Backpack-based inertial navigation and LiDAR mapping in forest environments

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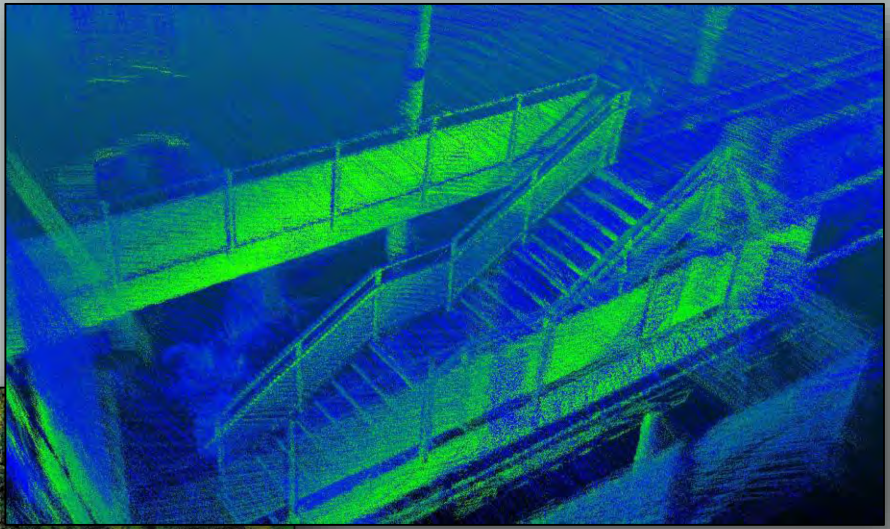
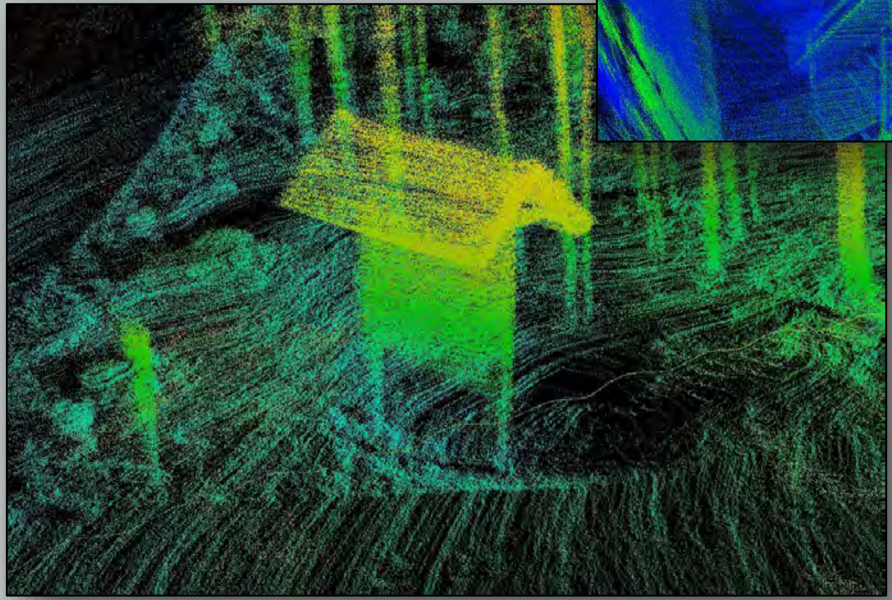
Introduction

- 3D model our environment

- **Li**ght **D**etection **A**nd **R**anging (LiDAR)
  - Light
  - Laser scanner
  - Point cloud

- Airborne or ground-based
  - Airborne Laser Scanning (ALS)
  - Terrestrial Laser Scanning (TLS)
    - *Static* TLS and *Mobile* TLS


Point cloud of stairs in SLU.


Point cloud of sign and trees at Stadsliden.

Introduction – Static TLS

- Commonly referred to as simply TLS
- Accurate
- Cumbersome!

Photo courtesy of *Swedish University of Agricultural Sciences.*

Photo courtesy of *Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology*.

Photo courtesy of *Martin Hämmerle et al.*

Introduction – Mobile TLS

- Commonly referred to as Mobile Laser Scanning (MLS)

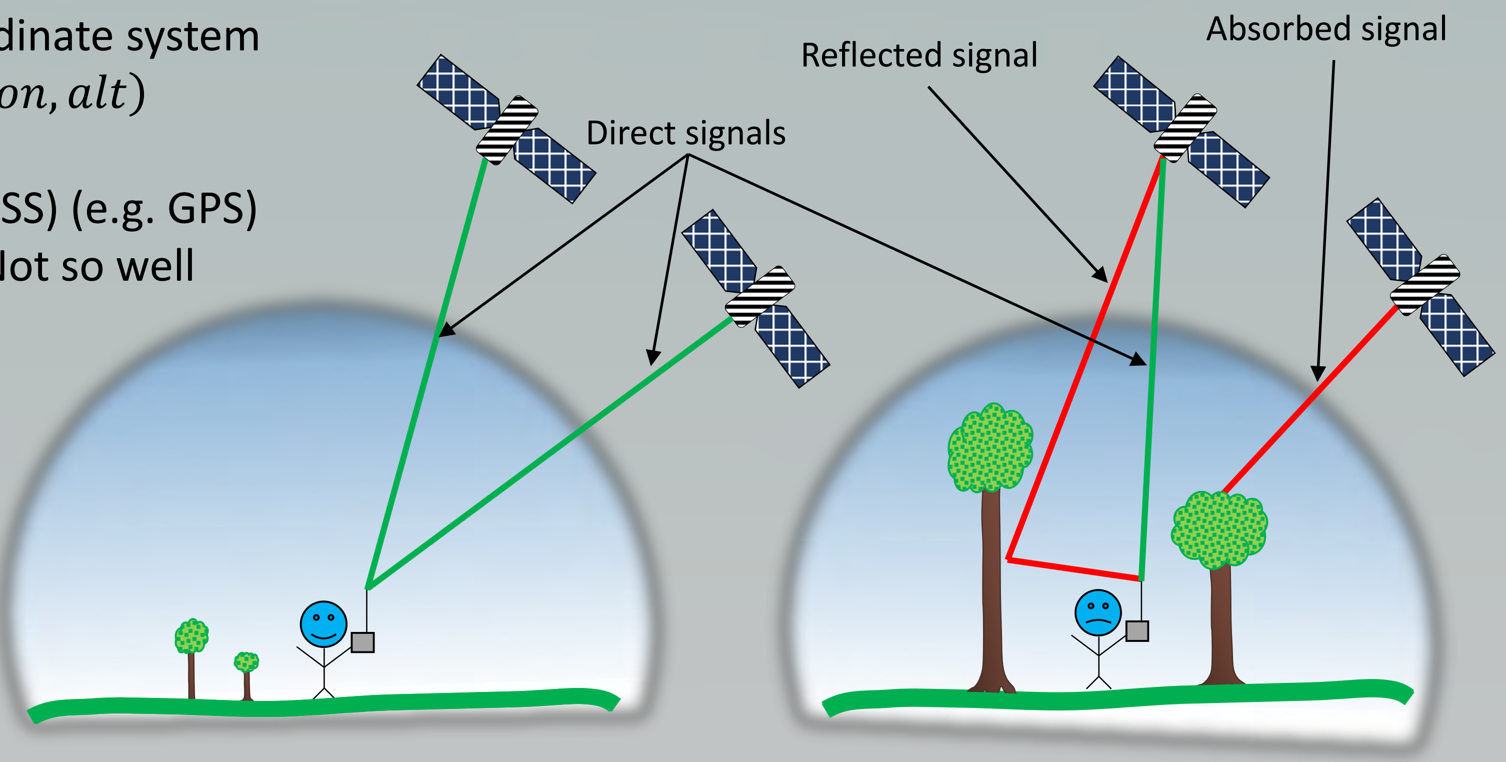
Photo courtesy of *REIGL* Laser Measurement Systems.

Photo courtesy of *Johan Holmgren.*

Photo courtesy of *REIGL* Laser Measurement Systems.

Introduction – Georeferencing

- Local coordinate system → world coordinate system
  $(x, y, z) \rightarrow (lat, lon, alt)$
- Global Navigation Satellite System (GNSS) (e.g. GPS)
  - Works well in large, open areas. Not so well otherwise…
- In forests:
  - Multipathing and absorption
    →
  - Varying signal quality
    →
  - Varying position estimate quality
- GNSS positioning harder for MLS compared to TLS…



Introduction – Georeferencing

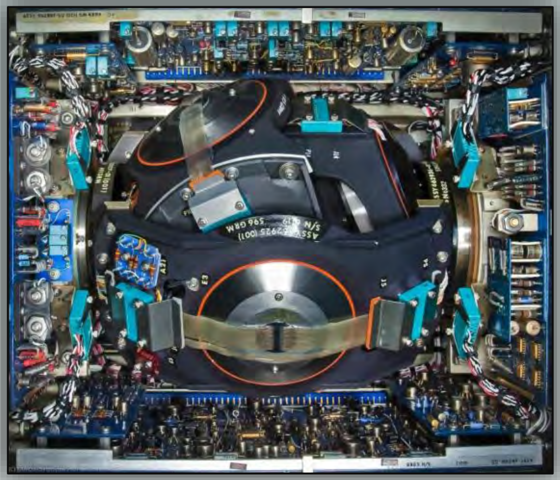
What do you do?

Introduction – Georeferencing

Include other measurement instruments!

Introduction – Georeferencing

- Most common measurement instruments:
  - GNSS
  - Laser scanner
  - Inertial Navigation System (INS)
  - Camera
  - Other…
- Accumulation of error – *Drift*
- The idea: The measurement instruments can support each other
- *Sensor fusion*
  - Post-processing
  - Real-time



INS used in Concorde. Photo courtesy of *Ramos Christophe.*

Stereo cameras. Photo courtesy of *FLIR Integrated Imaging Solutions.*

Introduction – Focus of this thesis

- Assembly and analysis of a backpack-based MLS system to be used in **forests**.
  - INS
  - GNSS
  - Laser scanner

- Post-process the data with the *Dynamic Calibration* algorithm
  - Expand and improve

- The MLS data was compared to TLS and manual caliper data sets
  - Diameter at breast height (DBH)
  - Root mean square error (RMSE)
  - Bias

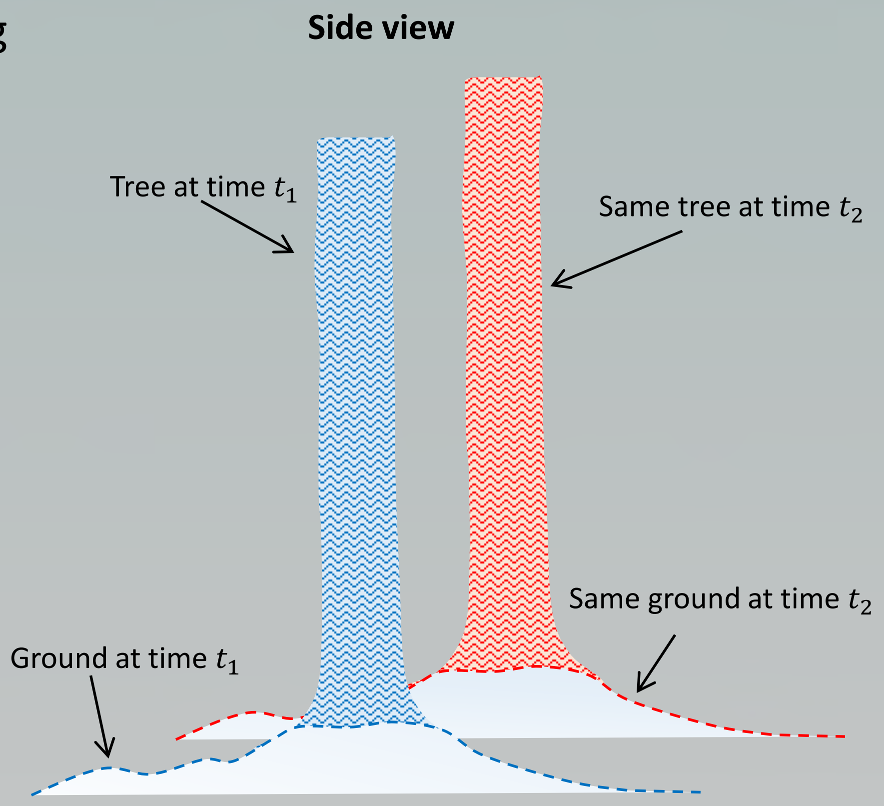
$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{ri})^2}{n}}$$

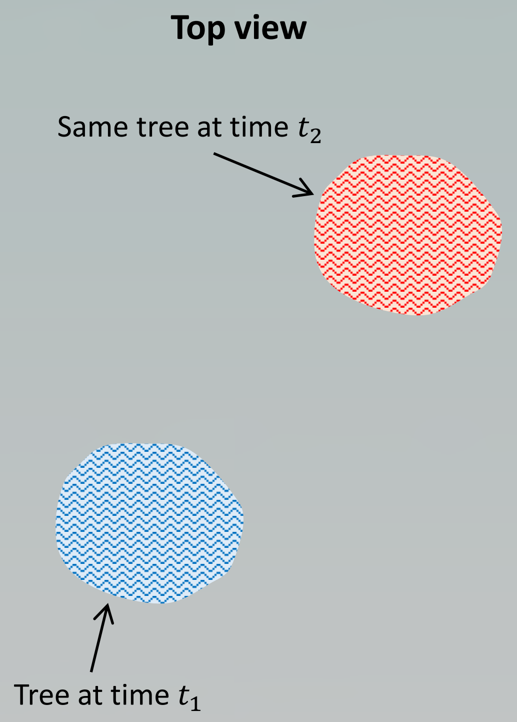
$$\mathrm{Bias} = \frac{1}{n}\sum_{i=1}^{n}(x_i - x_{ri})$$

x_i: *i*th estimation
x_{ri}: *i*th reference value
$\overline{x_r}$: average reference value
n: total number of estimations

Theory

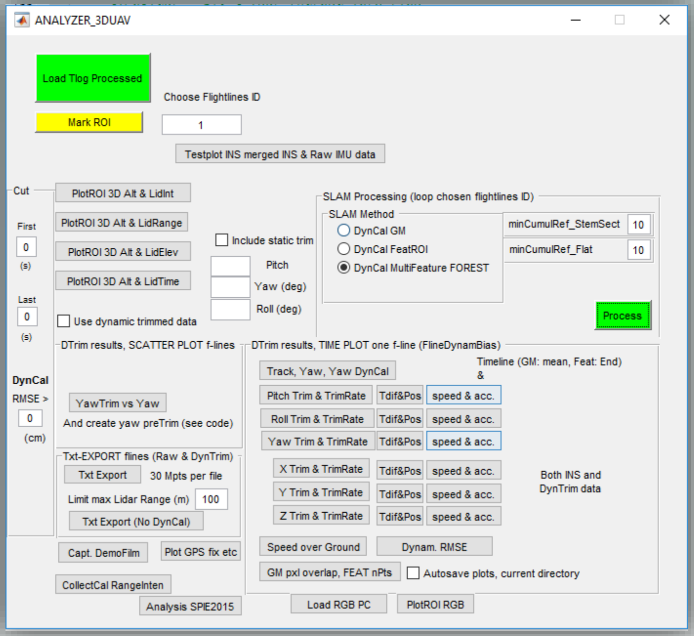
- Effects of drift & georeferencing
  - Multiple tree copies
  - Multiple ground layers

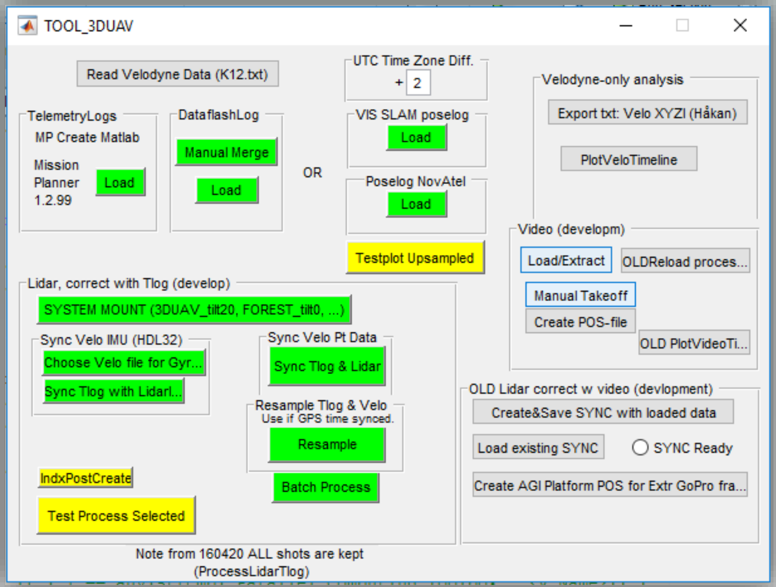




Theory – The dynamic calibration algorithm

- Series of Graphical User Interfaces (GUI:s) written in MATLAB
- Developed by Michael Tulldahl *et al.* at Totalförsvarets forskningsinstitut (FOI)
- Uses previous data to correct





MLS backpack system

- Instruments used:
  - Velodyne VLP-16 (laser scanner)
  - NovAtel GPS-702-GG (GNSS Receiver)
  - NovAtel SPAN IGM-S1 (INS)

Photos courtesy of *NovAtel and Velodyne LiDAR.*

Photo courtesy of *Johan Holmgren.*

Contributions to the dynamic calibration

- Adapted

- Expanded
  - Vertical point cloud correction
  - Other…

- Tested and bug fixed…

Survey Stadsliden

- Stadsliden, 2017-03-30
- Total survey duration: 12 minutes
- Area of interest: 40 m diameter
  - TLS data set: same size as MLS
  - Caliper data set: 24 m diameter

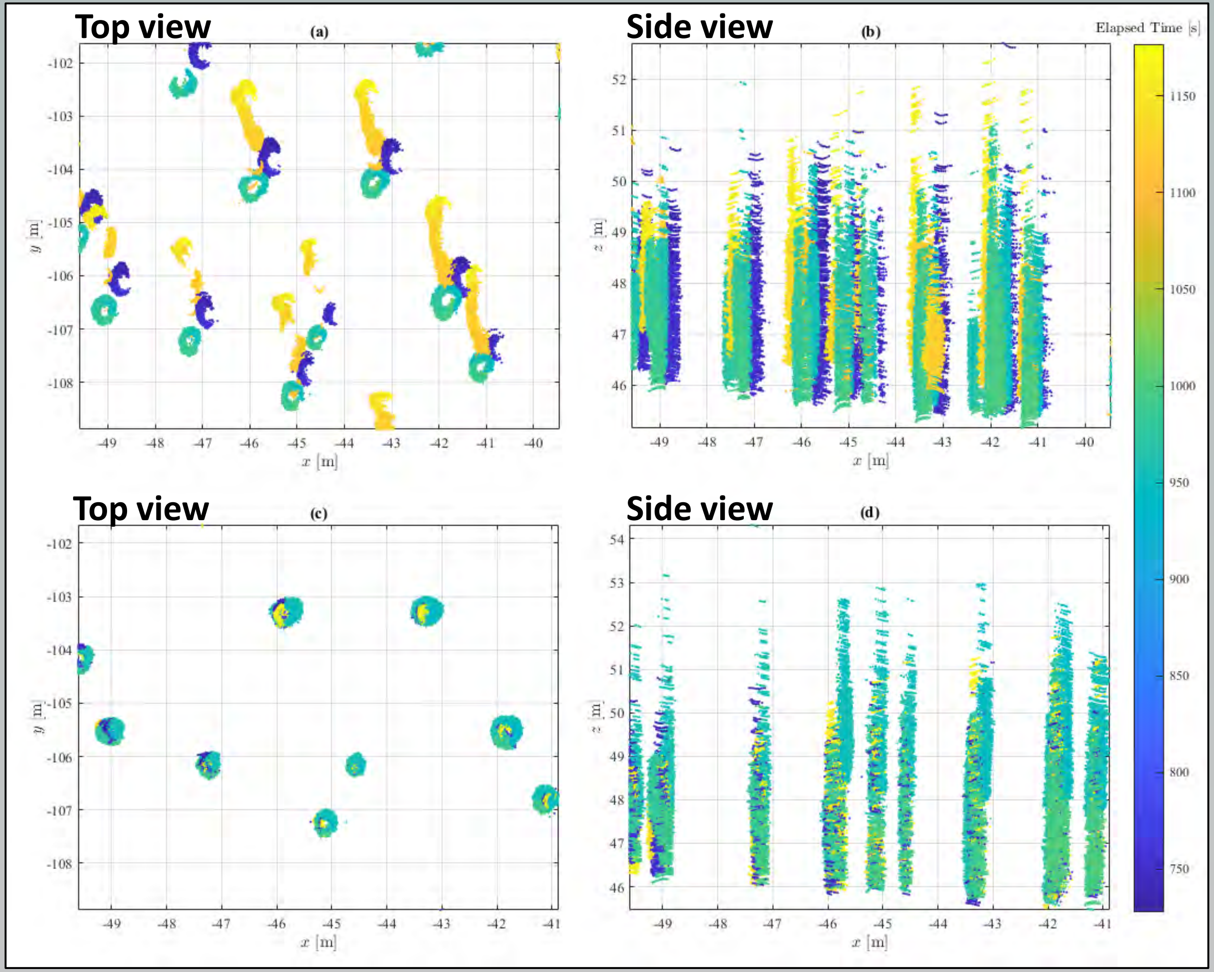
Photo courtesy of *Johan Holmgren.*

Post-processing…
Please wait

Results and Discussion

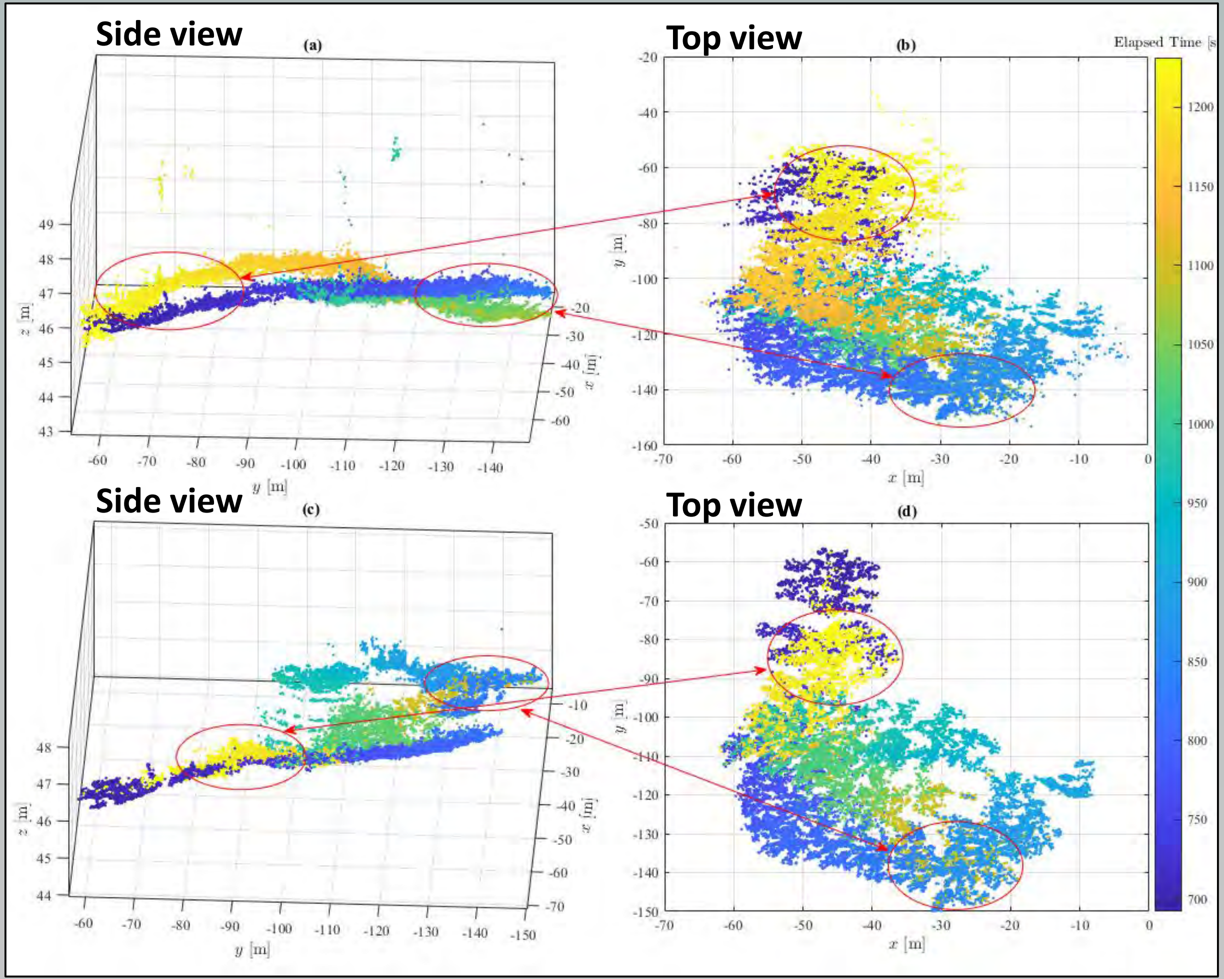
Multiple trees & ground correction

- Tree stems before and after (in a small region)
- Successful vertical translation



Multiple trees & ground correction

- Ground layer before and after
- Successful vertical translation



Co-registration – Comparison

	MLS & TLS	MLS & caliper	TLS & caliper
DBH RMSE	27.00 mm	16.95 mm	10.69 mm
DBH Bias	−9.33 mm	−10.58 mm	−0.97 mm

Other forest studies:

- TLS study by Olofsson & Holmgren:
  - TLS compared to caliper
  - DBH RMSE ≈ 10 mm
  - DBH Bias ≈ 0.6 mm

- Backpack MLS study by Liang *et al.*:
  - MLS compared to TLS
  - DBH RMSE = 50.6 mm
  - DBH Bias = −11.1 mm

Conclusions and future work

- Much potential to be used in the future

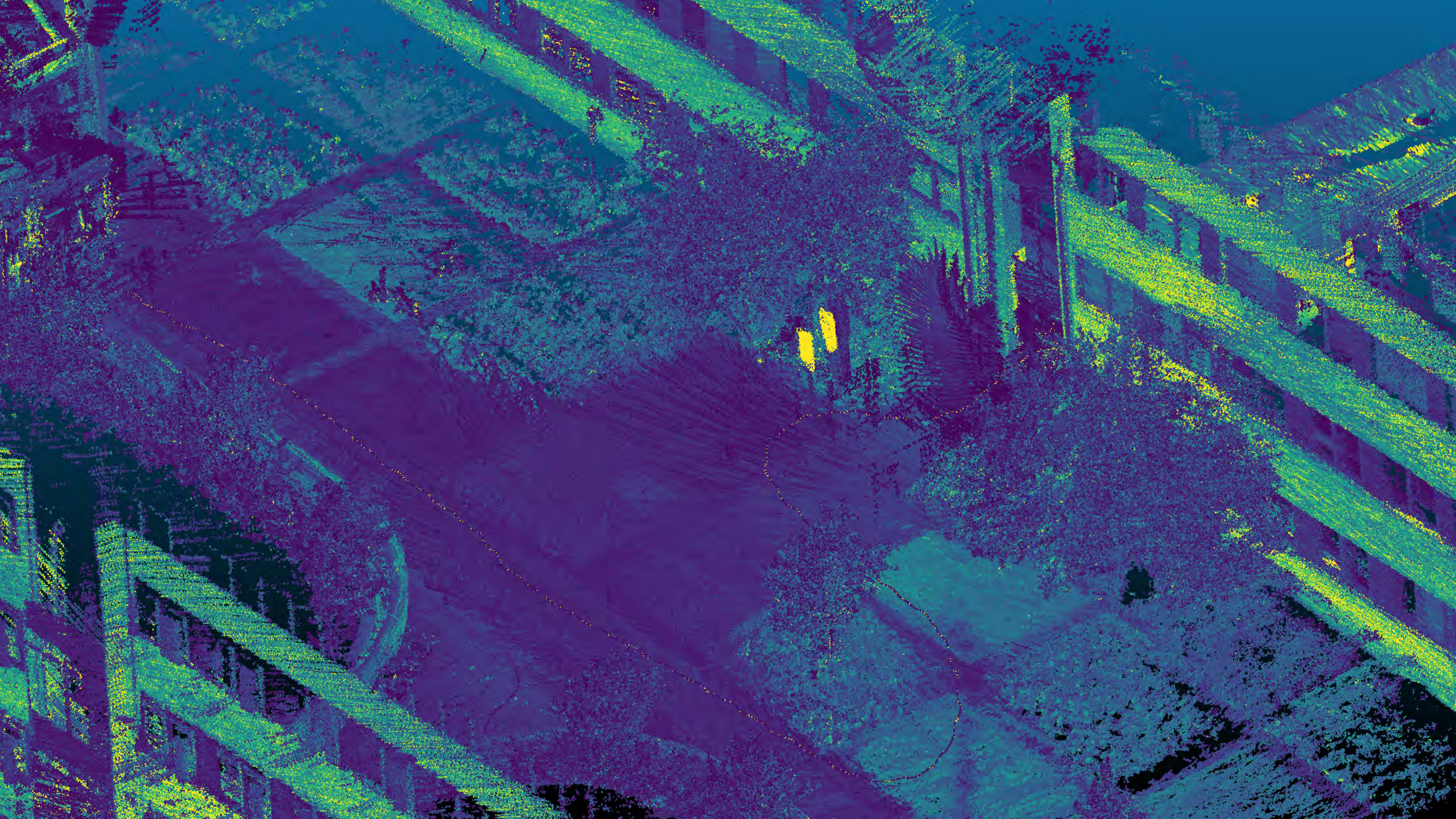
- Future work:
  - More forest tests (e.g. varying forest properties, different walking patterns)
  - Expand and test the dynamic calibration further

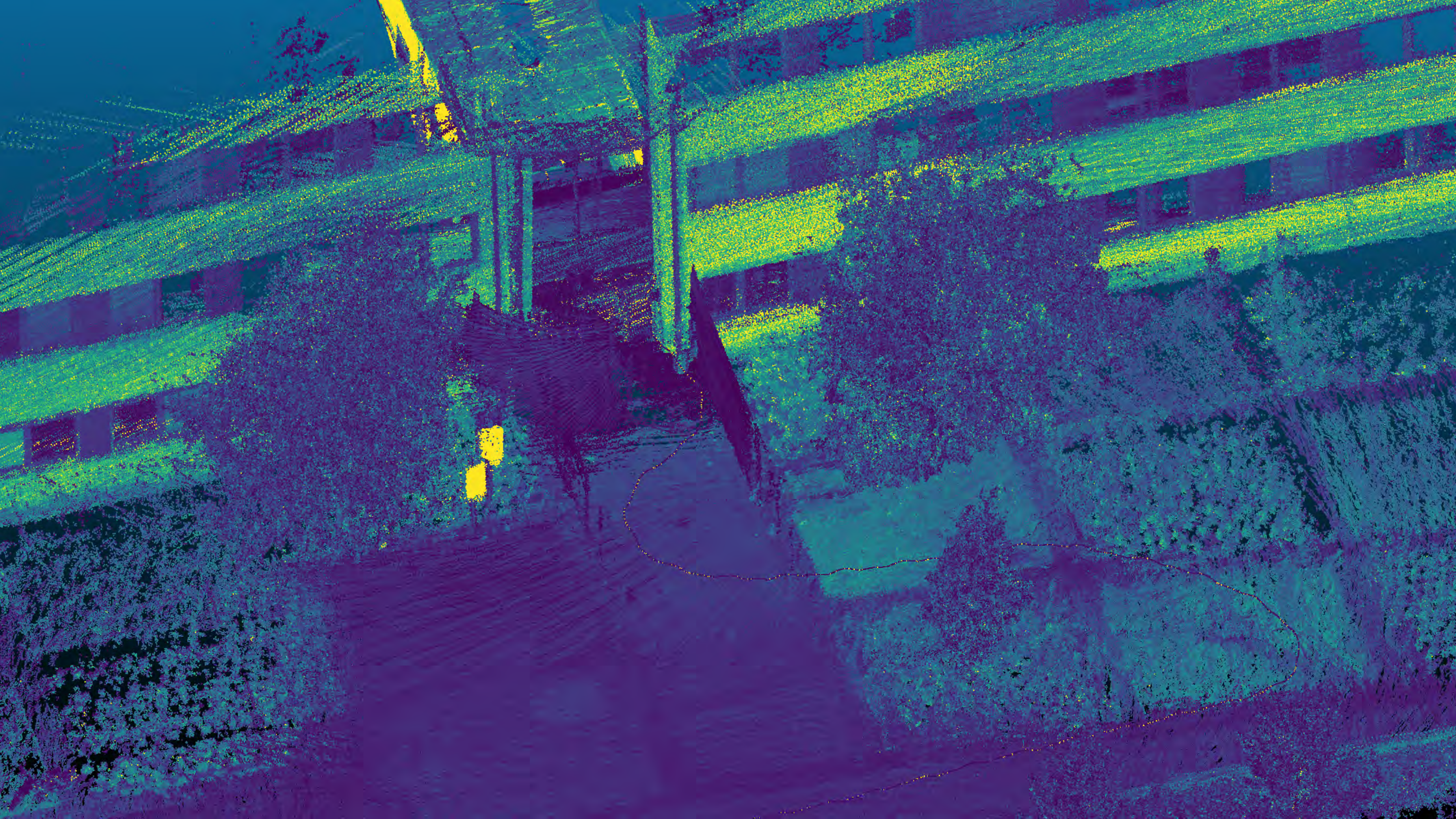
- Autonomous harvesters

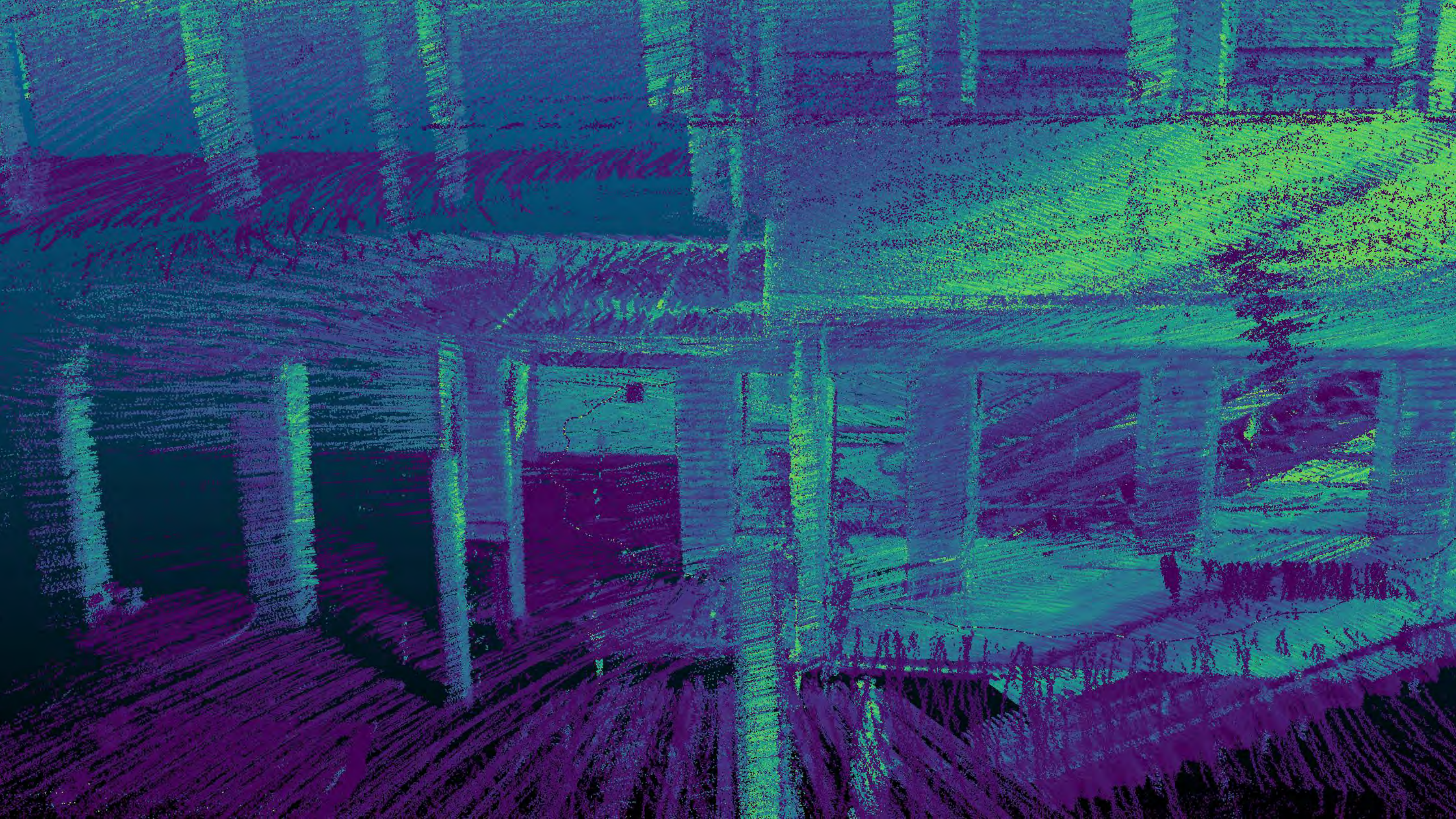
- Other applications such as
  - Self-driving cars/robotics
  - …

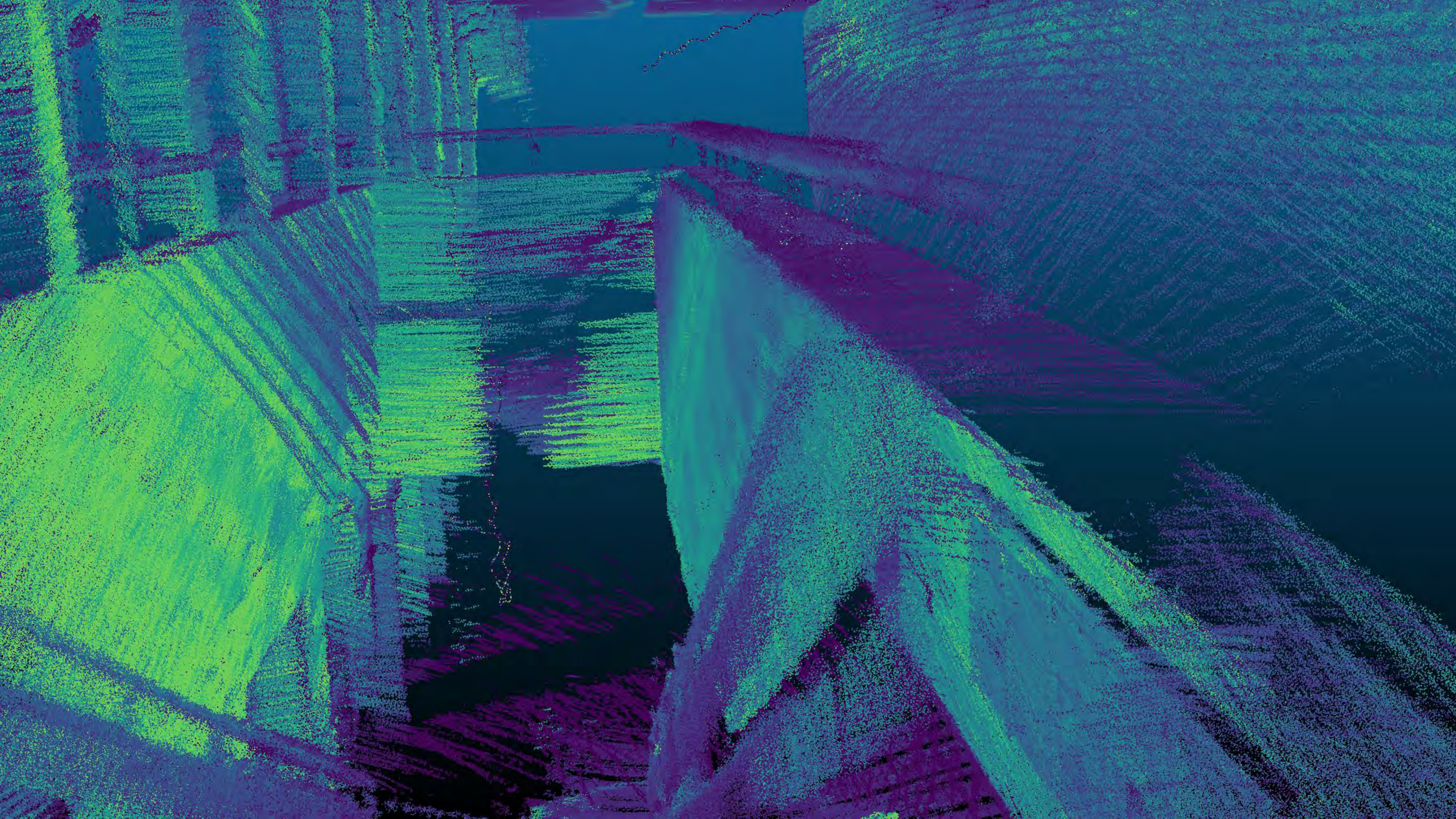
Summary

- The dynamic calibration successfully translates in the vertical direction
- Good DBH RMSE and bias
- Much potential to be used in the future
- Future work:
  - More forest tests (e.g. varying forest properties, different walking patterns)
  - Expand and test the dynamic calibration further









Thank you for listening!