ON THE QUALITY CHECKING OF THE AIRBORNE LASER SCANNING-BASED NATION WIDE ELEVATION MODEL IN FINLAND

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ABSTRACT:

Nationwide airborne laser scanning (ALS) has been carried out in European countries such as the Netherlands and Switzerland; in Germany large parts of the country has been scanned and the work is going on as federal basis. The decision makers of national mapping agencies are realizing the benefits of ALS, e.g. significantly improved accuracy, lower processing costs and higher automation, and, thus, plans of performing national laser scanning are planned in many other countries. The elevation model working group of the Ministry of agriculture and forestry of Finland recommended the usage of airborne laser scanning for the creation of a new multi-purpose nationwide elevation model in 2006, and thus the National Land Survey of Finland (NLS), in co-operation with the Finnish Geodetic Institute (FGI) had a more than 1000 km^2 practical test on using ALS for the new nationwide elevation model and its quality checking in late 2006 and early 2007. The objectives of the test were: a) to define the elevation quality of ALS flights from two point densities 0.5-1 and 0.1 points per square metre resulting in two flight altitudes 2000 m and 5000 m using the Optech ALTM 3100 and scanning angle of ±20 degrees and Leica ALS50-II and scanning angle of ±20 degrees, b) to compare the quality derived with two different sensors (Optech ALTM 3100 and Leica ALS50-II), c) to define the quality of ALS derived DEM in various surface types, d) to analyse the planimetric errors, and e) to develop methods to derive ground reference data effectively.

1. INTRODUCTION

The digital elevation model (DEM) in 25 by 25 m^2 grid covers the whole Finland and it has been updated gradually to 10 by 10 m^2 model. The height accuracy (St.Dev.) of the first model is 1.4 m (NLS 2008) and the latter 1.1 m (Oksanen and Sarjakoski, 2006). Using exactly the same study area as in Oksanen and Sarjakoski, 2006, the height precision (St.Dev.) of the 25 by 25 m^2 grid model is 2.1 m. In May 2007 half of the area of Finland was covered by this new 10 by 10 m^2 updated model. However, the height accuracy does not fulfil the modern demands. For example, European Union floods Directive 2007/60/EC on the assessment and management of flood risks entered into force on November 26, 2007. It requires the mapping of flood risk areas also in Finland. Additionally, International Civil Aviation Organization (ICAO) requires accurate elevation models of airport areas and their neighbourhoods. Some practical tests have shown that errors up to several tens of meters exist in the present model and the quality is heterogeneous (Oksanen and Sarjakoski, 2006).

New techniques enable producing more precise DEMs nowadays. Nationwide airborne laser scanning (ALS) has been carried out in European countries such as the Netherlands and Switzerland (e.g. Artuso et al. 2003); in Germany large parts of the country has been scanned and the work is going on as federal basis. The decision makers of national mapping agencies are realizing the benefits of ALS, e.g. significantly improved accuracy, lower processing costs and higher automation, and, thus, plans of performing national laser scanning are planned in many other countries.

The elevation model working group of the Ministry of agriculture and forestry of Finland recommended the usage of airborne laser scanning for the creation of a new multi-purpose nationwide elevation model in 2006, and thus the National Land Survey of Finland (NLS), in co-operation with the Finnish Geodetic Institute had a more than 1000 km^2 practical test on using ALS for the new nationwide elevation model and its quality checking in late 2006 and early 2007.

The objectives of the test and study were:
a) to define the elevation quality of ALS flights from two point densities 0.5-1 and 0.1 points per square metre resulting in two flight altitudes 2000 m and 5000 m using the Leica ALS50-II and scanning angle of ±20 degrees,
b) to compare the quality derived with two different sensors (Optech ALTM 3100 and Leica ALS50-II),
c) to define the quality of ALS derived DEM in various surface types,
d) to analyse the planimetric errors of ALS surveys, and
e) to develop and test practical methods to derive ground reference data effectively for large-area ALS collection.

The test site Salo was selected by the NLS. In earlier study by Ahokas et al. (2005), it was preliminary shown that scanning angles of up to 15 degrees can be used without scarifying the derived elevation accuracy. Based on specifications by the manufacturers the following accuracies are given. Leica´s ALS50-II accuracy assuming 0 cm GPS error is 5 cm in xy and 4 cm in z with slant range 500 m and pulse rate 150 kHz. Planimetric accuracy is 21 cm and vertical 8 cm with slant range 2000 m and PRF 58 kHz. Flying height 5 km is supposed to give accuracies of 53 cm in xy and 19 cm in z when PRF is 26 kHz. Accuracies of 64 cm and 23 cm, respectively, are given for 6000 m altitude. Optech ALTM Gemini gives 9 cm horizontal and <10 cm vertical accuracy from 500 m flying altitude at 100 kHz pulse rate. Planimetric accuracy is 36 cm and vertical <15 cm with slant range 2000 m and PRF 100 kHz. Quoted accuracies do not include GPS errors.
The evaluation of the quality of ALS is problematic, since the object, such as forest and slope may affect more on the accuracy

than ALS parameters (Hyyppä et al. 2005). Thus, the quality analysed for flat surfaces may be a neutral way to perform the analysis. Concerning nationwide laser scanning, rapid, cost-effective field surveying methods are needed to perform such an analysis.

As a result of the test project final flying and scanning parameters were further defined for operative nationwide laser scanning. Accuracy requirement for the new 2 by 2 m^2 grid model was set to be better than 30 cm (RMSE). 20 000 km^2 will be operationally surveyed using airborne laser scanning in 2008 by the NLS and private companies.

2. MEASUREMENTS

2.1 Airborne laser scanning

Two acquisitions were planned for the test: first performed by Optech ALTM 3100 in late 2006 (under leafless, snow-covered (less than 5 cm conditions), and the second performed by ALS50-II in early spring 2007 (after the snow melt, leaf-less season).

An airborne laser scanner Optech ALTM 3100 was used for scanning the northern part of the NLS test area and performed by TopScan GmbH on behalf of the SITO group, a Finnish Consulting Engineers Oy. Flights were carried out on the 21 December 2006. Flying heights were about 2000 m above ground. Aircraft was a Cessna 404. The project size was 700 km^2. Parameters were as follows: Pulse repetition frequency (PRF) 50 kHz, maximum scan angle 20 degrees, scan frequency 24 Hz, planned swath width about 1380 m. All laser points including strip adjustment were supplied to the customer and the accuracy analysis was carried out using these calibrated points.

An airborne laser scanner Leica ALS50-II was used for scanning the southern part of the NLS test area around the city of Salo in south-western Finland. The NLS rented the scanner from the FM International Oy and operated it by themselves. Parameters were as follows: Pulse repetition frequency 52 kHz, scan angle was ±20 degrees, scan frequency 45 Hz, planned swath width 1600 m. The flying height was 2200 m above ground. The resulting point density was 0.5 points/m^2.
Eastern part of the area was also flown from 4750 m and also partly 500 m flying heights were used. The NLS operated the twin engine Cessna 401B on April 26 – 30, 2007.

Strip adjustment was done with the TerraMatch software at the FGI. This software solves for systematic errors in position, orientation and mirror scale using flight trajectories, classified surface laser points linked to the trajectories with time stamps and additional known points if they are available. First we used the heading, roll and pitch shifts and mirror scale values for the whole project area. These values were provided by the NLS. After that the height shift and roll values were solved for individual flight lines and strips were corrected.

2.2 Reference points

Terrain elevations for various land cover types: In addition to the RTK GPS measurements in open environment, tachymeter measurements were made in the forests. The RTK GPS have been used for the starting point measurements for tachymeter in the areas where benchmarks were not available. These ground reference point measurements were made in 2003 and 2007. The GPS reference station has been set up on the nearest benchmark or a virtual reference station has been used. According to Häkli (2004) the RMSE of VRS RTK is 2 cm in xy and 4 cm in z. Bilker and Kaartinen (2001) give RMSE accuracies 1 cm + 1-2 ppm in xy and 2 cm + 2 ppm in z in their RTK GPS report.

Xy-locations for planimetric accuracy estimation: Reference points were measured with Leica SR530 Real Time Kinematic (RTK) GPS. Horizontal accuracy of the RTK measurements was verified to be about 0.015 m and vertical accuracy 0.02 m in another study (Bilker and Kaartinen, 2001).

Terrain elevations from hard targets to cover the collected area: Mobile VRS RTK measurements were made on May 24, 2007 to collect reference points for airborne laser scanning in Salo area in Finland. A GPS antenna was assembled on the roof of a van. Co-ordinates were registered every 2 seconds which corresponded to 20 to 30 m point distance depending on the speed of the car. More than 1400 points were measured during the day. Road numbers 52 Perniö – Salo, 186 Salo – Kisko and 1870 Kisko - Kitula were measured. Trees and cuttings obstructed the GPS signal and caused interruptions in measurements. Open field areas were excellent for this kind of mobile measurements.

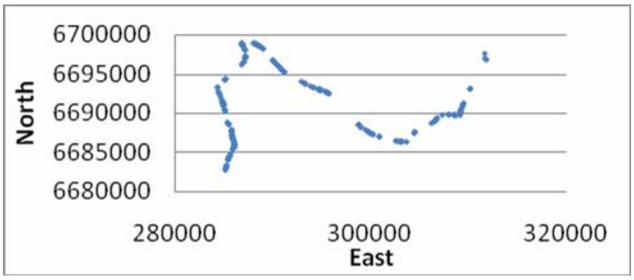

Figure 1. The geographic location of the mobile VRS-RTK points used for laser scanning height accuracy analysis, N=251 points.

2.3 Analysis

The comparison between the observations and reference points was made as follows. Laser points were selected so that the reference point and the compared laser point were within 0.5 m distance from each other. To increase the amount of compared points also distance less than 1 m was used for comparison.

If there were one or more laser points within the predefined distance (e.g. 50 cm) from the reference point the nearest laser point was selected and the height difference between the laser point and the reference point was calculated. In the earlier study of Ahokas et al. (2003), it was found that the interpolated height value, mean height value and the nearest laser point height value gave about the same height results in the comparison analysis. Laser points in various land cover classes were analyzed in this way.

The road point analysis showed that the registration of laser points from black asphalt was sometimes difficult. There were reference points available on the road in the open field environment but the corresponding laser points were missing due to the weak return signal.

3. RESULTS

3.1 Elevation accuracies as a function of land cover classes

Accuracies were first analyzed for various land cover types using reference points measured with RTK GPS and tachymeter.

The results are depicted in Table 1 for Optech. The bias was calculated by the height difference of laser points – reference points. As earlier stated, there was some centimetres deep snow cover partially on the ground during the Optech measurements in December 2006. This could have an effect on the results, e.g. the snow layer could produce a systematic shift to DTM, but the high reflectivity of the snow also could improve the distance measurements. In the forest areas otherwise very dark ground surface had now snow and echoes came back through the tree foliage that was without the snow cover.

Type	Bias	StD	RMSE	Ref. points
Asphalt	-0.07	0.08	0.10	24
Diverse open land	0.06	0.07	0.09	23
Rock	-0.01	0.08	0.08	28
Forest	0.03	0.12	0.12	38
Field	0.11	0.05	0.11	13
Gravel	-0.02	0.05	0.05	9

Table 1. Optech ALTM 3100, 0.7 points/m^2, H=1900 m. Height accuracies in (m). Search radius R<50cm

As can be seen, the open areas, such as diverse open and field had the highest positive bias i. e. laser points were above the ground surface reference points. The asphalt and gravel has the lowest bias. The snow was the thickest in the first two open areas. The bias can, thus, be explained by the snow and by the reflectivity (typically brighter areas have more bias). The surface of the fields may have also changed between the reference data collection and the ALS flight due to agricultural treatments like ploughing.

Concerning random errors, the forest had the highest errors due to varying surface topography. In general, the accuracies were better than expected by the NLS and met the terrain height accuracy requirements easily.

The corresponding analysis was performed for ALS50-II and the results are summarized in Table 2. The aerial coverage of the ALS50-II data was larger than the Optech one, hence more available ground reference points could be utilized for the accuracy analysis. The results are comparable to previous results. The variability of biases with different land cover is smaller due to absence of snow.

Type	Bias	StD	RMSE	Ref. points
Asphalt	0.06	0.04	0.07	20
Diverse open land	0.14	0.05	0.15	17
Rock	0.01	0.13	0.13	65
Forest	0.08	0.17	0.19	258
Field	0.10	0.03	0.11	16
Gravel	0.06	0.08	0.10	28

Table 2. ALS50-II. 0.5 points/m^2, H=2200 m. Height accuracies in (m). Search radius R<50cm

The height accuracies of the 2200 m data indicate that the specifications for the new DEM will be fulfilled. Random errors and RMSE are below 15 cm for unambiguous surfaces.

3.2 Planimetric accuracy

The planimetric accuracy of the Optech and Leica laser points (2000 m survey) was tested with the collected vertical pole information, since the point density did not allow the use of intensity values, e.g. paintings, for xy accuracy testing. The statistics of the results are shown in Table 3.

	Optech	Leica
Average planimetric shift	0.58	0.55
Planimetric std	0.35	0.34
Minimum planimetric shift	0.09	0.22
Maximum planimetric shift	1.26	1.38
Number of observations	9	11

Table 3. Horizontal accuracy in (m) of Optech and Leica points.

The planimetric accuracy of high altitude measurements was not tested because the laser point data was too sparse to hit the reference poles.

3.3 Elevation quality of high altitude measurements

Leica ALS50-II measurements at the flying height of 4750 m produced the point density of only 0.1 points/m^2, thus the number of reference points used were lower in this case although the search circle radius was increased to 1 m. Standard deviations have increased compared to the results of 2200 m flying height. The RMSE value has increased especially for the varying relief rock area.

Type	Bias	StD	RMSE	Ref. points
Asphalt	-0.06	0.06	0.09	12
Diverse open land	0.01	0.14	0.12	5
Rock	0.00	0.23	0.22	10
Forest	0.02	0.18	0.18	53
Field	-0.01	0.14	0.12	5
Gravel	0.04	0.01	0.04	2

Table 4. ALS50-II. Flying height 4750 m. Height accuracies after strip adjustment in (m). Search radius R<1m.

The obtainable accuracy of point is high, but the number of points hitting the ground is low and the quality of the DTM is dependant on the forest cover and modulation of the terrain, since continuous model is significantly based on interpolation rather than on laser points.

3.4 Mobile measurements as reference

Mobile virtual reference station (VRS) RTK measurements were made on May 24, 2007 to collect large amount of reference points on the roads. Trees and cuttings obstructed the GPS signal and caused interruptions in measurements. Open field areas were excellent for this kind of mobile reference point measurements.

The resulting 10 cm standard deviation (random error), Table 5, is about double the one obtained using static reference point measurements.

Standard deviation	Reference points	Search circle radius
0.10	76	R<0.5m
0.11	251	R<1.0m

Table 5. Height accuracies of Leica ALS50-II laser points on the asphalt road. (laser points-reference points)

The accuracy of the mobile measurements was estimated by measuring 51 static reference points with VRS-RTK GPS. Mobile derived XY co-ordinates were searched within 10 cm distance on the road. Results are in Table 6. We can say that the mobile reference point measurement system gives the accuracy that is good enough for the quality and gross error checking of ALS measurements.

Mean difference in Z	-0.004 m
Standard deviation	0.036 m
Max positive difference	0.118 m
Max negative difference	-0.063 m

Table 6. Accuracy of mobile VRS-RTK. Mobile – static reference point measurement.

4. CONCLUSIONS

In this article we have studied different aspects of the quality checking of the laser based nationwide digital elevation model using the Salo test data.

The data of two ALS systems, Optech ALTM 3100 and Leica ALS50-II, have been analyzed and found to be of high quality. The flight altitude of 4750 m gives such a sparse pulse density that a 2 by 2 m^2 grid model is unrealistic to create even though the obtainable elevation accuracy is high, partly thanks to the relatively flat test site. Significantly higher errors are expected to occur in more steep terrain and when obtained models are compared to the reference; in this comparison we always had laser and reference point close to each other (maximally, either 0.5 m or 1 m away from each other).

The quality obtained in all various surface types was better than the specified 30 cm.

The obtained planimetric accuracies of the scanners from the altitude of 2000 m were roughly within the specifications of the scanner manufacturers.

Black asphalt does not always reflect laser beam well enough for accurate measurements from 2200 m flying height. This causes the lack of laser points on the asphalt roads.

Results show that a mobile VRS RTK measurement system is a cost effective way to collect large amount of reference points that are cost-effective and accurate enough for checking the quality of ALS, especially for quality control of strip adjustment and quality checking of homogeneity of the data over large areas. Levelling and static reference point measurements are though needed in specific areas where more precise reference points are needed.

The test project showed that the airborne laser scanning parameters for fulfilling the nation-wide elevation model accuracy specifications could be as follows: Scan angle of ±20 degrees, flying height of about 2000 m, point density at least 0.5 points/m^2, side lap 20 % minimum.

After the strip adjustment and the elimination of systematic errors in the laser data of the national laser scanning vertical accuracy of the unambiguous planar areas will be better than 15 cm (RMSE). Without strip adjustment, there were even errors up to more than 1 m, thus, the strip adjustment is a needed procedure even at nation-wide data collection. The required 30 cm RMSE of the new 2 by 2 m^2 grid model for unambiguous planar surfaces will be met with 0.5 pulses per m^2 density.

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