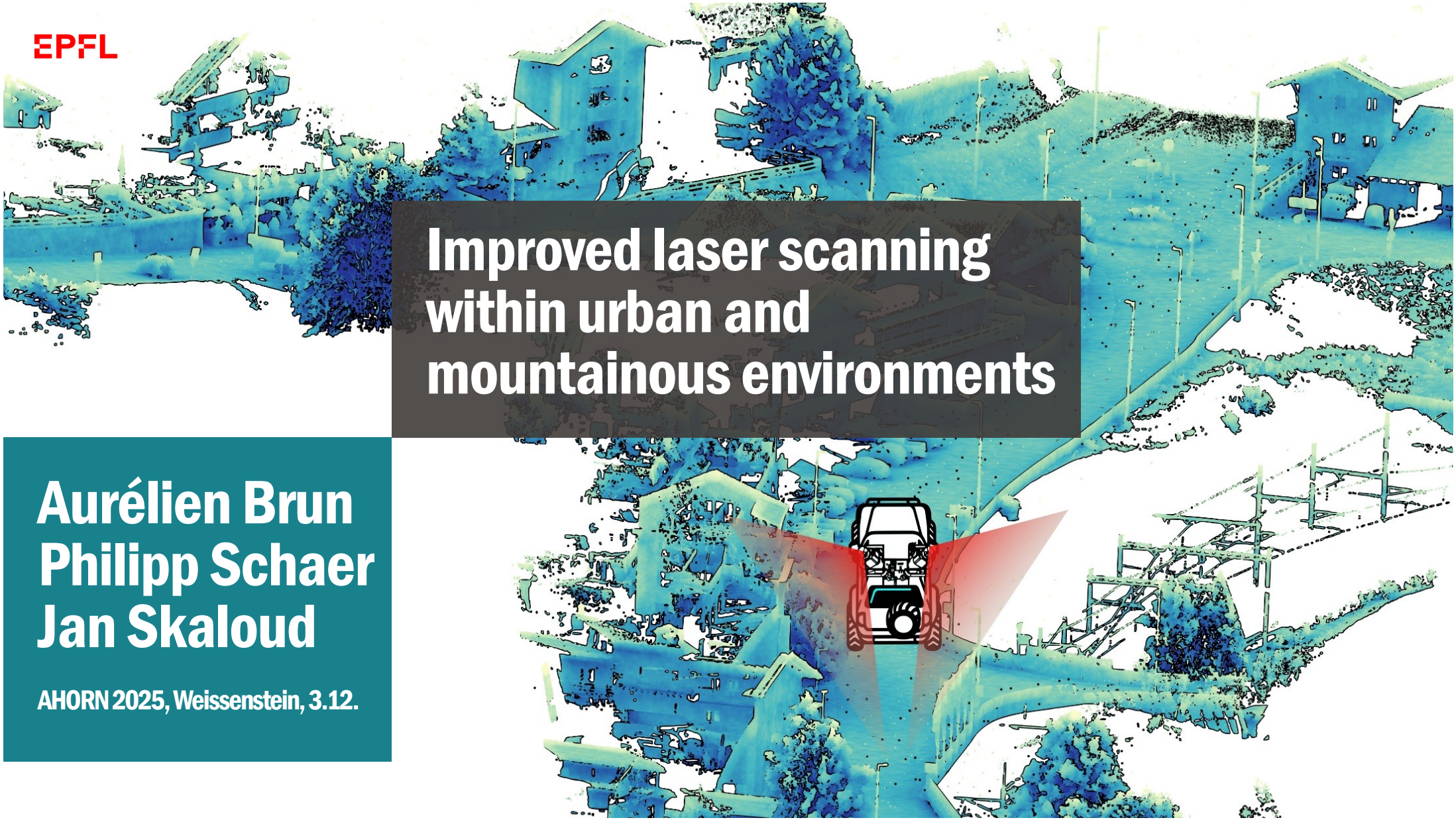
EPFL

Improved laser scanning within urban and mountainous environments



Aurélien Brun
Philipp Schaer
Jan Skaloud

AHORN 2025, Weissenstein, 3.12.

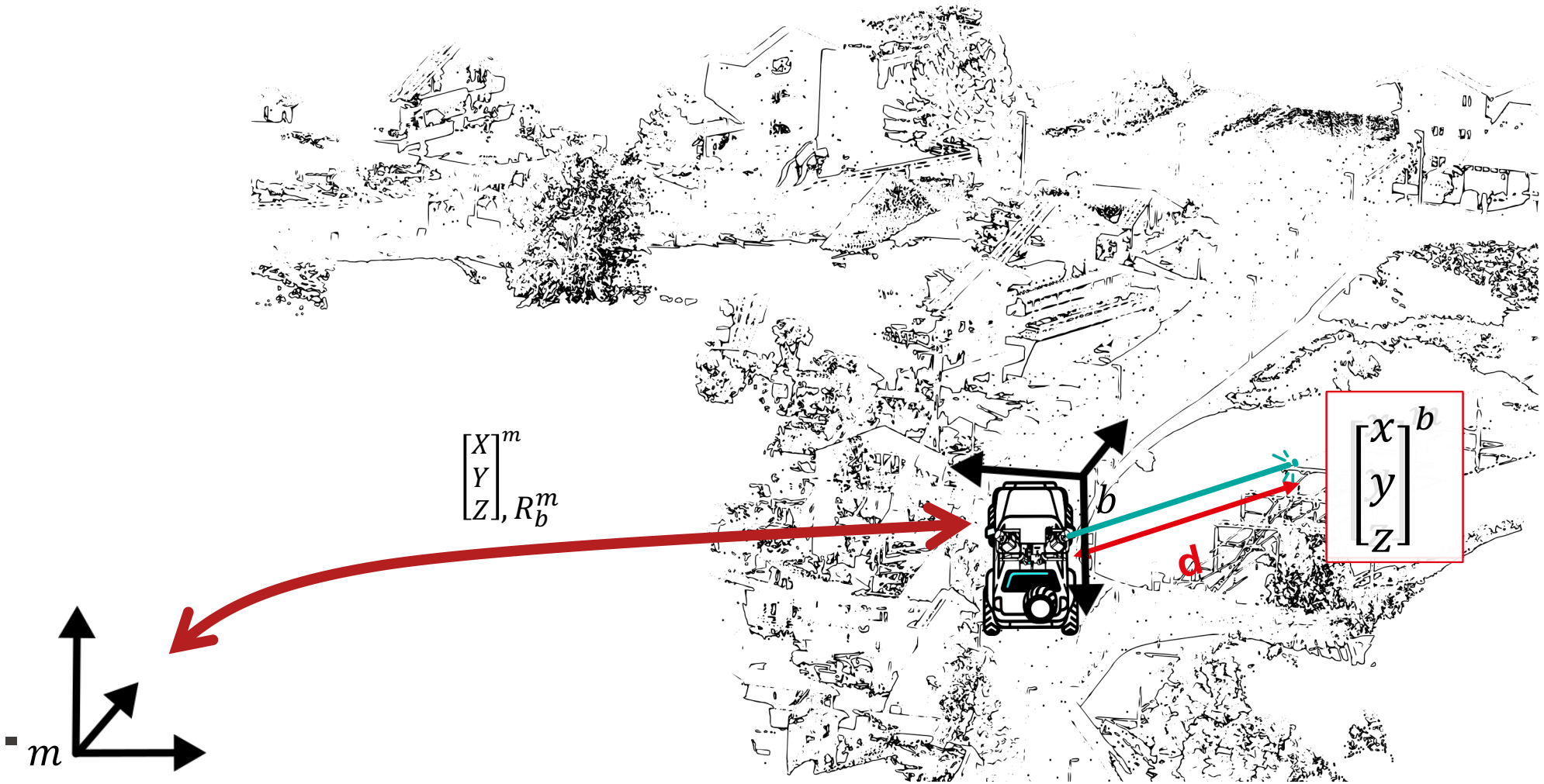
Lidar mapping platforms

ALS (high)

ALS (low/mid)

MLS

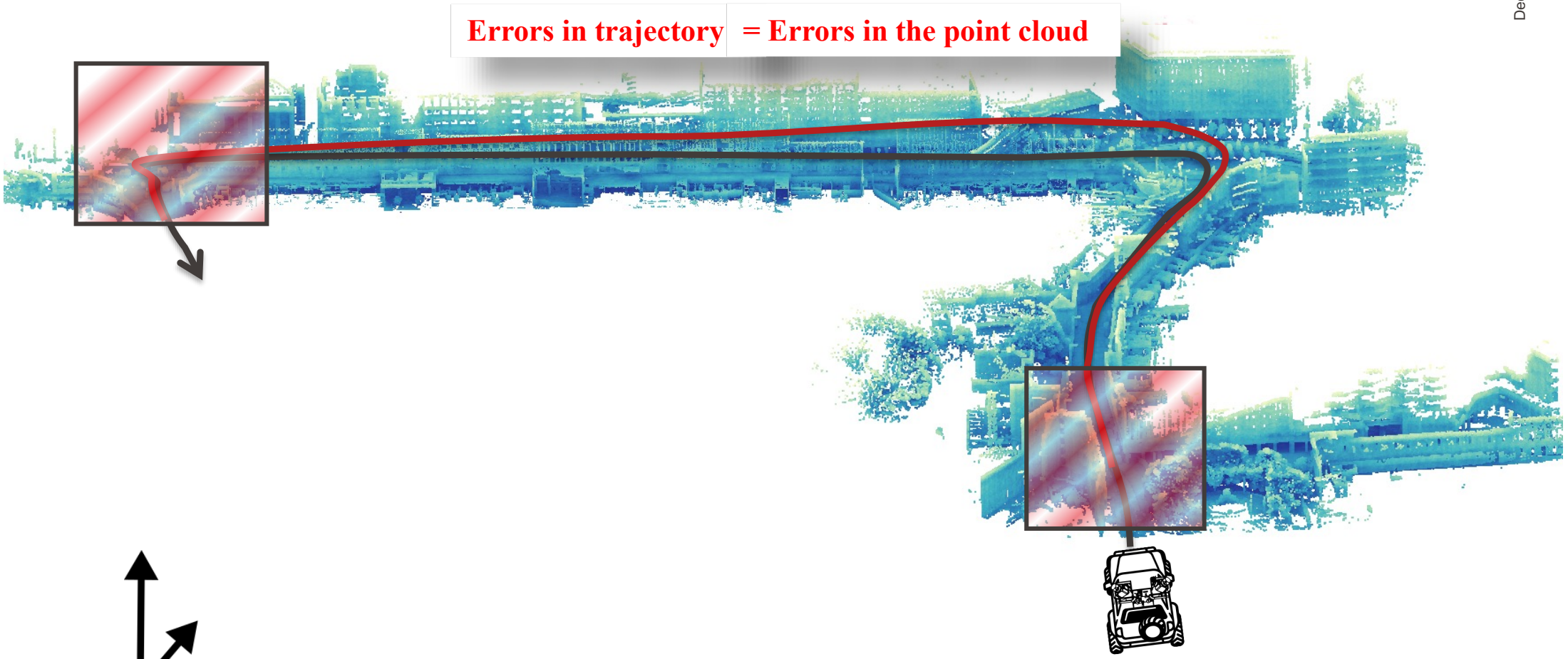
Lidar mapping principle



Lidar mapping

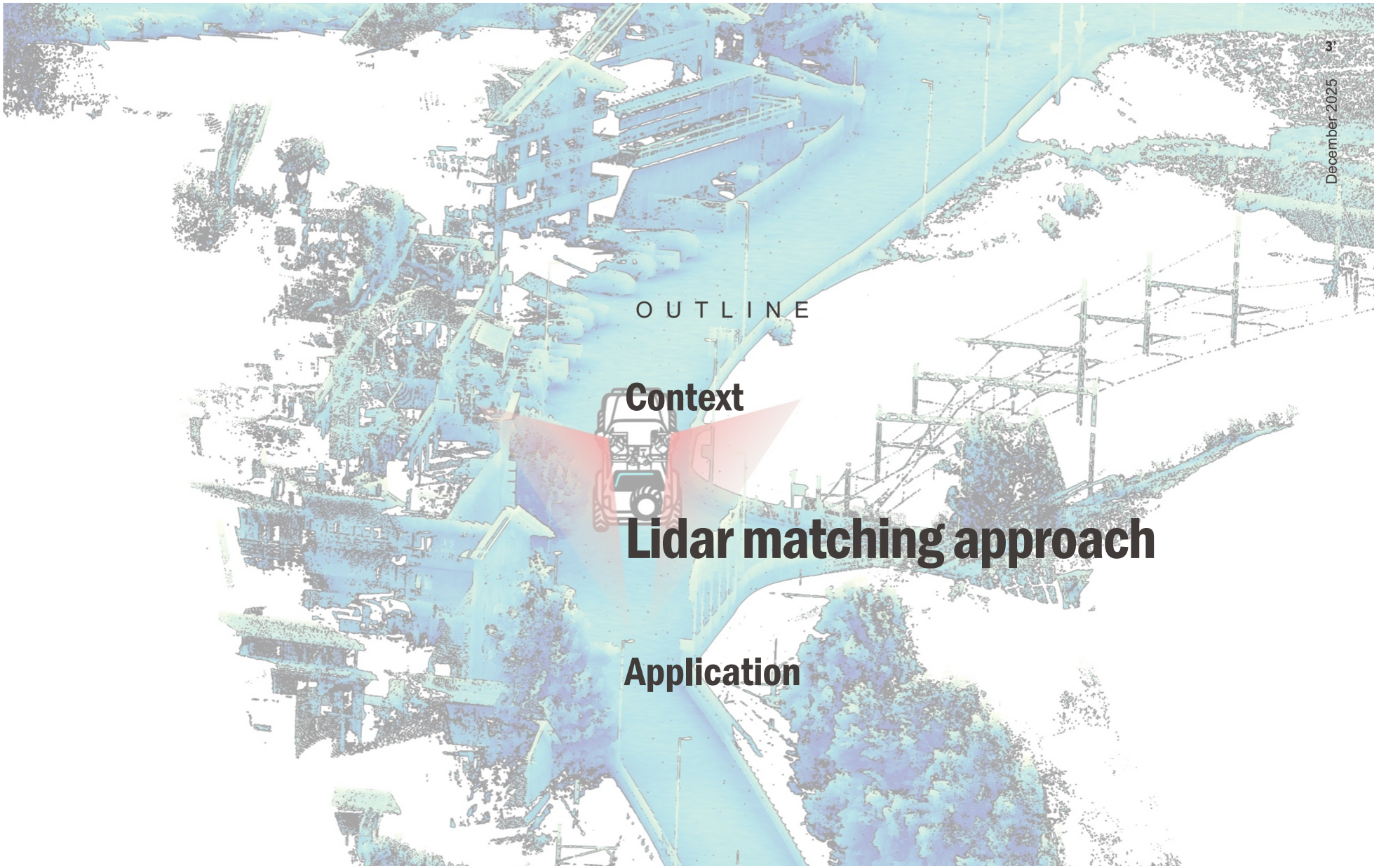
Limitations

Errors in trajectory = Errors in the point cloud



m

Today's actual (yet "old") example: GNSS signal degradation



OUTLINE

Context

Lidar matching approach

Application

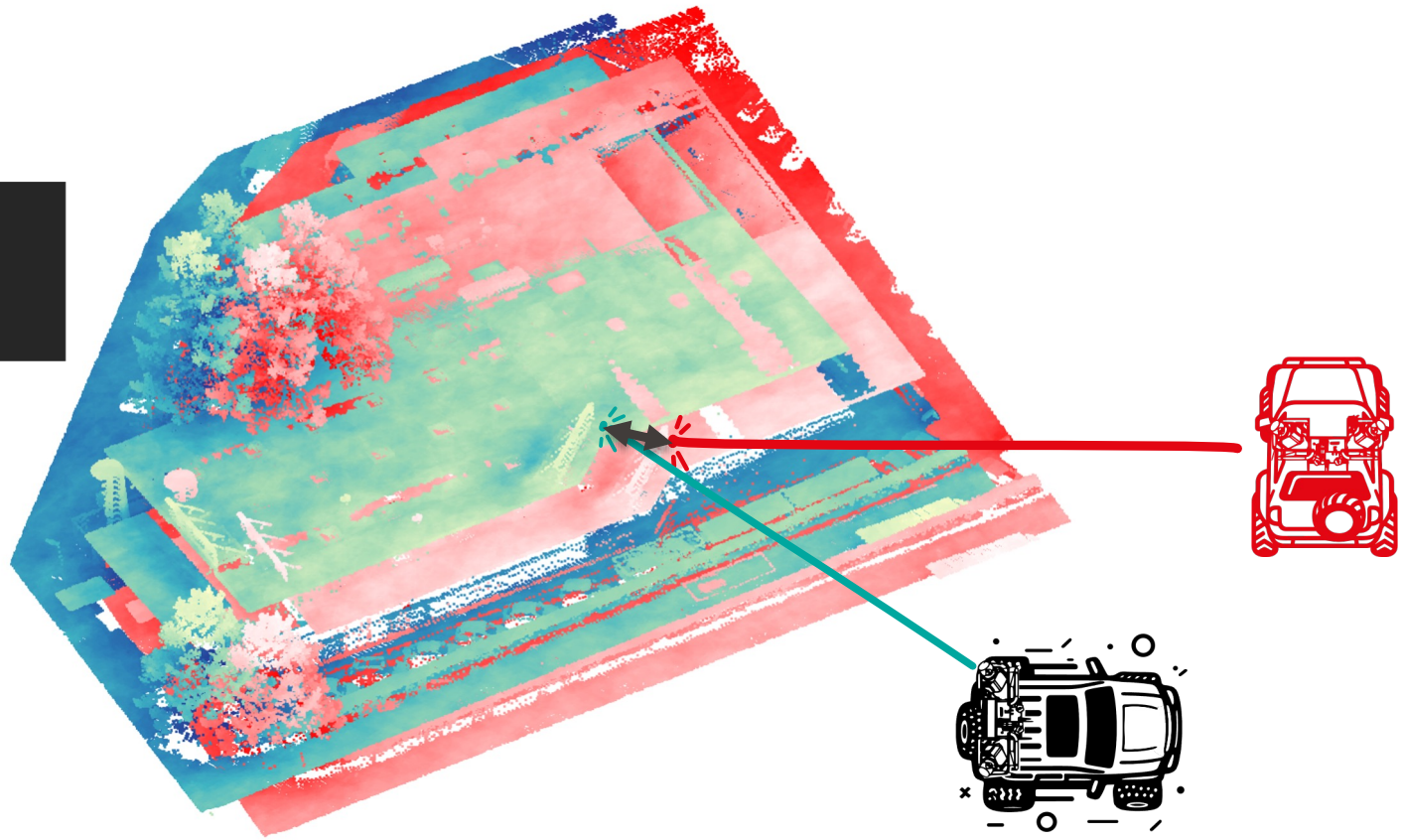
General idea

Step 1 – Lidar-to-lidar correspondences

Detect misalignment by identifying common ”points” in the point cloud

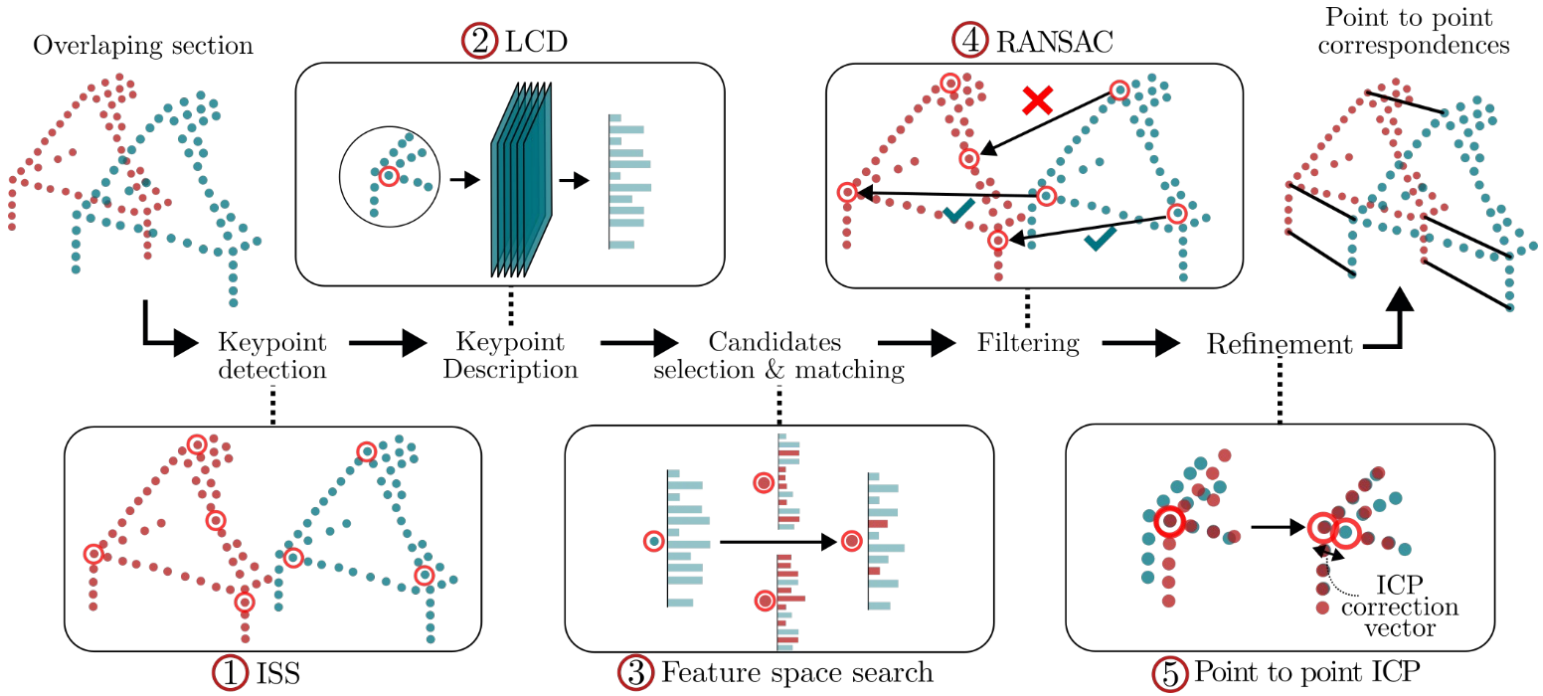
Limatch
Point cloud correspondence toolkit

1. Point to point
2. Fully automated
3. Retrieve hundreds to thousands correspondences per overlapping section



General idea

Step 1 – Lidar-to-lidar correspondences

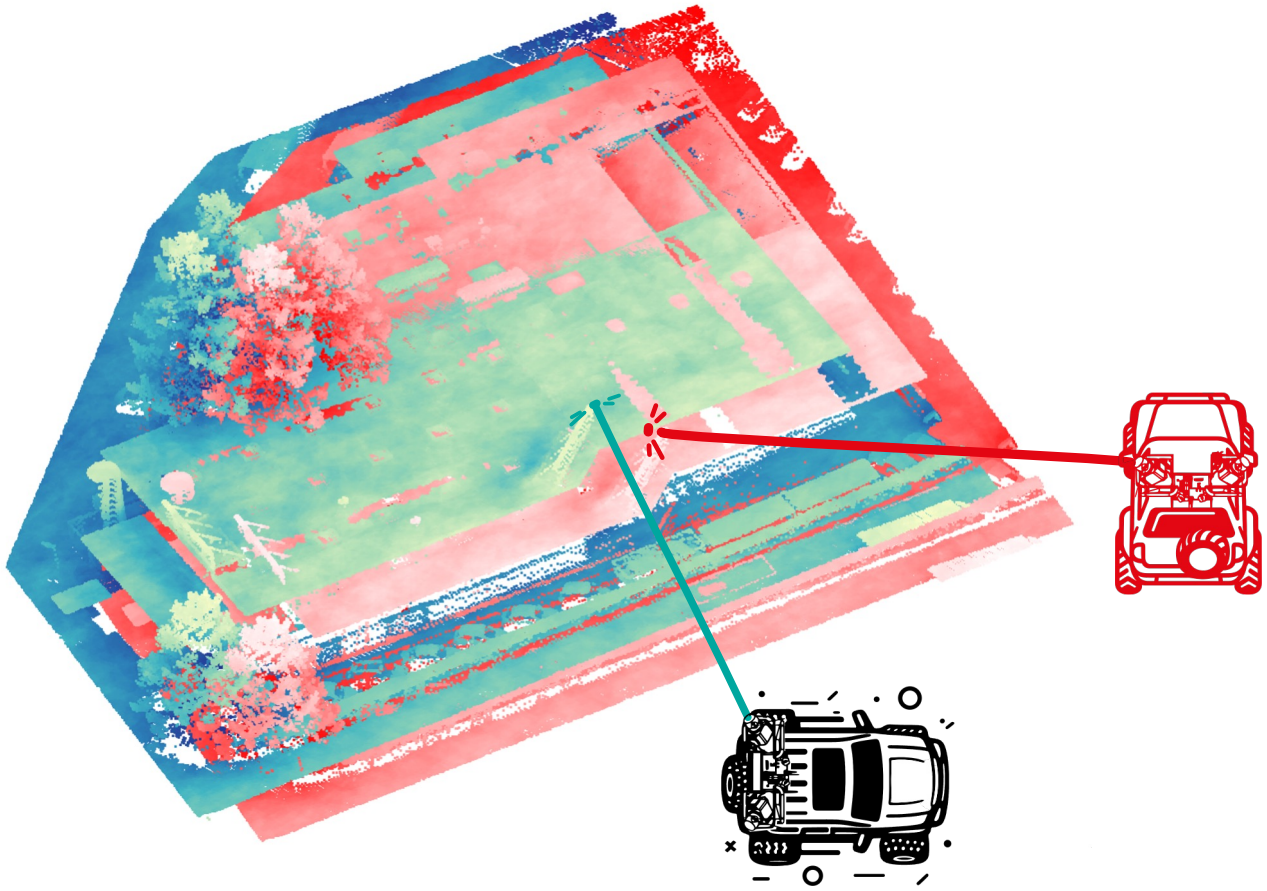


Brun, A., et al. 2025. **Generalization of point-to-point matching for rigorous optimization in kinematic laser scanning**. ISPRS Journal (1)→(5)
Zhang, I., et al. 2009. **Intrinsic shape signature: A shape descriptor for 3D object recognition**. IEEE 12th ICCV Workshops (1)
Pham, Q.-H, et al. 2020. **LCD: Learned cross-domain descriptor for 2D-3D matching**. AAAI Conf. Artif. Intell. (2)

General idea

Step 2 – Trajectory optimization

Correct the trajectory such that point-to-point misalignments are minimized



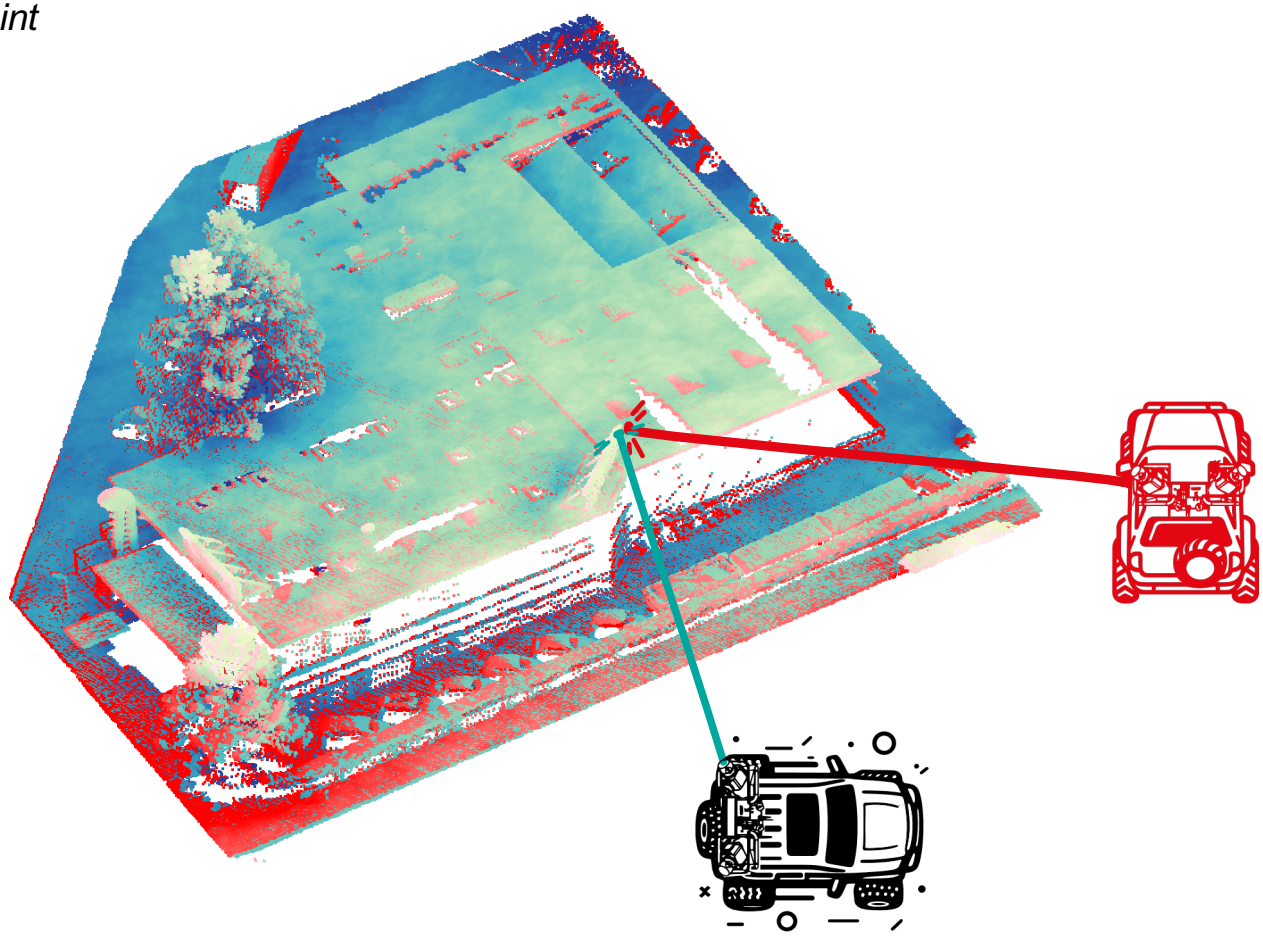
General idea

Step 2 – Trajectory optimization

Correct the trajectory such that point-to-point misalignments are minimized

Approaches

1. *focus ”cause” (rigorous, general)*
2. *focus ”effect” (ad hoc, case specific)*



General idea - focus "cause"

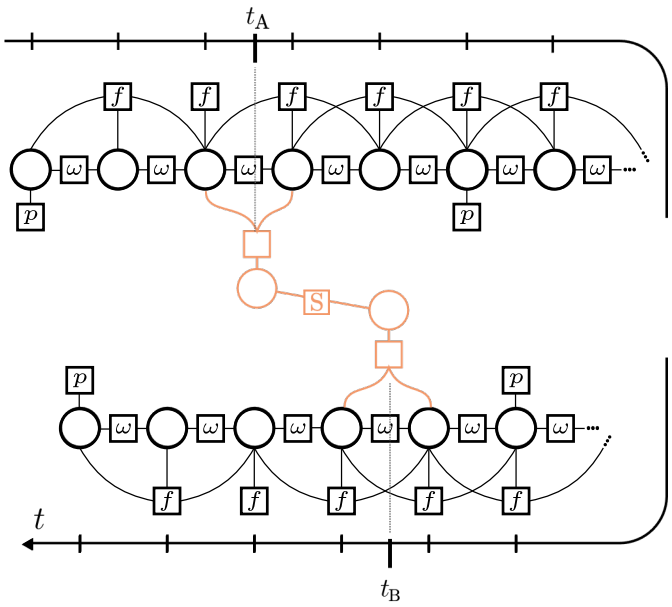
Dynamic Network - Nonlinear least squares adjustments – factor graph formulation

states = unknowns (position, orientation, calib. parameters)

measurements

p, ω, f temporal constraints (gnss, gyro, accels)

S spatial constraints (tie-points, lidar-to-lidar)



Geodetic networks parallelism:

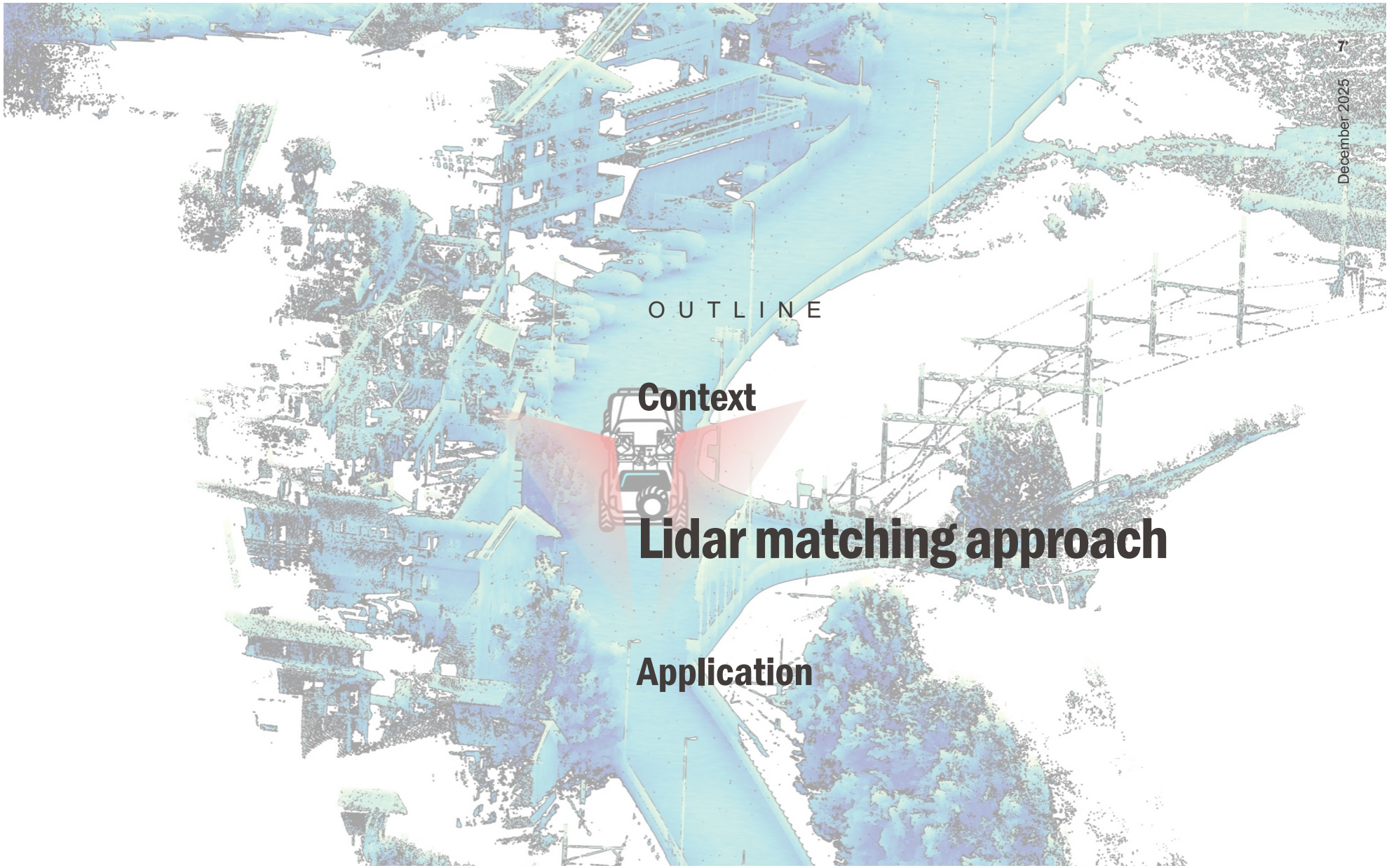
states (fixed survey points/ reference points, …)

measurements (directions, distances, …)

Cucci, D. A., et al. 2017. **Bundle adjustment with raw inertial observations in UAV applications**. ISPRS Journal (image tie-points)

Brun, A., et al. 2025. **Generalization of point-to-point matching for rigorous optimization in kinematic laser scanning**. ISPRS Journal (lidar-to-lidar)

Mouzakidou, K., et al. 2024. **Airborne sensor fusion: Expected accuracy and behavior of a concurrent adjustment**. ISPRS Open Journal (image tie-points + lidar-to-lidar)



OUTLINE

Context

Lidar matching approach

Application

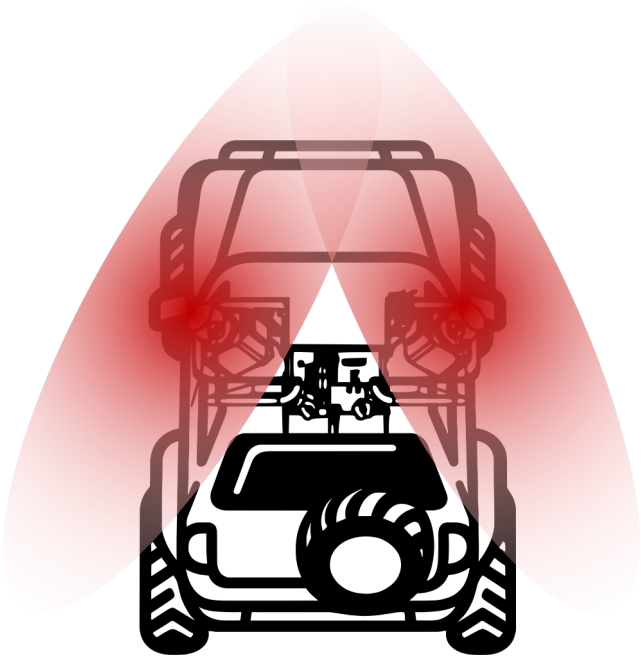
MLS with GNSS outage

Case 1

Compared trajectories

1. Optimal Kalman smoother — GNSS, IMU
2. Dynamic Network — GNSS, IMU, L2L

L2L = lidar to lidar correspondences



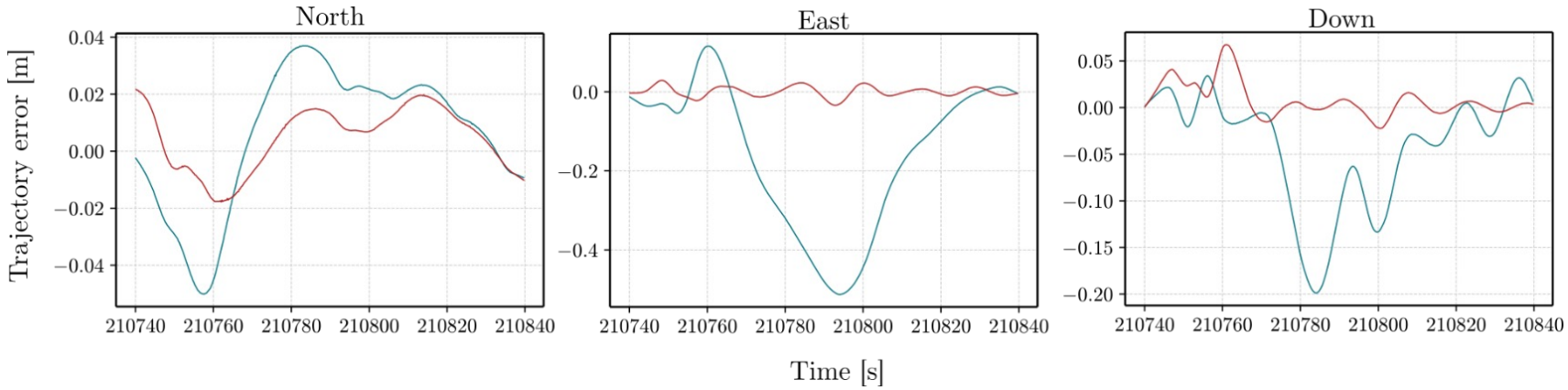
- Navigation grade IMU (sub-optimal, ”EPFL calibration parameters”)
- Dual single-beam rotating lidar, mm-level ranging accuracy

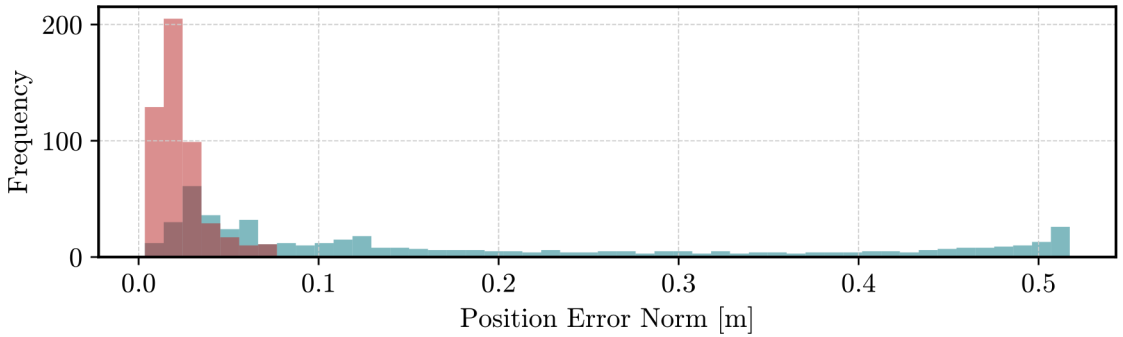
MLS with GNSS outage

Position error – Case 1

Trajectory. 1 GNSS INS — Dynamic Network

Trajectory. 2 GNSS INS LiDAR — Dynamic Network



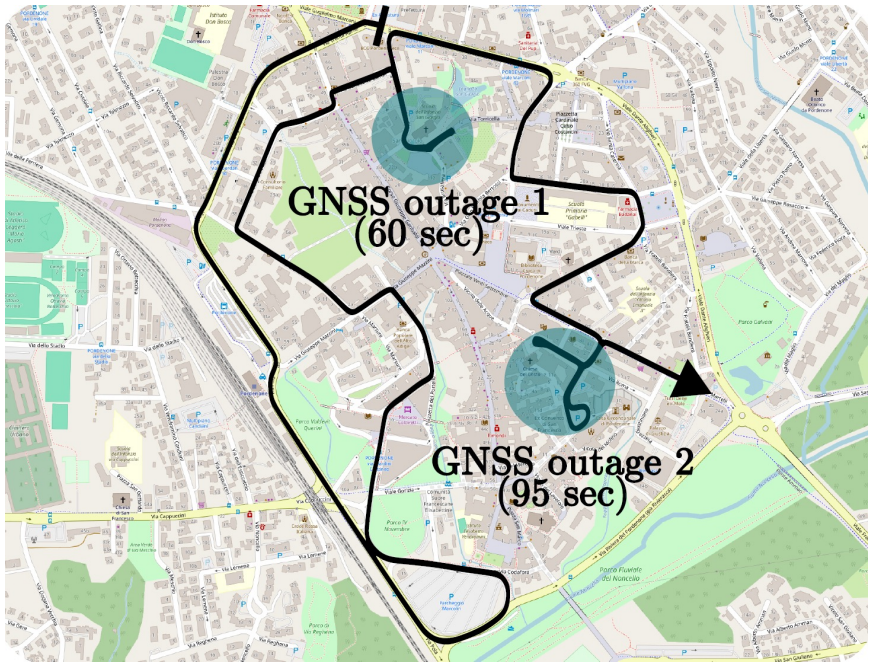


Position errors reduced by a factor 4 → 5

Mean error reduced from 17cm to 3.5 cm

MLS with GNSS outage

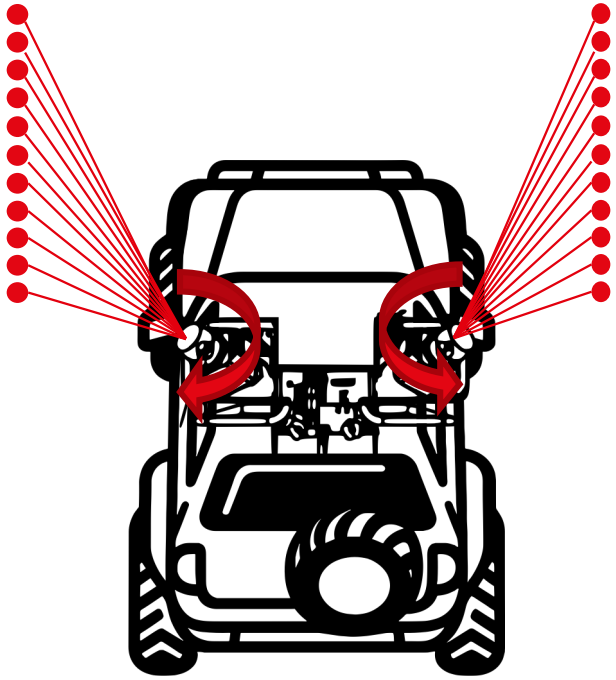
Case 2



Compared trajectories

1. Optimal Kalman smoother — GNSS, IMU
2. Dynamic Network — GNSS, IMU, L2L

L2L = lidar to lidar correspondences

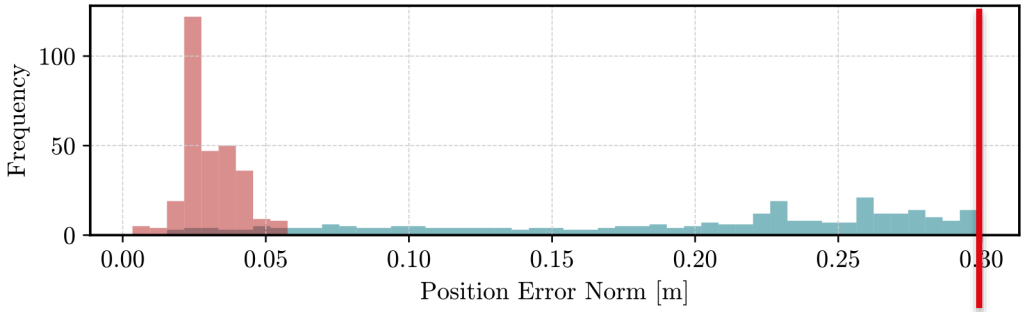


- Top tactical grade IMU
- Dual/Triple multi-beam rotating lidar, cm-level ranging accuracy

MLS with GNSS outage

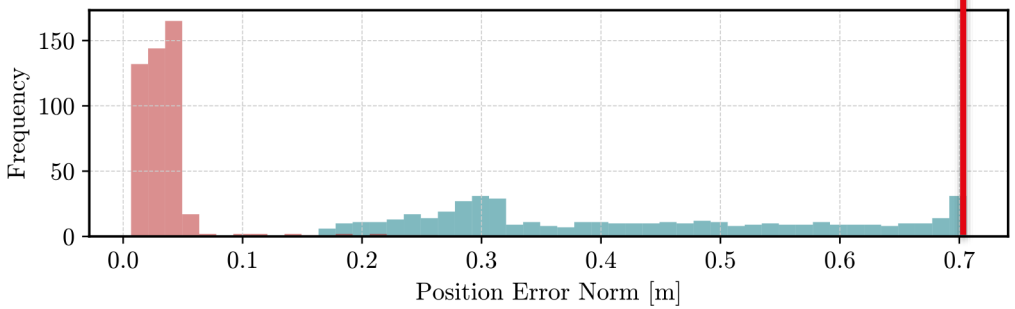
Position error - Case 2

GNSS outage 1 (60 sec → 200 m)



0.15 % of distance travelled

GNSS outage 2 (95 sec → 520 m)



Trajectory. 1 GNSS INS

Optimal Kalman Smoother

Trajectory. 2 GNSS INS LiDAR

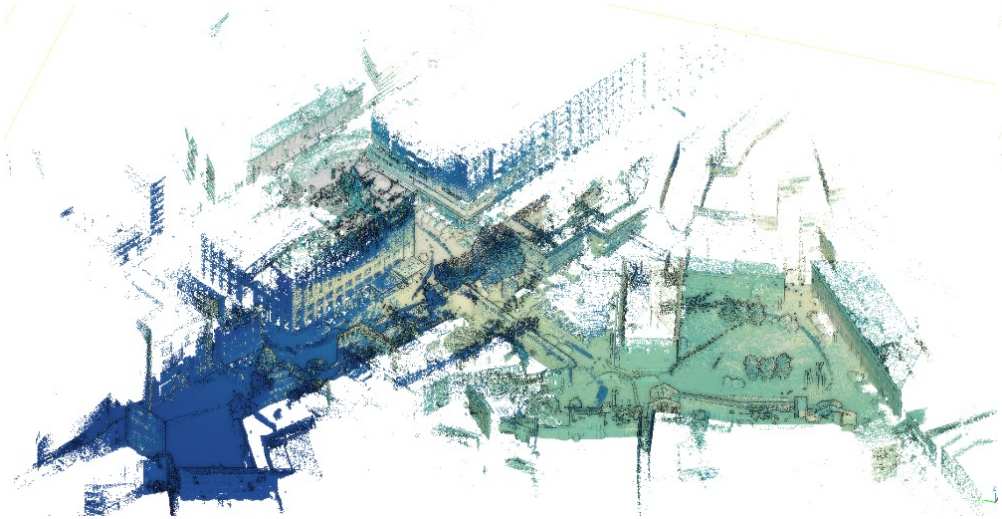
Dynamic Network

Position errors reduced by a factor 8→10

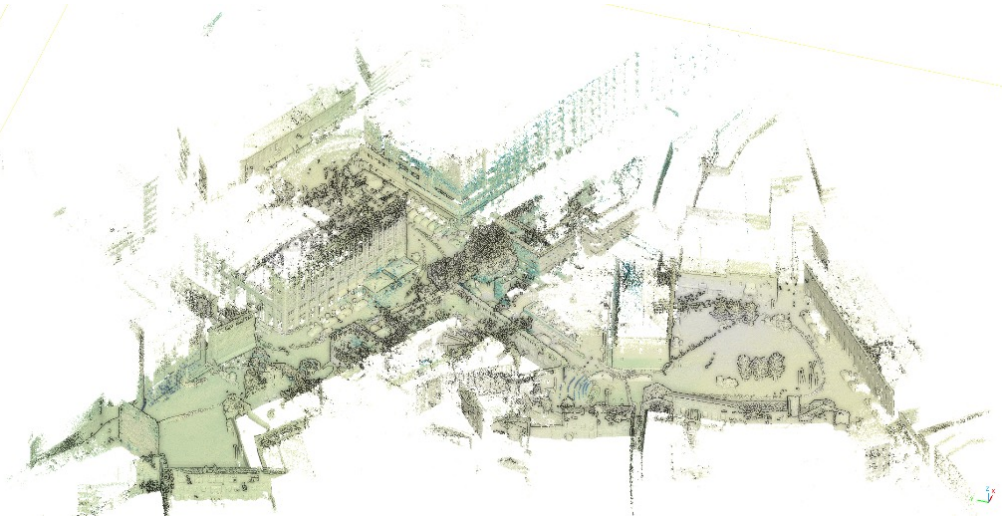
MLS with GNSS outage

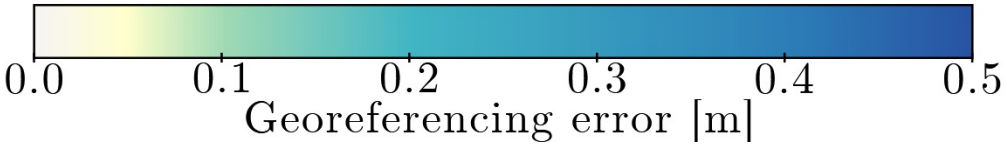
Point cloud error – Case 2

Nominal (smoother/factory)



Optimal (dynamic network)





- Mean georeferencing error reduced from 24 cm to 3 cm
- Max. georeferencing error reduced from 50 cm to 5 cm

Outlook

Method proven efficient…

… in another system / field

- Handheld lidar[1]
- ALS[1]

…in another application

- Lidar to photogrammetric-cloud matching[2]
- Lidar calibration[3]

Open source

Limatch
Point cloud correspondence toolkit

Open service

ODyN
Online Dynamic Network Solver

1. Brun, A., et al. 2025. **Generalization of point-to-point matching for rigorous optimization in kinematic laser scanning**. ISPRS Journal
2. Mouzakidou, K., et al. 2015. **Extraction of Image-to-Lidar Correspondences and their Impact on Optimal Sensor Fusion**. *(under review)*
3. In production …