EuroSDR benchmarking of Mobile Mapping Algorithms and Systems

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Benchmarking objectives

1. The focus is on semi-automatic and **automatic algorithms**. Interpret the laser point clouds into 3D objects:
   - **buildings (building planes),**
   - **trees,**
   - **pole type objects**,
   - DTM,
   - curb stones,
   - zebra line / paintings,
   - bushes, traffic islands and fences.
2. **Quality of mobile laser scanning systems**
   - Setting up a test field
   - **Run test with various MLS in good GPS coverage conditions**
   - **Analyze general accuracy range of various MLS systems**

Espoonlahti test field for mobile laser scanning

- Test field covers 1700 m of road environment

Objective 1

Distributed mobile mapping data

- Data collected in Espoonlahti June 10th 2009 using FGI's ROAMER
  - FARO Photon 80 laser scanner
  - NovAtel SPAN navigation system
    - NovAtel DL-4 plus GPS-receiver
    - NovAtel GPS-702-GG antenna
    - Honeywell HG1700 AG58 IMU
- Two profiling frequencies used: 30 Hz and 48 Hz

Participants who used ROAMER data

Participant	Country	Contact	Delivered data
University of Waterloo	Canada	Hamad Yousif, Jonathan Li	Article: Yousif H, Li J, Chapman MA, and Shu YM, 2010. Accuracy enhancement of terrestrial mobile lidar data using theory of assimilation, International Archives for Photogrammetry, Remote Sensing and Spatial Information Sciences, Newcastle upon Tyne, UK, 38(5), pp. 639-645.
Stuttgart University of Applied Sciences	Germany	Susanne Becker, Norbert Haala	
The International Institute for Geo-Information Science and Earth Observation (ITC)	**The Netherlands**	**Martin Rutzinger, Shi Pu, George Vosselman**	Classified points: facades, fences, trees and poles

Results, ITC

- Automatic extraction and classification of raised features by ITC using ROAMER data
  - Pre-processing
    - Raw point cloud is clipped along the trajectory into road parts
    - For facade extraction the pre-processing is not applied (all data used)
  - Point cloud segmentation
    - Planar regions are detected and labelled using a surface growing algorithm with 3D Hough transformation for the detection of seed surfaces
  - Rough classification
    - For each segment the size, orientation and connectivity to other segments is investigated in order to roughly classify the ground, vertical walls, and raised features, which are on top of the road

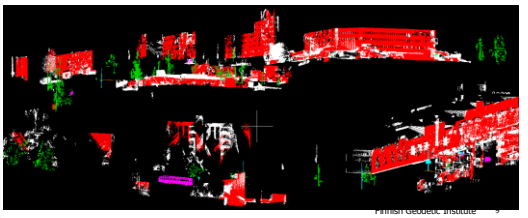
Results, ITC

- Facade classification by ITC
  - Points classified as facade were compared to original data

Point class in original data	%
Facade	87.4
Vegetation	5.9
Bus or truck	3.4
Pole	2.0
Ground	0.9
Noclass	0.2

Results, ITC

- Facade classification by ITC
  - White points original facade points
  - Red points classified as facade by ITC
  - Other colours misclassified as facade



Pole diameter from ROAMER data

- Pole diameter accuracy
  - 41 poles were measured manually from MMS-data
  - Reference: cylinder fitted to stop-and-go –data (test site reference data, see Objective 2)
  - Diameter deviation:

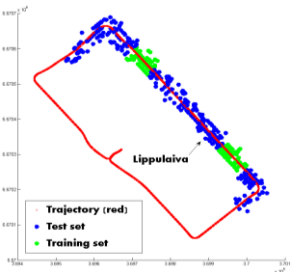
	Deviation [mm]
Mean	-3.1
STD	7.8
RMSE	8.3
Min	-29.9
Max	17.3

Detection of tree trunks and poles

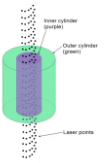
- Test area:
  - Appr. 800 m of road with two crossroads including more than 500 poles (lamp posts, traffic signs, etc.) and tree trunks
- Field reference:
  - All poles and tree trunks longer than one meter were mapped manually from the stop-and-go laser scannings which covered the test area with a high point density.

- Data reference:
  - Field reference targets that were visible in the mobile laser data.
  - 74% of targets were visible in 30 Hz mobile data, one driving direction, max. 30 m from the trajectory
  - 80% were well and 95% at least uncertainly visible in 48 Hz mobile data, combined data from two driving directions, max. 15 m from the trajectory

Test area



Algorithms



- ITC's algorithm described above
- FGI's algorithm
  - First each scan line was segmented into connected components. Then components on top of each other in adjacent scan lines were merged into candidate clusters
  - Candidates were classified as poles and non-poles using a mask that resembled a pole-like structure (see figure upright) and other features, that described the size, shape and orientation of the cluster.
  - For more details, see Lehtomäki, M., Jaakkola, A., Hyyppä, J., Kukko, A. and Kaartinen, H., 2010. Detection of Vertical Pole-Like Objects in a Road Environment Using Vehicle-Based Laser Scanning Data. **Remote Sensing**, 2, pp. 641–664.
- Both algorithms extracted pole positions and pole core points (e.g. tree stem points) and estimated pole lengths.
- ITC's algorithm also classified targets into trees and artificial poles (e.g. lamp posts and traffic signs).

Test data and reference

- ITC's test data
  - ROAMER 48 Hz mobile data
  - A combined data set from two opposite driving directions
  - Max. distance to the trajectory 15 metres
- FGI's test data
  - ROAMER 30 Hz mobile data collected in one driving direction
  - Max. distance to the trajectory 30 metres.
  - Part of the data for training of the algorithm (appr. 100 poles) and the remaining independent part for testing (appr. 300 poles)
  - Results are reported for the independent test set
- Algorithms were evaluated against *data reference*, i.e., targets that were visible in the mobile data (checked manually)

Results for ITC's group

- Data reference targets were divided into two groups:
  1. Targets that were *clearly visible* in the MLS data (231 in total)
  2. Targets that were *uncertainly visible* in the MLS data (42)

How many percent of the clearly visible reference targets were detected?	51.9 %
How many percent of the uncertainly visible reference targets were detected?	11.9%
How many percent of the detections were correct?	86.2 %
Error of the tree/artificial pole classification (from all correct detections)	16.0 %

Results for FGI's Group

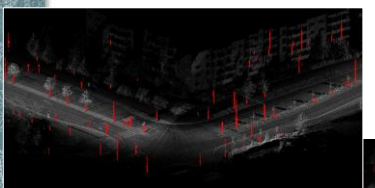
- Results for the whole independent test set of the data reference; no division to clearly and unclearly visible. 330 targets in total in 30 m distance.

Maximum distance to the trajectory:	**30 m**	**12.5 m**
How many percent of the targets were detected?	69.7	71.6
How many percent of the detections were correct?	86.5	95.1
Mean accuracy	77.2	81.7
Detection rate for trees (127 in total)	59.1	
Detection rate for traffic signs (79 in total)	82.3	
Detection rate for lamp posts (46 in total)	95.7	

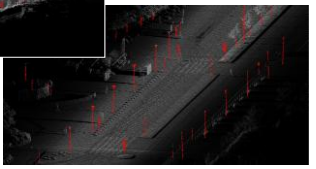
Results for FGI's group

- Missed targets
  - **Pole or trunk inside vegetation**; the mask did not recognize it as a pole.
  - **Few echoes gained from the pole**.
  - **Pole or trunk partly shadowed by a parked car** between the scanner and target.
- False detections
  - Mostly building structures and billboards.
  - Narrow elongated wall parts facing the trajectory; **looked like poles in the mobile data**.
    - E.g. walls/bars/columns between windows, doors and balconies.
  - Also **narrow corners in the walls**.

Extracted poles by FGI's group



Extracted poles and tree trunks marked with red colour.



Lehtomäki , M., Jaakkola, A., Hyyppä, J., Kukko, A. and Kaartinen, H., 2011. Performance analysis of a pole and tree trunk detection method for mobile laser scanning data. ISPRS Workshop Laser Scanning 2011, Calgary, Canada
http://www.isprs.org/proceedings/XXXVIII/5-W12/Papers/ls2011_submission_36.pdf

Merivirta test site in Espoonlahti

- FGI's algorithm was tested also on another area in Espoonlahti (Merivirta street) in 2009.
  - Test area was a 450 m long straight stretch of road.
- Reference data was collected by manually mapping poles and trunks in the field.
  - Minimum length of a target was 1 m and maximum distance to the trajectory 30 m
- In total 173 targets were recorded in the test field
  - Included 79 tree trunks, 43 lamp posts, 37 traffic signs
- 148 targets were visible in the mobile data (85.5%)
  - These constituted the data reference.

Results for Merivirta test site

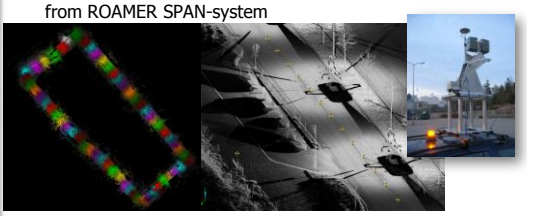
Results for FGI's algorithm in the Merivirta test site in Espoonlahti. Detection rates are for the targets that were visible in the mobile laser data (data reference).

Maximum distance to the trajectory (m):	**30**	**12.5**
How many % of the targets were detected?	77.7	83.5
How many % of the detections were correct?	81.0	86.5
Mean accuracy (%)	79.3	85.0
Detection rate for trees (%)	76.1	
Detection rate for traffic signs (%)	73.3	
Detection rate for lamp posts (%)	93.0	

Objective 2

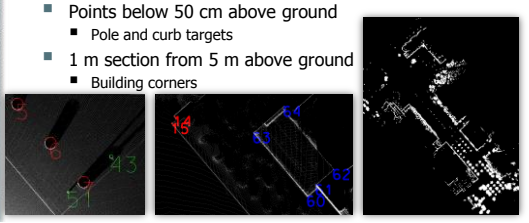
Reference data

- Reference based on static TLS-scan stations (stop-and-go mobile mapping) using FGI ROAMER
- Scans have been georeferenced using position and heading from ROAMER SPAN-system



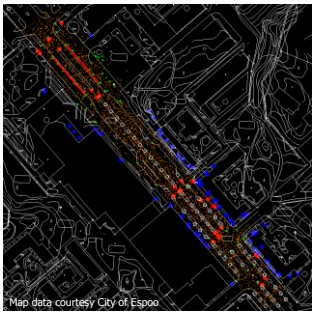
Reference for planimetric accuracy

- Targets include poles, building corners and curbs
- Point clouds were cut into two sections for measuremets
  - Points below 50 cm above ground
    - Pole and curb targets
  - 1 m section from 5 m above ground
    - Building corners



Reference data

- Test plot
  - Length 350 m
  - 3282 elevation points (orange)
  - 273 planimetric targets
- Good GNSS visibility



Mobile mapping systems

- The Espoonlahti test site was mapped by several systems
  - Two research prototypes by FGI
    - High-end system ROAMER and budget system Sensei
  - Various commercial systems
- Most systems are also capable of simultaneous image data acquisition, but only laser point data was used for analysis

Systems by FGI

ROAMER

- Data collected June 2009
- One Faro Photon scanner
  - Continuous laser, phase-based distance measurement
  - 120 kpoints / sec (2010: up to 976 k)
  - 48 profiles / sec (2010: 3-61)
  - Range ~ 50 m (2010: 120 m)
- Navigation NovAtel SPAN
  - IMU + GPS (one antenna)

Sensei

- Data collected May 2011
- Ibeo Lux scanner
  - Pulsed laser
  - 38 kpoints / sec
  - Range up to 200 m
- Navigation NovAtel SPAN-CPT
  - IMU + GPS (one antenna)

Examples of commercial systems

Streetmapper

- Data collected June 2011
- Two Riegl scanners
  - Pulsed laser
  - 2 x 300 kpoints / sec
  - Range up to 500 m
- Navigation
  - IMU + DIA + GPS (one antenna)

Riegl VMX-250

- Data collected March 2010
- Two Riegl VQ-250 scanners
  - Pulsed laser, time-of-flight – based distance measurement
  - 2 x 50-300 kpoints / sec
  - Up to 2 x 100 profiles / sec
  - Range up to 500 m
- Navigation
  - IMU + odometer + GPS (one antenna)

Optech LYNX Mobile Mapper (operated by TerraTec As)

- Data collected June 2011
- Two Optech scanners
  - Pulsed laser
  - 2 x 200 kpoints / sec
  - Range up to 200 m
- Navigation Applanix POS LV 420
  - IMU + odometer + GPS (two antennas)

Mobile mapping systems

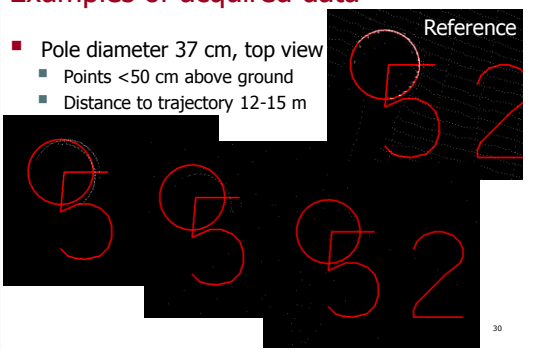
- The test site was driven in both directions with all systems
- Point densities close to trajectory vary from 100 to 6000 points per m^2 while driving in one direction at speed of about 20-30 km/h

Examples of acquired data

- Visualization by
  - Intensity
  - Elevation
  - Color from images

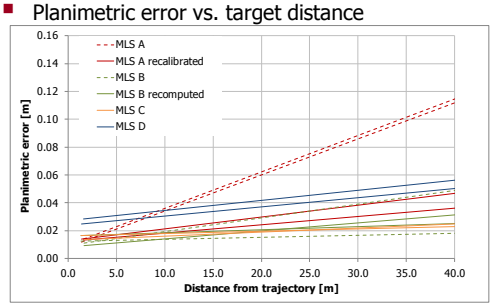
Examples of acquired data

- Pole diameter 37 cm, top view
  - Points <50 cm above ground
  - Distance to trajectory 12-15 m



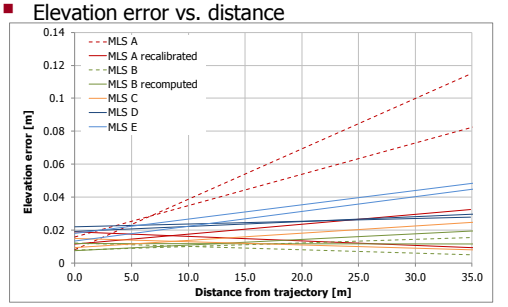
Results of two runs

- Planimetric error vs. target distance



Results of two runs

- Elevation error vs. distance



MLS results

- For all systems calibration was a major error source
  - Relative orientation can be improved using measured data. The accuracy (std) of MLS A before and after the fine adjustment using measured data
    - Elevation accuracy 4 cm -> 2 cm
    - Planimetric accuracy 2 cm -> 1 cm
  - Errors in scanner relative orientation cause multiple images of scanned objects