Airborne Lidar Terrain Mapping System

LiteMapper 2800-900W

Performance and Accuracy Analysis Report

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Introduction

This document describes the results obtained in a performance and accuracy test of the LiteMapper 2800-900 system and the procedures used.

The system under test was a production system of the LiteMapper 2800 series, equipped with the “large beam divergence” option and the RGB true color option. The specifications of the unit under test are listed in the following table:

Scanner Model	LMS-Q 280i (SN 9994699)
PRF	24 kHz
Scan angle	±22.5° and ±30°
Beam divergence	1.2 mrad (large divergence option)
RGB color channel option	yes
IMU	AEROcontrol IId
IMU sampling rate	256 Hz

Test flights

The analysis was performed using data collected during two test flights performed on Aug. 18, 2004 and Sept. 02, 2004. For the flights the system was mounted below the cabin of a Bell Jet Ranger helicopter.

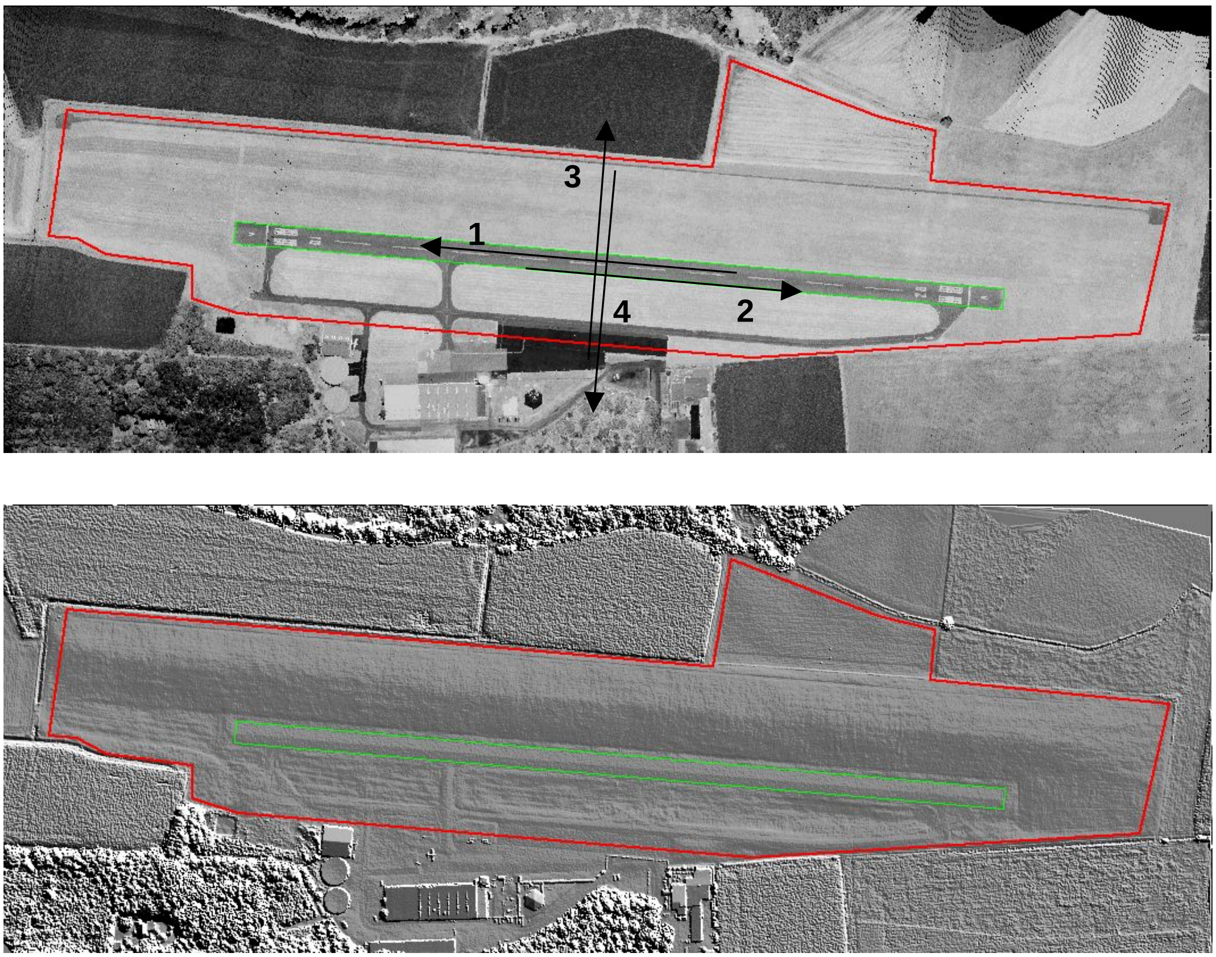
Test flight installation

Data was collected at several sites to analyze different aspects of system performance and accuracy:

Site	Altitude above ground	Speed	Point spacing	Parameter
Airfield	400 m	20 m/s	0.75 m	accuracy
Highway	65 m	18 m/s	0.27 m	resolution
Powerline 380 kV	85 m	22 m/s	1.3 m x 0.1 m	resolution
Railway line	55 m	20 m/s	1.0 m x 0.06 m	resolution

Accuracy analysis

A flight pattern of two lines along the runway in opposite directions (lines 1 + 2) and two flightlines crossing the runway orthogonally in opposite directions (lines 3 + 4) was flown at an altitude of 400 m AGL over the airfield. One line along the runway (1) and one of the crossing lines (3) were used to determine calibration parameters (boresight offsets). The remaining lines were then used to measure relative accuracy, i.e. the repeatability/stability of the system.



Test site “Airfield” – lidar intensity image, shaded relief of DSM

Internal/relative system accuracy was determined by comparing the measurements of the flight lines with each other.

The residual errors for heading, pitch, and roll were determined as follows:

- **Heading offset**

The centerline in (1) and (2) is not influenced by a heading offset. A heading offset in (3) and (4), on the other hand, causes the runway center line marks to be rotated around the vertical axis in intensity images of these lines. In the intensity images the end points of the runway centerline marks were selected. The angles the centerlines of (3) and (4) have compared to the centerline in (1) therefore directly gives the heading (yaw) angle offset.

Lines	Residual heading error [°]	Uncertainty [°]
3 – 1	**0.025**	0.02
4 – 1	-0.005	0.02

The heading uncertainty value estimates the ambiguity encountered during the interactive determination of the centerline position.

- **Pitch offset**

The centerlines in (1) and (2) are not influenced by a pitch angle offset. A pitch angle offset does, however, displace the centerline in (3) and (4) in the direction of flight. The pitch angle offset is proportional to the mean displacement of the centerline in (3) and (4) compared to (1), and can be calculated from the displacement in relationship to the flying height above the ground at the intersection.

Lines	Displacement [m]	Uncertainty [m]	Residual pitch error [°]
3 – 1	-0.10	0.15	-0.014
4 – 1	0.10	0.15	0.014

The pitch uncertainty value estimates the ambiguity encountered during the interactive determination of the centerline position.

- **Roll offset**

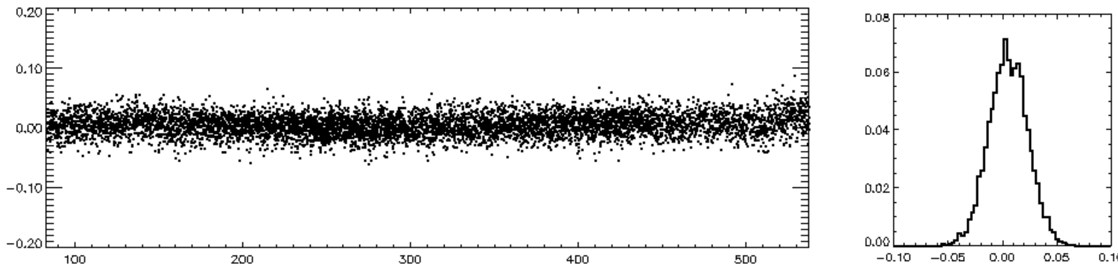
The roll angle offset leads to a tilt of each line about its longitudinal axis, that can be measured

- as an inclination in the cross-section height-difference profiles. The along-track centerline height profiles of the perpendicular lines were used as the reference, as they are not influenced by a roll error ((1) and (2) as references for (3) and (4) and vice versa),
- or as an inclination between the cross-section height-difference profiles of two parallel lines flown in opposite directions ((1)+(2) and (3)+(4)). One line was used as a reference and the inclination of the difference profile of the second was determined. In this case the roll offset is half the measured inclination angle.

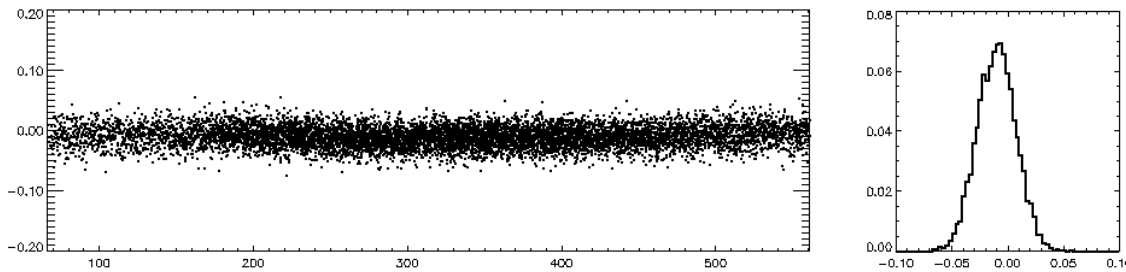
First, the measurement points from lines (1) and (3) were triangulated to provide reference TIN models. The height differences of the measurement points from (3) and (4) were compared to the TIN model of (1) within a 10-m-wide profile along the runway center were analyzed for tilt. Similarly, the height differences of the measurement points from(1) and (2) were compared to the TIN model of (3). The angle of the height difference profile to the horizontal directly represents the roll offset.

Lines	Target	Residual roll error [°]	Uncertainty [°]
3 – 1	cross-section difference profile	**0.0008**	0.0001
4 – 1	cross-section difference profile	0.0001	0.0001
1 – 3	cross-section difference profile	**0.0008**	0.0004
2 – 3	cross-section difference profile	-0.0001	0.0003

The roll uncertainty value is the standard deviation of the roll error measurement.



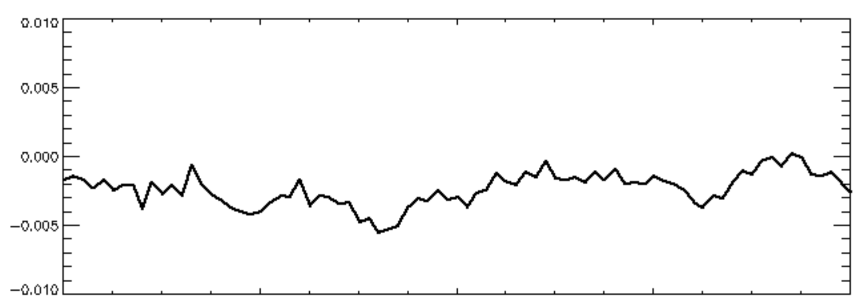
Height difference profile and histogram of height differences of (3)-(1)



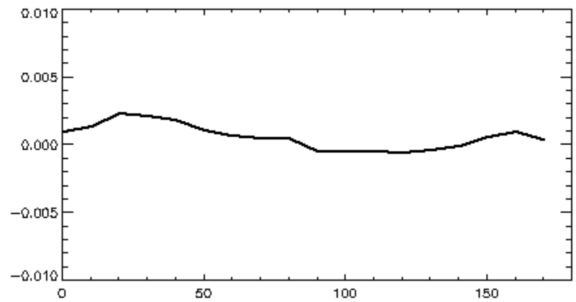
Height difference profile and histogram of height differences of (4)-(1)

Roll angle repeatability was determined using the height difference of measurement points from (2) compared to the TIN model of (1) within consecutive 10-m-deep cross-sections perpendicular to the direction of flight of (1). The same was done for points from (4) in comparison to the TIN model of (3).

Lines	Target	Mean residual roll error [°]	Standard deviation[°]
2 – 1	cross-section difference profiles	0.0003	0.0012
4 – 1	cross-section difference profiles	**0.0006**	0.0026
4 – 3	cross-section difference profiles	0.0004	0.0009



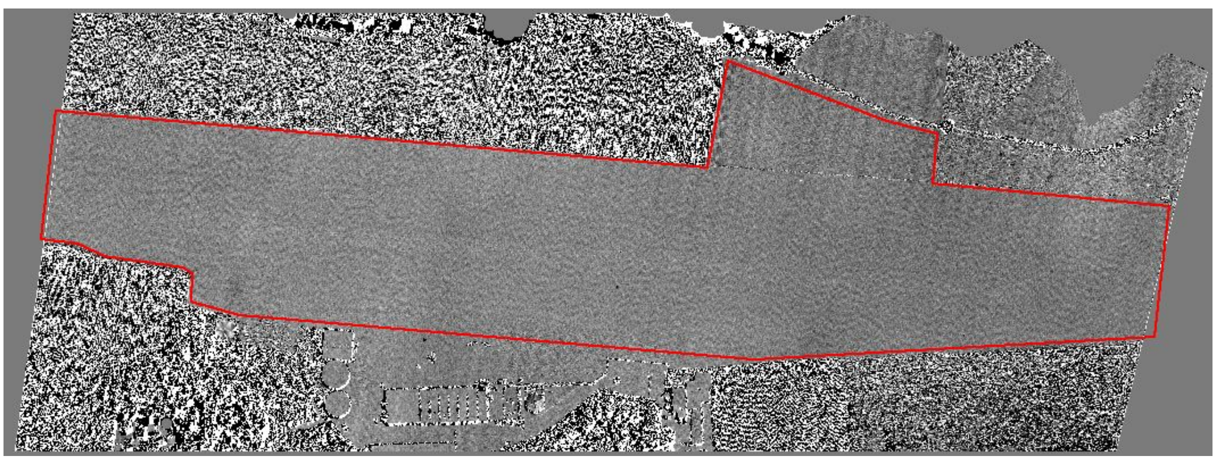
Roll angle offset of line 2 compared to line 1 in 10-m-segments along line 1



Roll angle offset of line 4 compared to line 3 in 10-m-segments along line 3

- **Vertical accuracy**

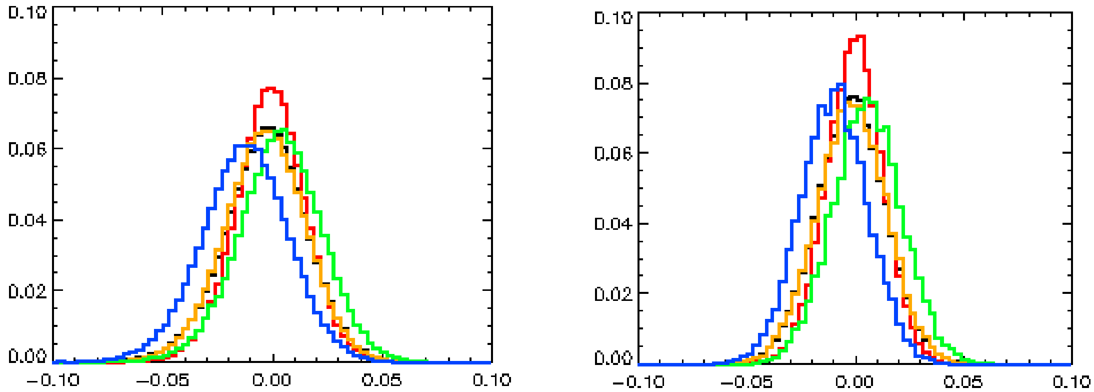
Range noise and the repeatability of height measurements is quantified by the height difference statistics of each flightline in comparison with the other lines in the intersection area. To eliminate the influence of surface features the statistics were calculated for the zones outlined in red (zone 1: runway and surrounding grass areas) and green (zone 2: paved runway only). The reference model was smoothed to give a more representative indication of height noise.



Height difference image between lines 1 and 2 (black: -0.1 m, white: +0.1 m)

Lines	Mean height difference [m]		Standard deviation [m]		95% - Interval [m]	
	zone 1	zone 2	zone 1	zone 2	zone 1	zone 2
(1 – 1)	**-**	**-**	0.018	0.013	0.033	0.026
2 – 1	-0.003	-0.001	0.020	**0.016**	0.038	**0.032**
3 – 1	0.004	0.001	**0.021**	**0.016**	0.040	**0.032**
4 – 1	**-0.012**	**-0.009**	**0.021**	**0.016**	**0.041**	0.031
1 – 3	-0.005	-0.006	**0.021**	**0.016**	0.040	0.031
2 – 3	-0.009	-0.008	0.020	**0.016**	0.038	0.031
(3 – 3)	-	-	0.019	0.014	0.034	0.028
4 – 3	**-0.016**	**-0.015**	0.020	**0.016**	0.039	0.031

Mean height differences are predominantly caused by GPS fluctuations.



Histograms of Height Differences (left: red zone, right: green zone, red: line 1, yellow: line 2, green: line 3, blue: line 4, reference: line 1)

The theoretical vertical accuracy, calculated as the RMS of the vertical deviations to be expected from the worst-case angular offsets in heading, pitch and roll amounts to 0.018 m RMSE at the swath center and 0.021 m RMSE at the swath edges which corresponds well with the observed values.

- **Planimetric accuracy**

The horizontal accuracy is calculated as the RMS of the planimetric displacements caused by the worst case heading, roll, and pitch errors. Using the residual error values above, for an altitude of 400 m AGL and the maximum scan angle of ±30° the resulting horizontal errors are 0.10 m RMSE at the swath center and 0.14 m at the swath edges. Due to the limited planimetric resolution (point spacing: 0.75 m) planimetric errors of the given magnitude could not be observed directly in the data. However, comparisons of elevation profiles across sloped surfaces (e.g. building roofs) indicate that planimetric deviations do not exceed these calculated values.

Summary

The data acquired at the “Airfield” test site revealed a very high internal geometrical accuracy of the LiteMapper 2800 system with

- vertical noise and in-line deviations in the order of 1.6 cm (1 σ) or 3.2 cm (95% = 2 σ) on flat surfaces
- vertical deviations between lines of less than 2 cm
- horizontal/planimetric errors of less than 0.15 m (1 σ)

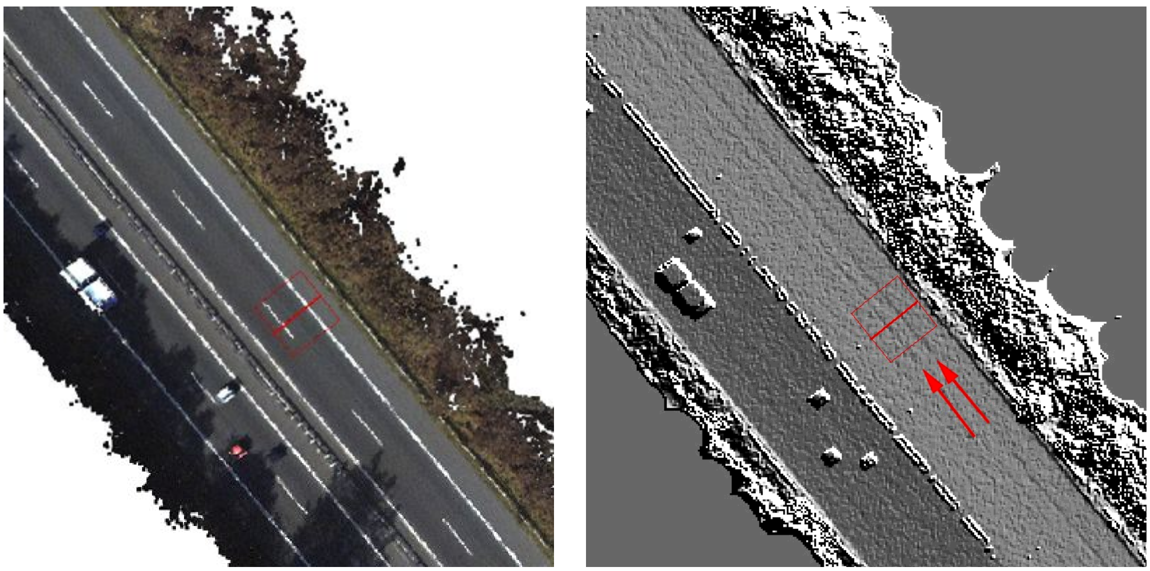
from an altitude of 400 m within the entire swath of 460 m.

Measurement resolution

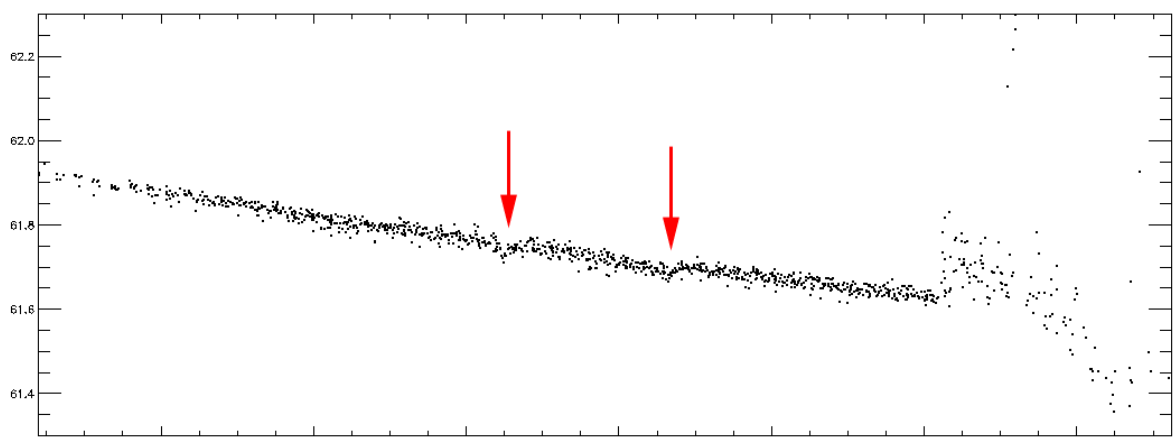
- **Vertical resolution**

The vertical resolution is determined by the ranging resolution of the lidar system. The hardware range resolution is 0.5 cm. As was shown above, under homogeneous surface conditions (runway) elevation noise was around 1.3-1.6 cm. The following highway example shows that this value is actually a realistic indicator of which height differences the system is able to resolve. The data was collected from an altitude of 65 m AGL at a speed of 18 m/s. The point density is 13 measurements/m^2.

On the right lane of the highway track grooves only 1-2 cm deep were detected in the asphalt.



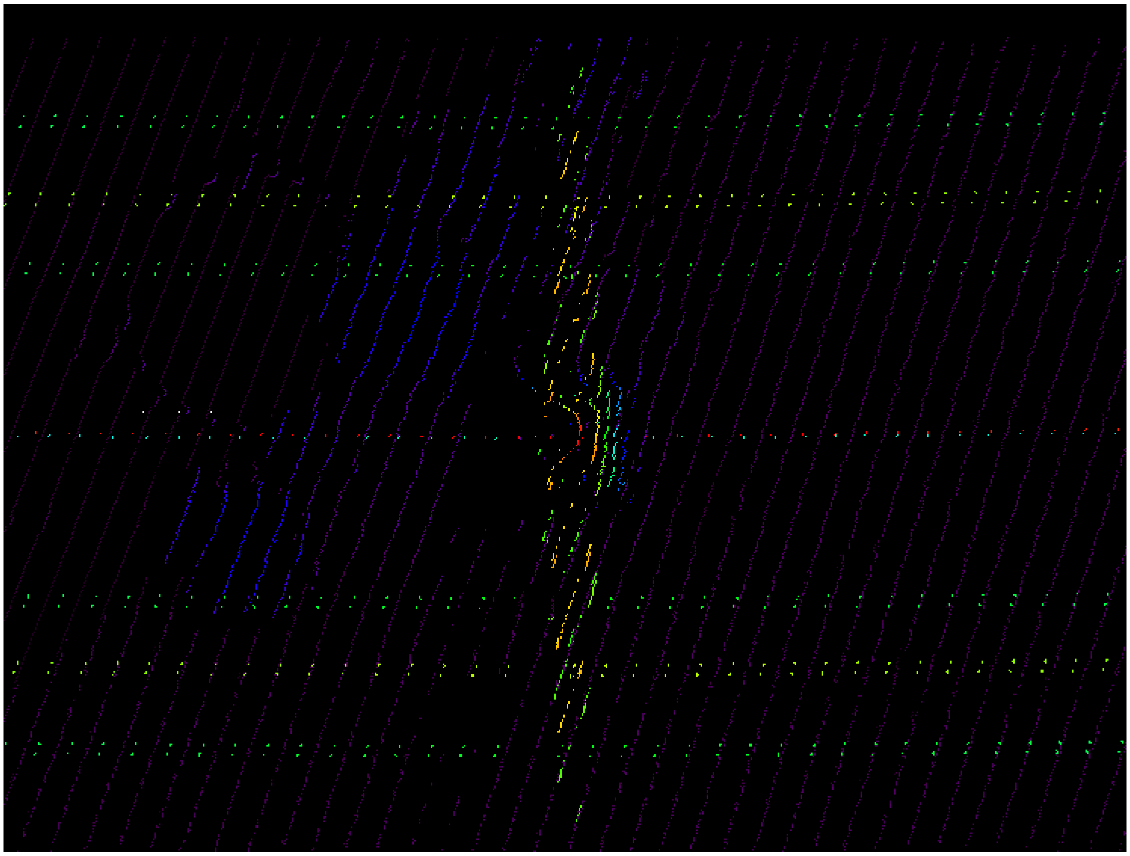
Lidar RGB surface color image and shaded relief view of highway with track grooves



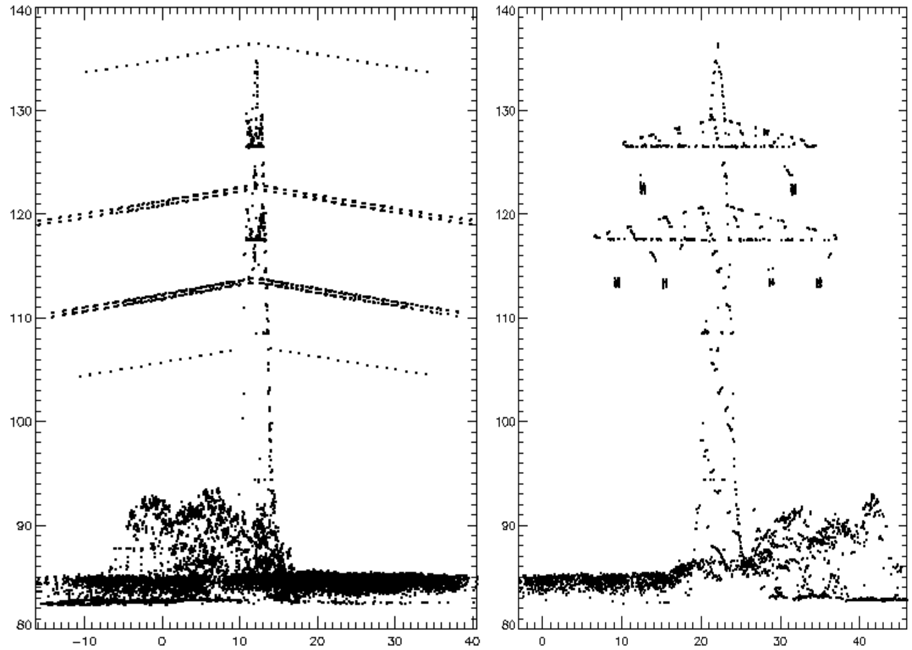
Cross-section profile of right lane

- **Horizontal resolution**

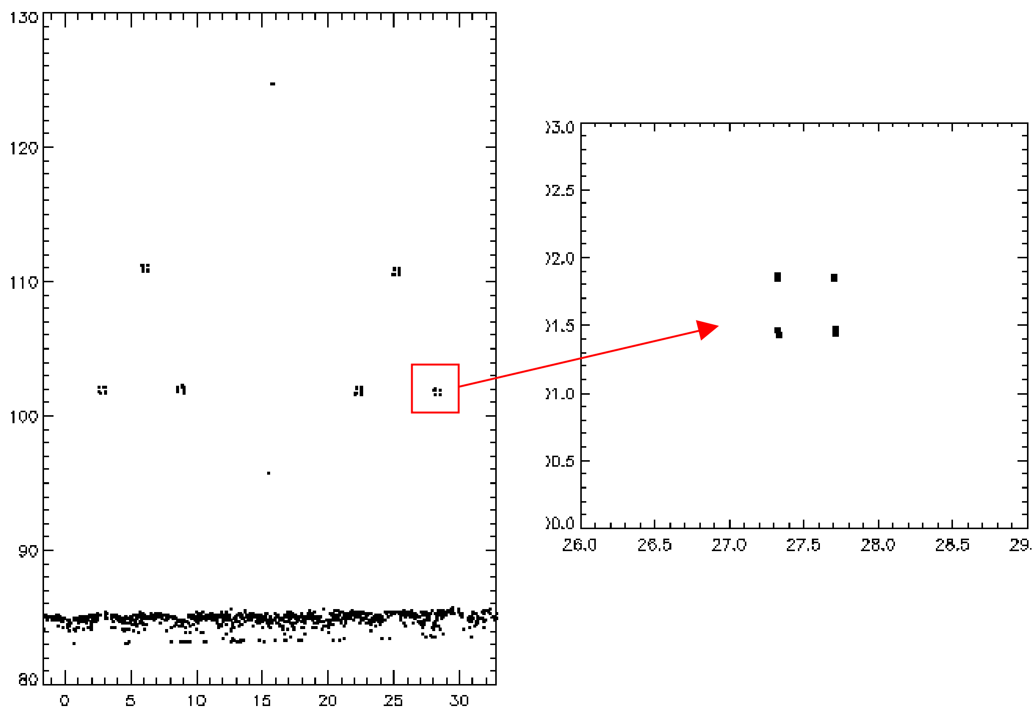
The horizontal resolution is determined by the beam divergence and the scanner settings. The system under test has the wide-divergence option to optimize the detection of powerline wires. At a scan frequency of 16 Hz consecutive measurement beams touch each other permitting to detect wires reliably in every scan. The beam divergence of 1.2 mrad limits the horizontal resolution. It is, however, sufficient to resolve multiple wires in a bundle as shown in the following example. The data was collected from an altitude of 85 m AGL at a speed of 22 m/s. The point spacing on the ground was 0.1 m in the scan direction and 1.3 m in the direction of flight. At this altutude the beam diameter was 0.11 m.



380kV powerline tower from above

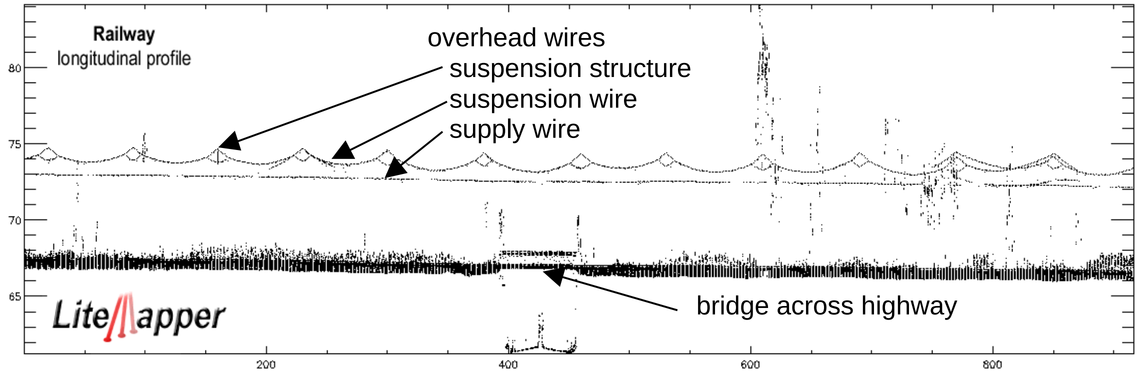


380 kV Powerline tower side views



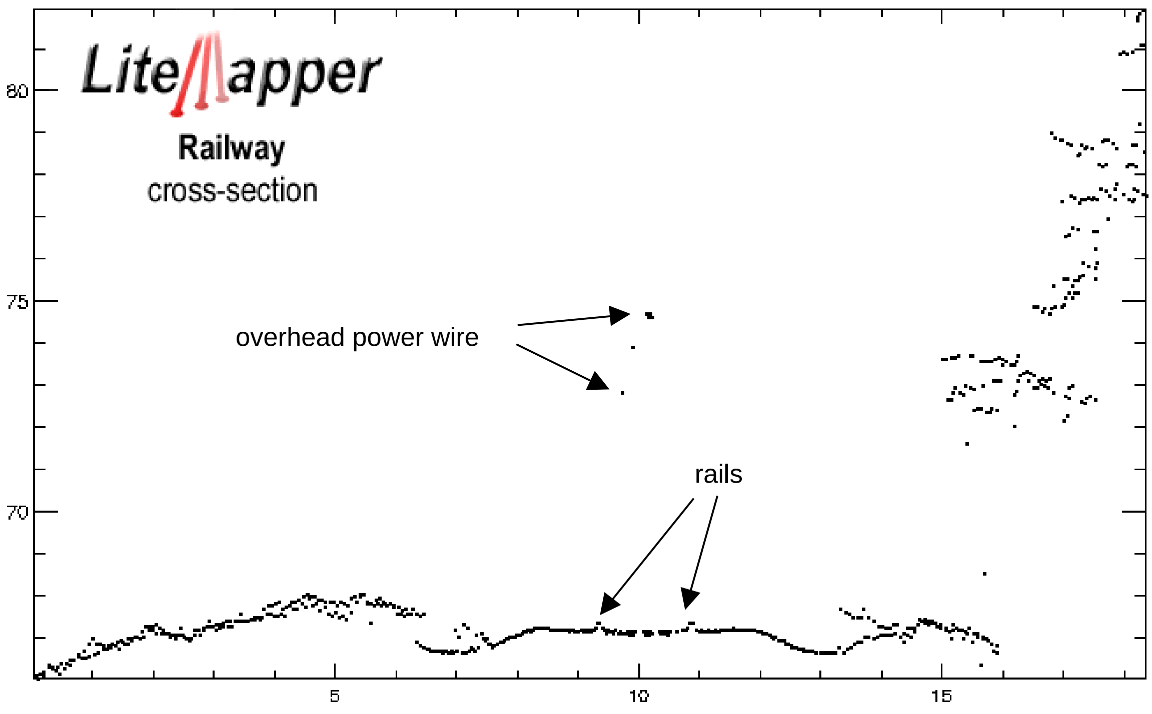
380 kV Wire cross-section and wire bundle detail

The data of the last example was collected at an altitude of 55 m AGL at a speed of 20 m/s over a railway line. With the scan frequency of 20 Hz a point spacing on the ground resulted to be 0.06 m in the scan direction and 1.0 m in the direction of flight, with a beam diameter of 0.066 m.



Railway line longitudinal profile

The overhead power wire (diameter < 1 cm) is detected reliably. Occasional missing points on the lower wire are due to obscuration by the upper suspension wire.



Railway line cross-section

In the cross-section the individual rails can be identified clearly.