Aalto-yliopisto
Perustieteiden korkeakoulu

Improving kinematic laser scanning point cloud accuracy with graph optimization

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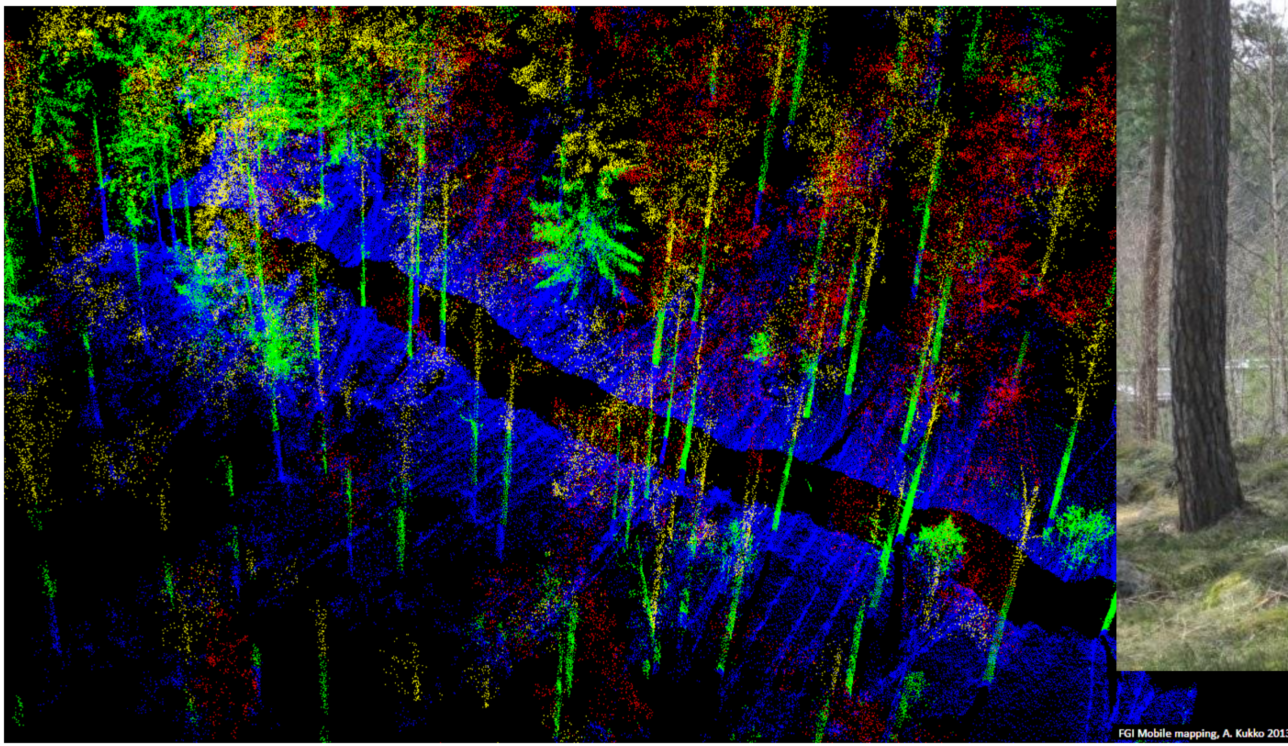
Background

- Forest inventory
  - Data from forests to support decision-making and management decisions.
  - Individual tree attributes such as height, stem curve and tree locations

- Data collection
  - 3D Laser scanning (LIDAR)
  - Set of range estimates from the scanner (point cloud in 3D-space)
  - Combining the separate point clouds using point cloud respective location data such as GPS

Backpack MLS



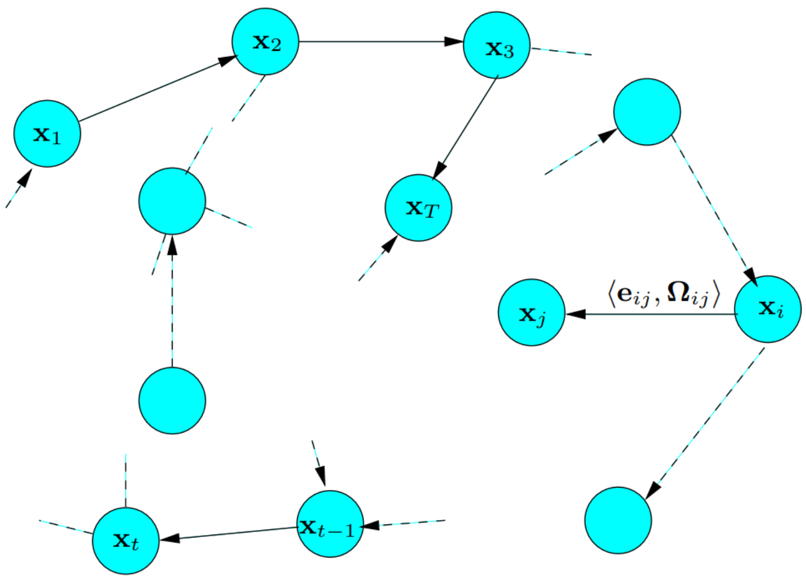
What happens if some point clouds don't have GPS-timestamps?

Methods: Forest Graph-SLAM

- Graph-SLAM
  - Numerically estimates the location and environment map of a moving sensor
  - In this case, sensor data is in point cloud and GPS format
  - Obtains the estimates as a solution to a non-linear least-squares minimization problem presented as a graph

- Programming tools:
  - C++ Library for the least-squares optimization
  - Python-scripts for Graph creation
  - Matlab-toolbox for point cloud and trajectory visualization and analysis

Methods: Graph-optimization problem



$$F(\boldsymbol{x}) = \sum_{i,j \in C} e(x_i, x_j, z_{ij})^T \Omega_{ij}(x_i, x_j, z_{ij})$$

$$\boldsymbol{x}^* = \operatorname{argmin} F(\boldsymbol{x}),$$

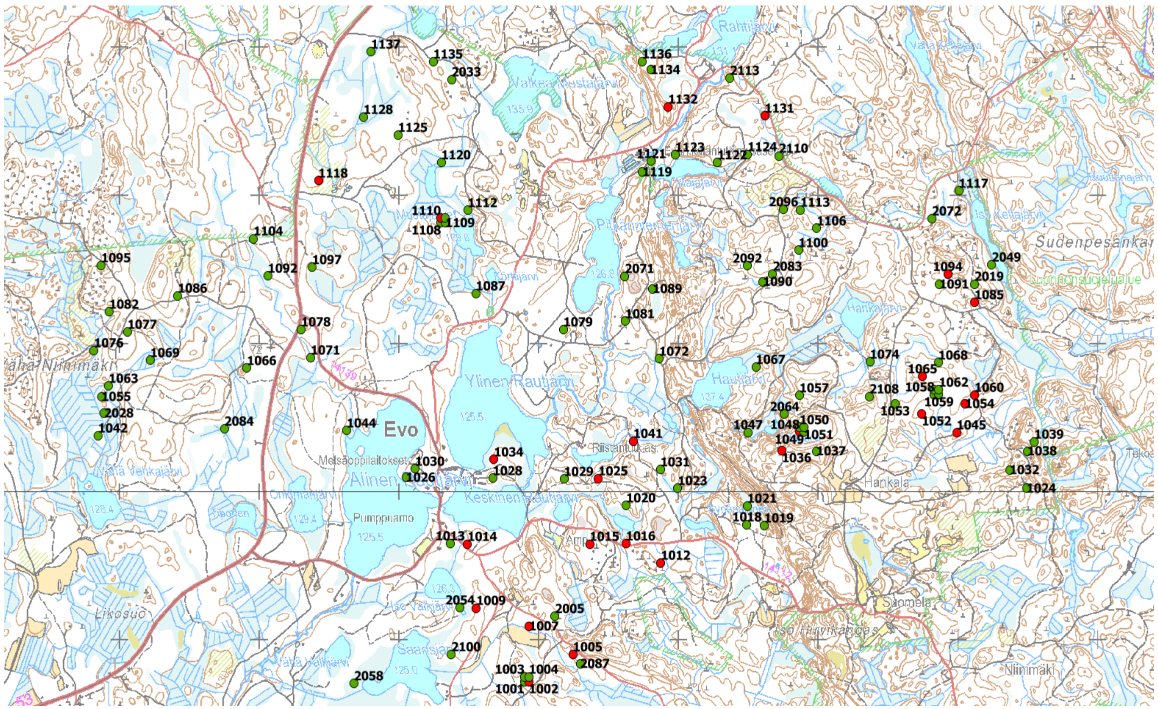
Find a set of poses that minimize the value of the error function. Constraints (z) are created from GPS-data.

Test data and equipment

- AkhkaR4DW VUX-1HA laser scanner with GNSS/IMU localization system
- Initial trajectory with standard deviation for both orientation and location in 3D with GNSS/IMU
- Point cloud data from laser scanner to produce tree observations

Test sites

- Five 32x32m test sites in Evo, Hämeenlinna
- Different trajectories and environment



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Test sites

Table 2: Measurement information for each forest plot located in test site Evo

Plot number	1	2	3	4	5
Trajectory length (m)	380.3	415.2	527.3	420.5	326.1
Trajectory duration (s)	345	399	633	448	351
Number of trees	95	197	281	136	75
Number of observations	225	263	226	182	474
Initial plot height error (m)	0.528	2.955	2.866	1.310	0.645

Test statistics

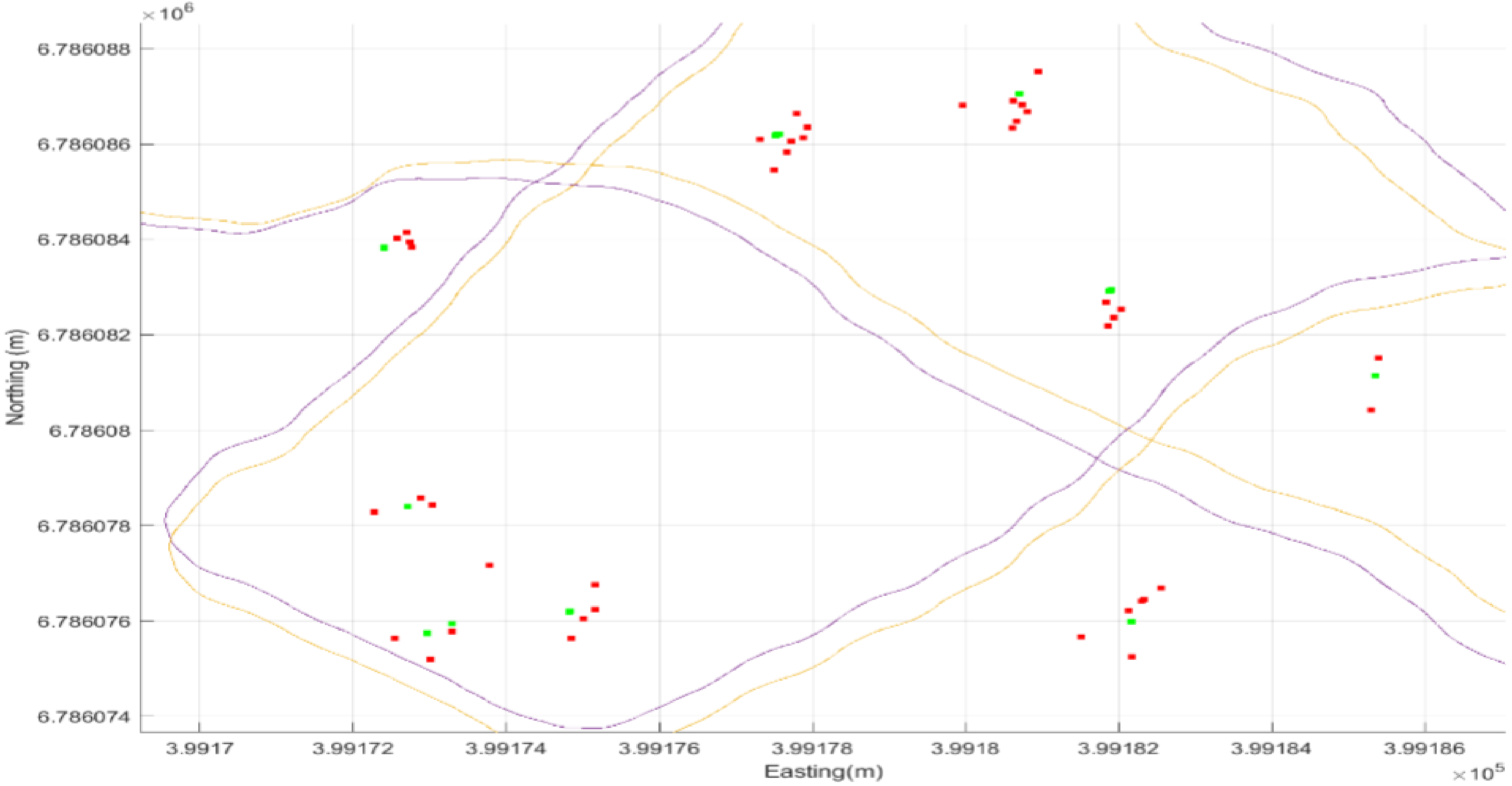
- How to measure the goodness of the optimization?
- Two Different error measurements were used:
- 1. Internal Accuracy
  - Planar accuracy of landmark locations
- 2. Overall accuracy
  - Elevational accuracy of the whole point cloud

Internal Accuracy

- The average distance from tree observations belonging in the same tree cluster to the center of this cluster
- Averaged over all trees

Plot number	1	2	3	4	5
Mean error (initial)	0.353	0.687	0.361	0.759	0.645
Mean error (optimized)	0.005	0.002	0.002	0.006	0.013
Error STD (initial)	0.236	0.484	0.367	0.534	0.438
Error STD (optimized)	0.005	0.002	0.003	0.005	0.014
Max error (Initial)	1.117	2.070	1.180	2.025	2.292
Max error (optimized)	0.040	0.010	0.013	0.027	0.124

Internal accuracy

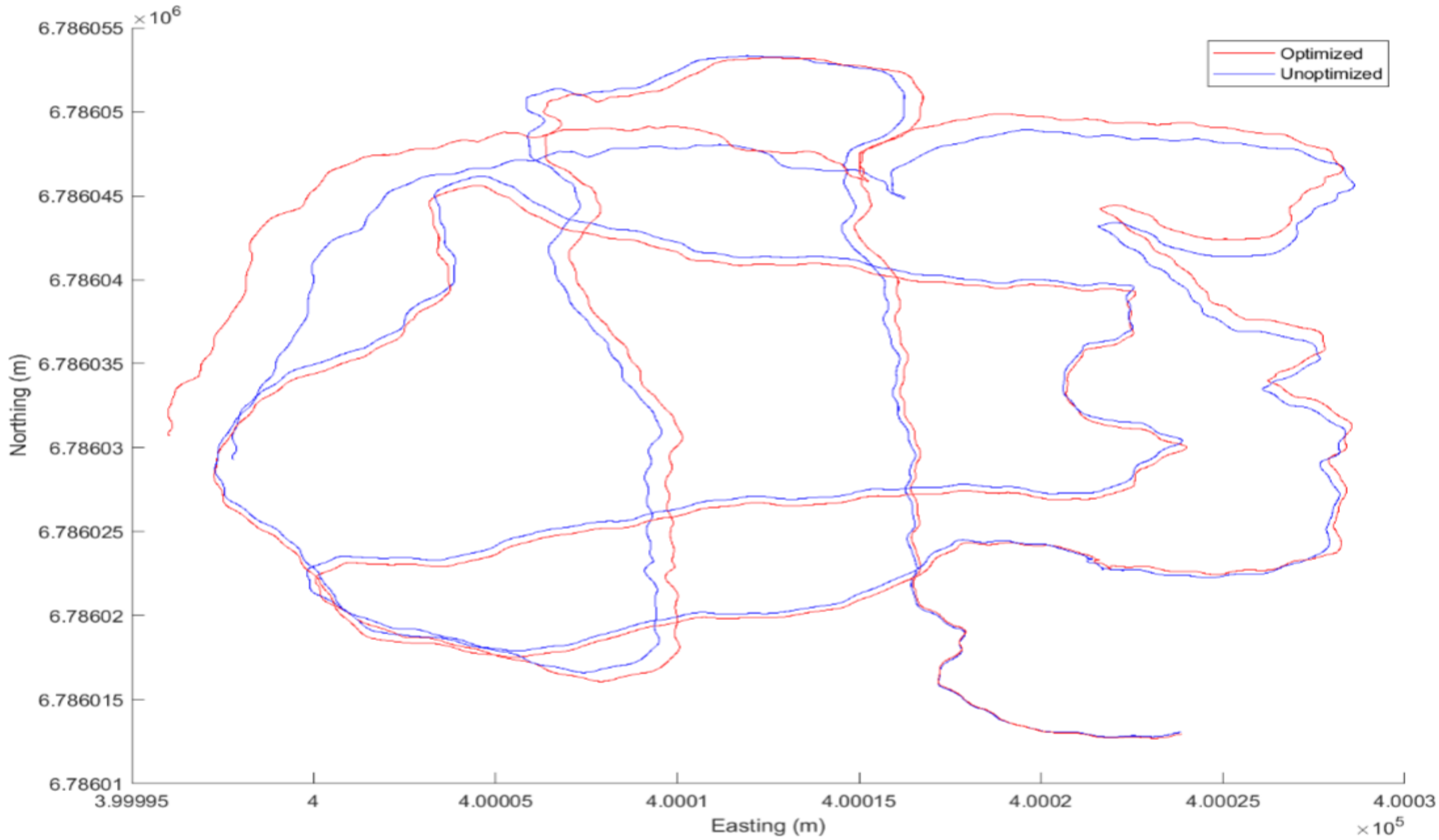


Overall accuracy

- The elevational (z-coordinate) difference of two trajectory points with same planar location ie. Trajectory crossing
- Averaged over all trajectory crossings

Plot number	1	2	3	4	5
Mean error (initial)	0.528	2.955	2.866	1.310	0.645
Mean error (optimized)	0.373	0.789	2.015	0.690	0.085
Error STD (initial)	0.402	1.790	2.037	0.920	0.313
Error STD (optimized)	0.294	0.623	1.994	0.705	0.054
Max error (Initial)	1.298	5.902	5.372	2.907	1.325
Max error (optimized)	0.880	2.215	5.235	1.742	0.139

Trajectory improvement example



Summary

- The internal accuracy of the point cloud was increased consistently trough all five different plots
- The overall accuracy increase wasn't nearly as consistent: Initial elevation error and number of trees affect the result
- Potential improvements to framework for example:
  - Iterative processing
  - Improvements to ground extraction
  - Tree detection parameter simulation

Improvement example