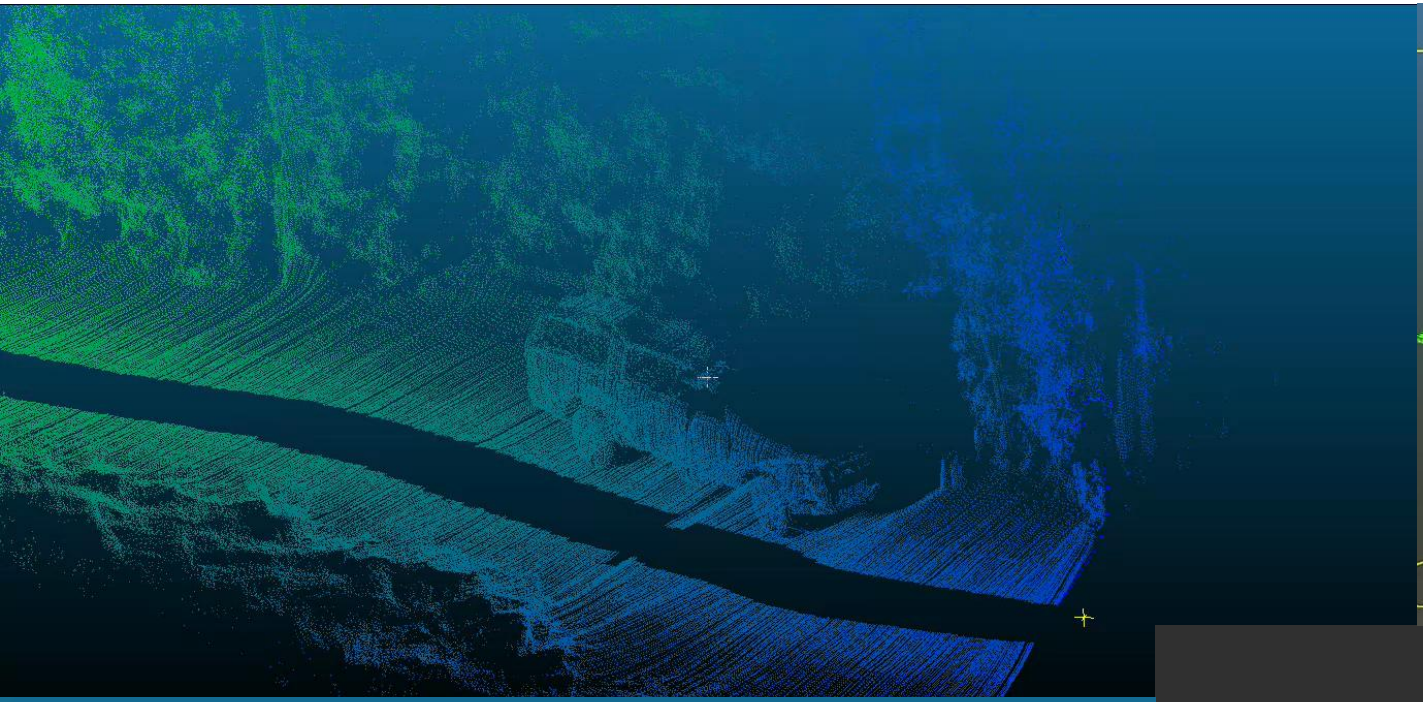
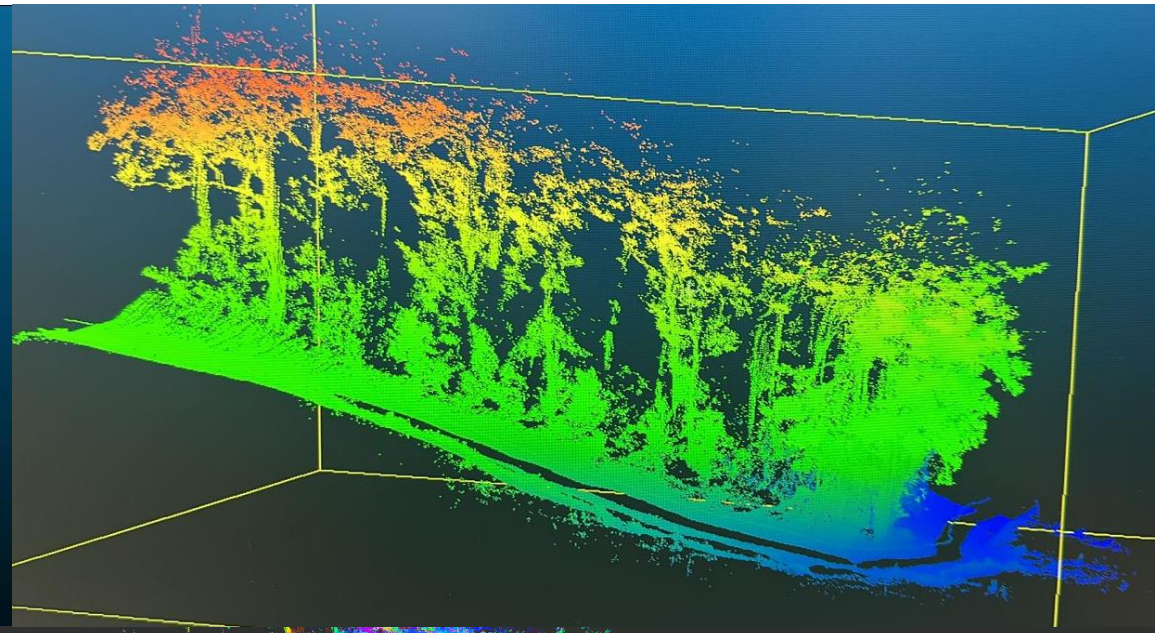
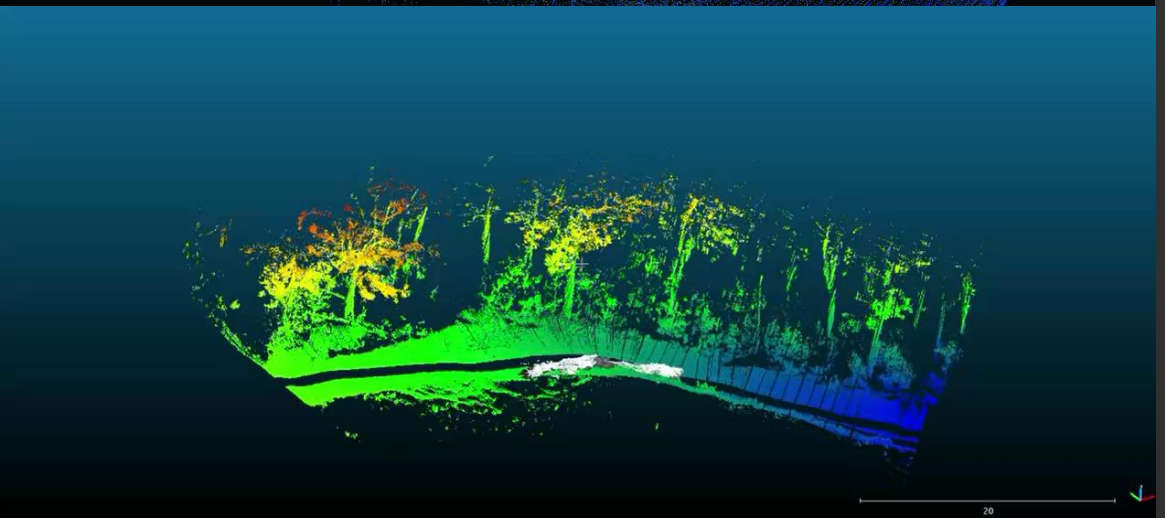
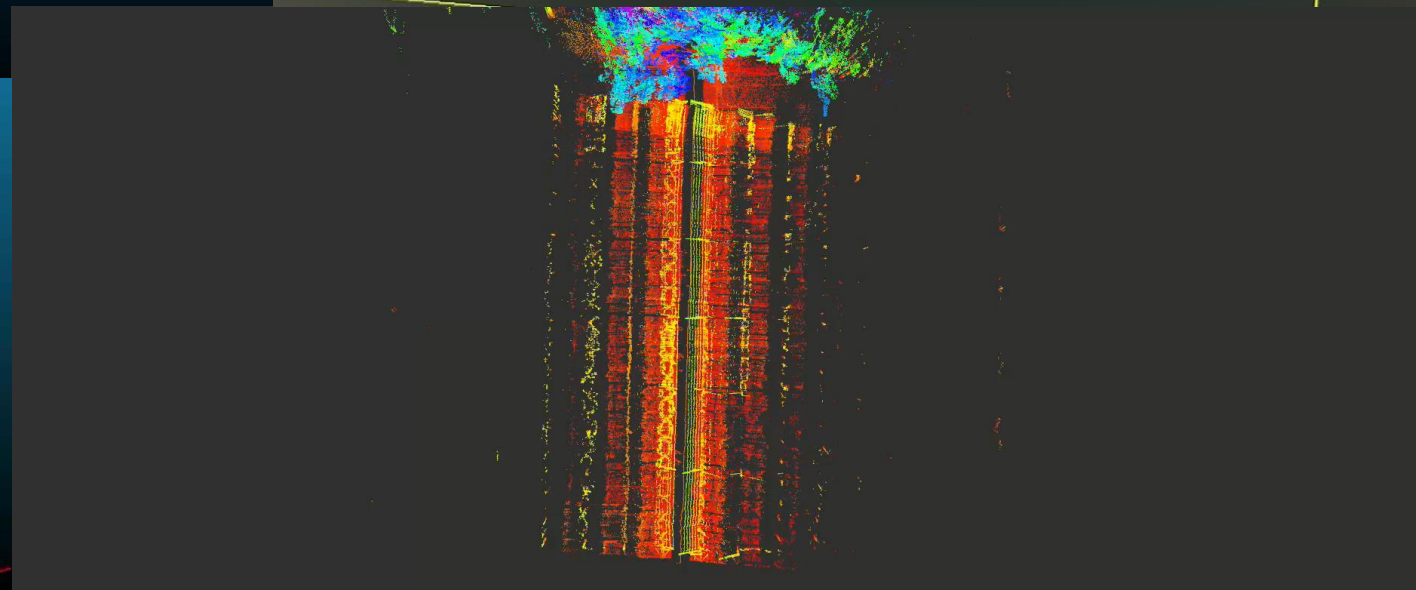


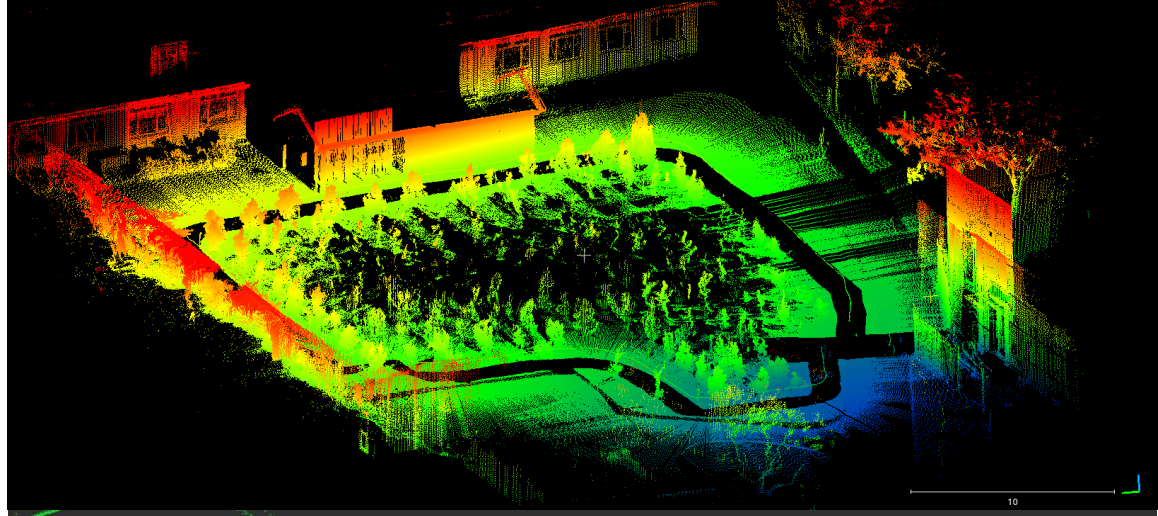


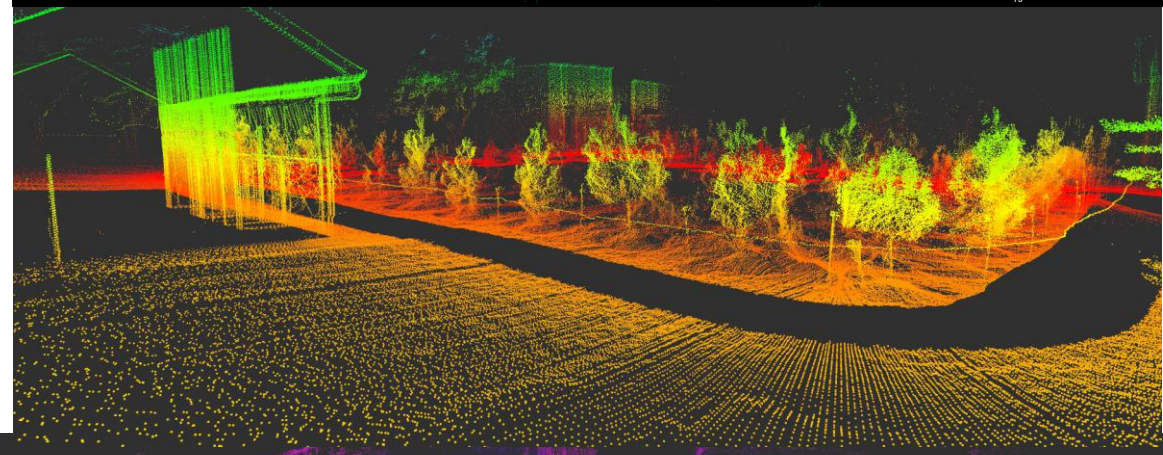


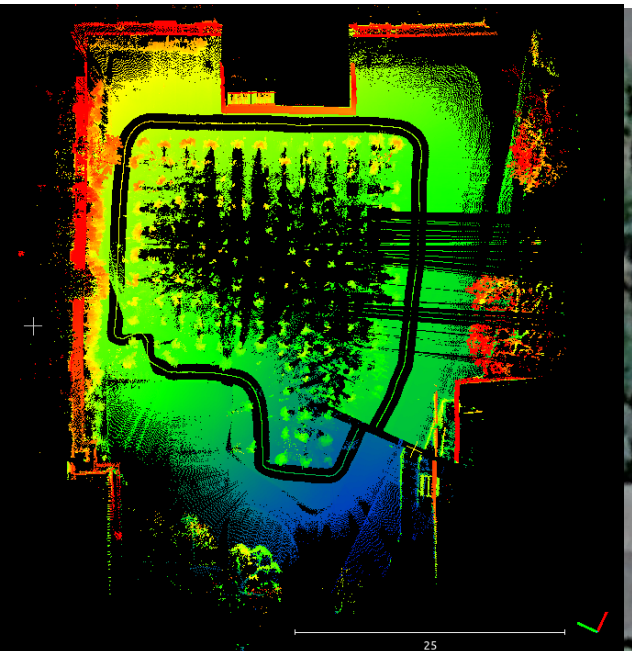


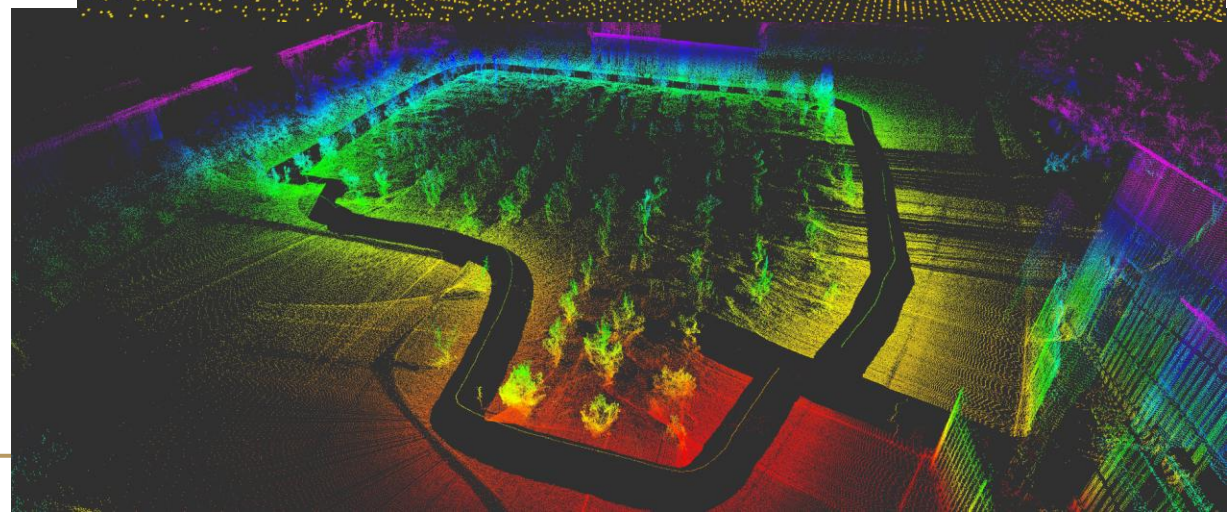
Forest tree test: No loop closure

- the EKF drifted by a total (Euclidean of xyz) of 1.91 m.
- Loop was 136.80 m long
- Drift rate of 1.40 %, or 1.40 cm of drift per metre driven.

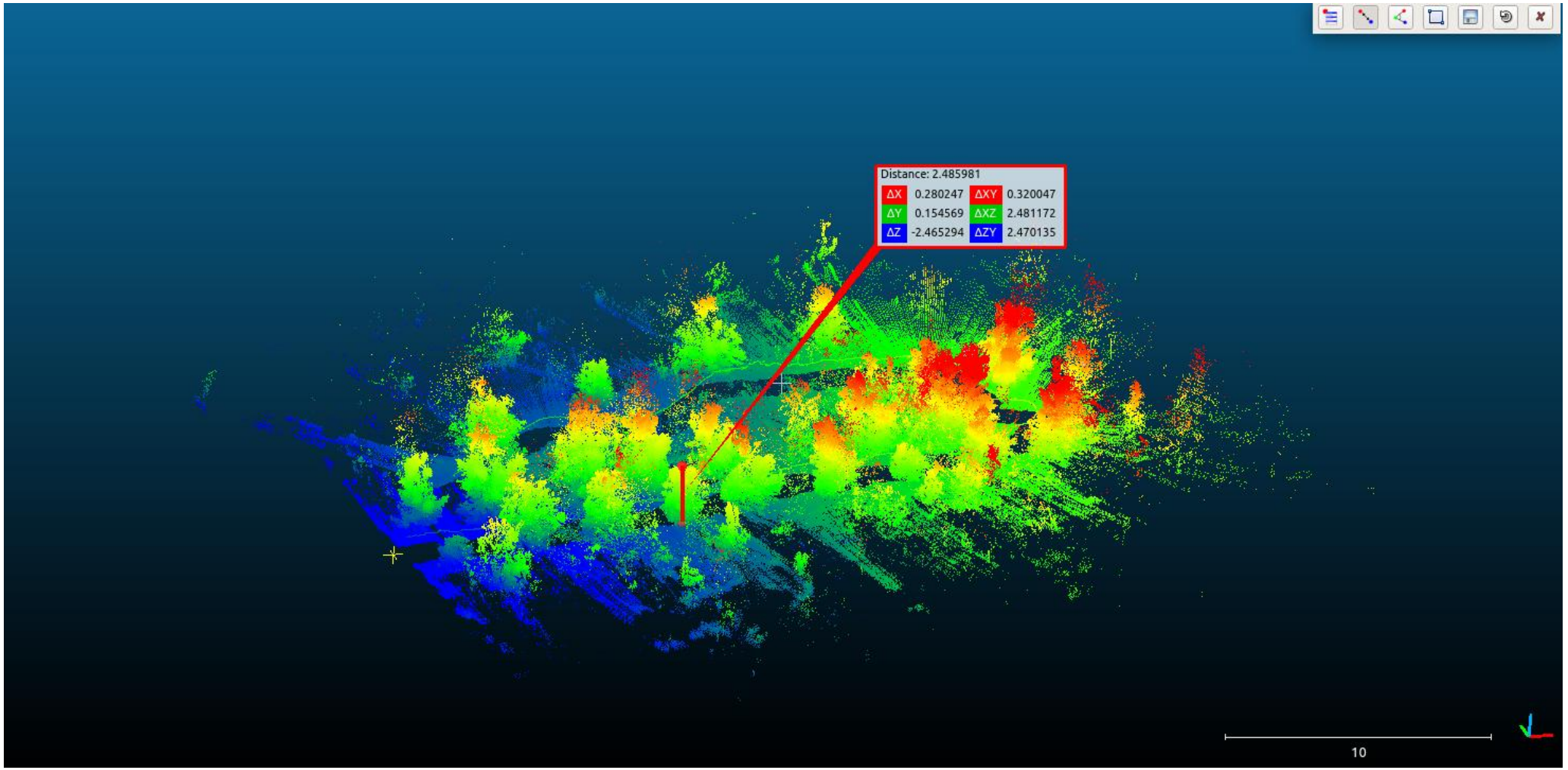






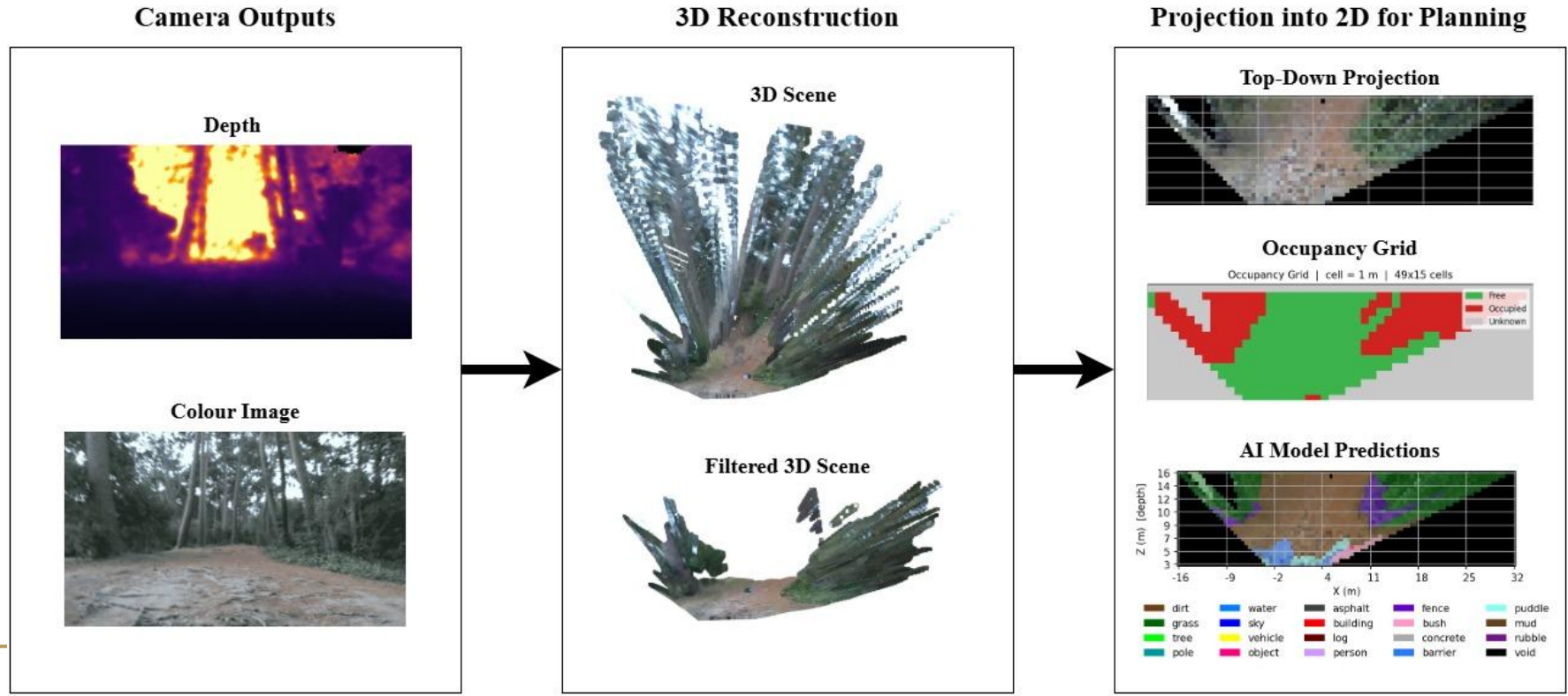


Some of the new results:
Low res scan of trees and measurements



Cost map: terrain classification

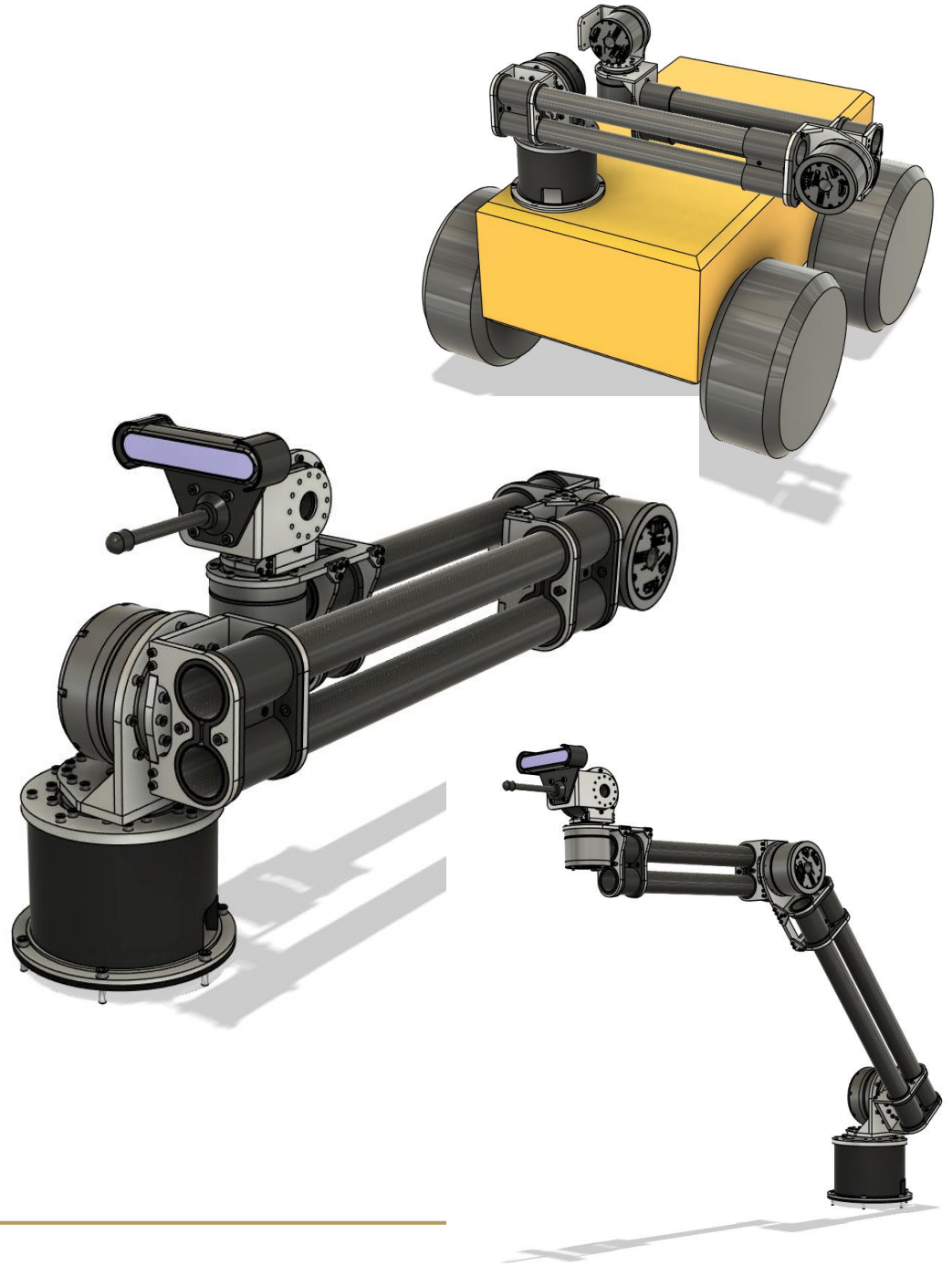
- The current measurements are random values
- Prediction by the semantic segmentation model needs improvement.
- Data from the trails at constantia



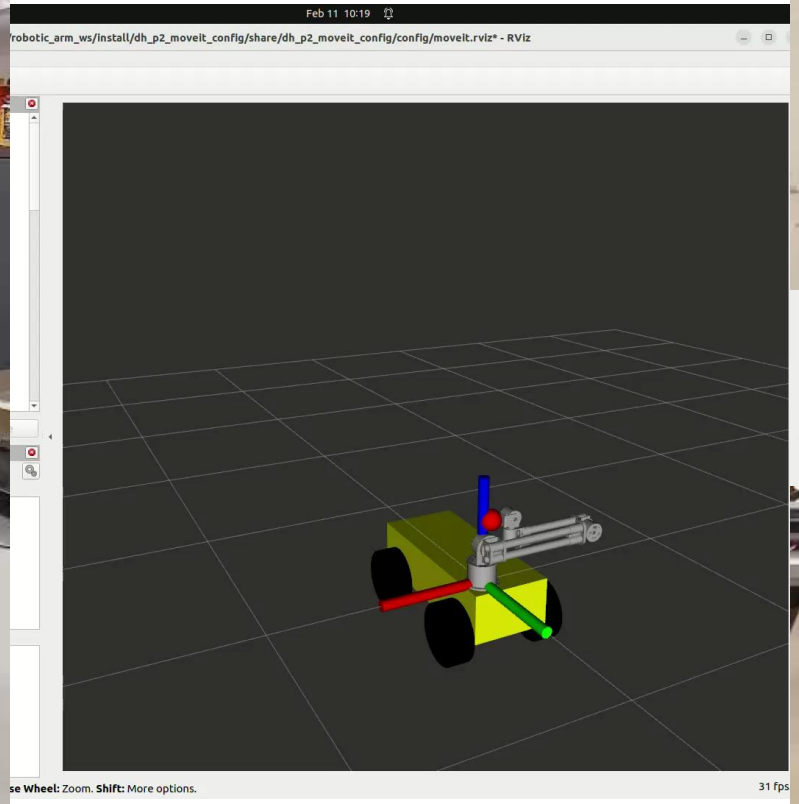
Robotic Arm Specifications

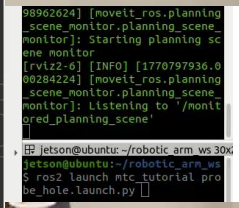
- 1.1 m Reach
- Total mass of 11.8 kg
  - Actuators - 8.8 kg
  - Other Components - 3 kg (excl. wiring)
- 5 kg payload (yet to be tested)
  - Functional at 4 Kg
- 5 Degrees of Freedom (DOF)
- Communication Protocol - EtherCAT
- Added depth camera and probe

- Purpose:
  - Tree samples
  - Stope face inspection



Robotic arm development





Preparation for underground testing

Status of project

- Mapping:
  - 2D and 3D mapping complete
  - LiDAR and RGB overlay
  - Loop closure and map storage working
- Sensor pack:
  - Handheld sensor pack that attaches to robot
  - Enables mapping and robot control
- Autonomy:
  - Basic autonomous navigation working
  - Frontier exploration working
- Next steps:
  - Terrain identification and improved path planning
  - Improved autonomous navigation (Terrain aware)
  - Deploy drones

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