OPTIMIZATION OF THE SCANNING ANGLE FOR COUNTRYWIDE LASER SCANNING

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ABSTRACT

Countrywide collection of laser scanning, mainly due to DTM derivation, is becoming increasingly attractive. Since Finland is a large country, optimization of scanning parameters is important from the economical point of view. High altitude measurements with large scan angle would be cost-effective if accuracy requirements are fulfilled. In this study two cases are described. In Masala low altitude airborne laser scanning was compared to tacheometer measurements and in Sammatti high altitude Optech measurements were compared to dense Toposys Falcon measurements. The very first results indicate that scanning angle effect can still be moderate until 15 degrees and there seems to be other error sources of the same magnitude as the scanning angle error. High altitude laser scanning gives precision that is roughly about ±20 cm (std), which is good enough for most terrain models required in forested areas. There is a need to continue the studies of the effect of scanning angle on obtained accuracy.

1. INTRODUCTION

Countrywide collection of laser scanning, mainly due to DTM derivation, is becoming increasingly common. Started in Netherlands, and continued in Switzerland and various states of Germany, and nowadays discussed in several countries, national laser scanning (NLS) concepts are currently under development. In the Netherlands, the national laser scanning was initiated to meet the demand for detailed and up to date height information from water boards, provinces and Ministry of Transport (Rijkswaterstaat). The Netherlands was collected with a relatively sparse point cloud. Today, preferred point cloud density is about 0.5-1 point per m^2 (e.g. Artuso et al. 2003). The development of new systems however, allows higher flight altitudes, and thus lower costs per m^2.

In central Europe, countrywide laser data collection for DTM requires the use of last pulse mode under leaf-off conditions in order to guarantee high quality DTM in forested areas. The permitted flight period extends from November to March in Switzerland (Artuso et al. 2003)

The quality of DTM derived from laser scanning is influenced by a number of factors which can be grouped as follows; errors caused by the laser system (laser instrument, GPS and INS), and data characteristics (e.g. first/last pulse, point density, flight height, scan angle), as well as errors created during processing of the data (interpolation errors, filtering errors, errors caused by improper break-line detection, segmentation and smoothing of the data), and errors due to characteristics of the target (type of the terrain, flatness of the terrain, density of the canopy above). In countrywide terrain models, the accepted height errors are typically less than 50 cm, where as the smallest obtainable errors with laser scanning range between 5-10 cm in forested terrain (Hyyppä et al. 2005). Therefore, the collection of countrywide DTMs with laser scanning can also be carried out with non-optimal parameters to save money.

The discussion of covering Finland with laser scanning is a new concept. Possible applications in Finland for the laser-derived terrain and surface models include national DTM, forest inventory (76% of the area covered by forests, 15-20 € used for forest inventory per hectare in approximately 10 years periods), flood monitoring, map updating, 3D landscape model, to name but a few major applications.

Finland is relatively large in size (338 000 km^2), characterized with relatively flat topography. About 190 000 lakes and ponds (area larger than 500 m^2) serve as a good opportunity to control the terrain model with strip adjustment and other up-to-date techniques, e.g. discussed in (Elberink et al., 2003). The quality requirements of the models are dependant on the importance of the areas and surface topography. Therefore, the potential Finnish NLS is expected to be based on several sets of laser scanning acquisition parameters. The snow cover, lasting from October-December to March-May makes the leaf-off period in Finland relative short in spring for laser surveys (2-5 weeks). In autumn, the undergrowth stays high until the snow comes.

In Finland, based on studies of Yu et al. (2005) and Hyyppä et al. (2005), even the use of first pulse and leaf-on conditions will result in reasonably good quality DTM with dense point clouds in forested areas. Since the pulse density is increasing, the costs of laser scanning can be decreased by increasing flight altitude and scanning angle. In Hyyppä et al. (2005), the effect of flight altitude was discussed using altitudes between 400 and 1500 m. Using first pulse of Toposys Falcon (83 kHz), ±7.1 scanning angle, 1500 m flight altitude and leaf-off conditions, the DTM was obtained with a precision better than 20 cm.

There have been several empirical studies on DTM quality with laser scanning. However, the effect of scanning angle has not been carefully analyzed before. Test flights (TopoSys, 1996) have shown that at scanning angles of more than 10 degrees off-nadir, the amount of shadowed area increases substantially, i.e., the number of measured ground hits decreases and gaps in the DTM occur more frequently. On flat areas, the effect of scanning angle up to 20 degrees is negligible (Hyyppä and Hyyppä, 2005). This paper concentrates in analyzing the effect of scanning angle of DTM accuracy.

2. TEST DATA

2.1 Test Sites

Two test areas in Finland were selected for the study. One located in Sammatti, 80 km west of Helsinki, and another in Masala, 20 km west of Helsinki. The Sammatti area consists of varying topography and landscape (both forests and agricultural areas exist). The Masala study area is a forest-covered area situated on a small hill with slopes ranging from 0^o to 50^o. Forest cover consists of a mixture of pine (main species), spruce and birch. Canopy cover is about 36%. Boulders of varying size are distributed all over the area adding local variation.

2.2 Studied Laser Surveys

An Optech 2033 airborne laser scanner was used for data collection in the Sammatti area on June 29, 2004 under leaf-on conditions. Flying altitude was 2000 m above ground level and scanning angle was ±15 degrees resulting in point densities of approximately 0.7 points/m^2. Nominal point density was 0.4 points/m^2. Classified ground point density was 0.2 points/m^2. In Masala, laser data were collected with a TopEye laser scanner on September 5, 2002 during leaf-on conditions from an altitude of 105 m (a.g.l.). As a result, point densities were 4 to 7 points/m^2.

2.3 Reference Data

Reference data in the two study areas were collected in order to test the accuracy of derived DTMs. The measurements were carried out using a tacheometer in Masala and high-density laser scanner point cloud in Sammatti.

In Masala, ground reference points were collected with tacheometer within an area of 50 m by 100 m. Altogether 3014 points were used in the analysis.

German TopoSys II airborne laser scanner was used for DTM reference collection in the Sammatti area on 14 May, 2003 under leaf-off conditions. The pulse repetition frequency (PRF) (83 kHz), maximum scan angle (±7.1°), beam size (1 mrad) and flight altitude of 800 m resulted in point density of 6.7 points/m^2. The accuracy of this laser derived reference DTM in Sammatti was analyzed to be approximately 10 cm with tacheometer measurements.

3. METHODOLOGY

In Masala, laser point clouds were first classified by TerraScan software (see www.terrasolid.fi) to separate the ground points from other points. Then a raster DTM grid with a 50 cm pixel size was created from classified ground points by taking the mean value of the ground points within the grid. Missing points in the DTM were afterwards interpolated using Delaunay triangulation and the bilinear interpolation method. To evaluate laser DTM accuracy, the differences between laser-derived terrain elevations and field measurements at the location of reference points were calculated.

In Sammatti, both the Optech and Toposys laser point clouds were first classified by TerraScan software to separate the ground points from other points. At the location of each classified Optech point, a 0.5 m radius circle around that point was formed. If there exist more than 5 ground-classified Toposys II points, the average of them was calculated as the reference value. The difference between this reference and classified Optech point was then compared.

The TerraScan classification is based on a method developed by Axelsson (2000), where surface was allowed to fluctuate within certain values, controlled by minimum description length, constrained spline functions, and active contour models for elevation differences. Ground points are connected in a TIN. A sparse TIN was derived from neighbourhood minima, and then progressively densified to the laser point cloud. In every iteration, points are added to the TIN, if they are within defined thresholds.

Scanning angle was an approximation of actual scanning angle by assuming that the aircraft flies along a straight path at a constant height.

In fully-forested areas, most applied strip adjustment techniques mainly correct the systematic shifts of the data as a function of scanning angle, therefore, the analysis was decided to carry out with no strip adjustment done and systematic and random errors were analyzed separately. It should be noticed that the time-variant component of strip adjustment is mixed with random error and therefore the study will be repeated later on with detailed strip adjustment done. However, the budget of countrywide laser scanning does not allow sophisticated strip adjustments.

4. RESULTS

4.1 Scanning angle effects at Masala

The effects of scanning angle on laser DTMs are shown in Figure 1 for Masala. The mean error (referring to systematic error) statistics shows that there seems to be a 5 cm tilt in the strip (see laser points, LP). The shadowing effects are shown with interpolated points (IP). When the scanning angle increased, the standard deviation of the errors increased. The random error obviously has a minimum around zero scanning angle, and the effect of the scanning angle can be estimated to be about 10 cm for all and interpolated points. When analyzing merely laser points, the effect is smaller.

The conclusion from this first study (low altitude measurement, high pulse density) on scanning angle was that for classified laser points the effect of the scanning angle is relatively small. It was expected that the reason for higher errors at higher scanning angle was the misclassification of laser points (low vegetation causing errors) and more difficult geometry. The scanning angle had a higher impact on the obtained terrain model, since due to the shadowing the number of ground hits decreased and the number of interpolated pixels increased.

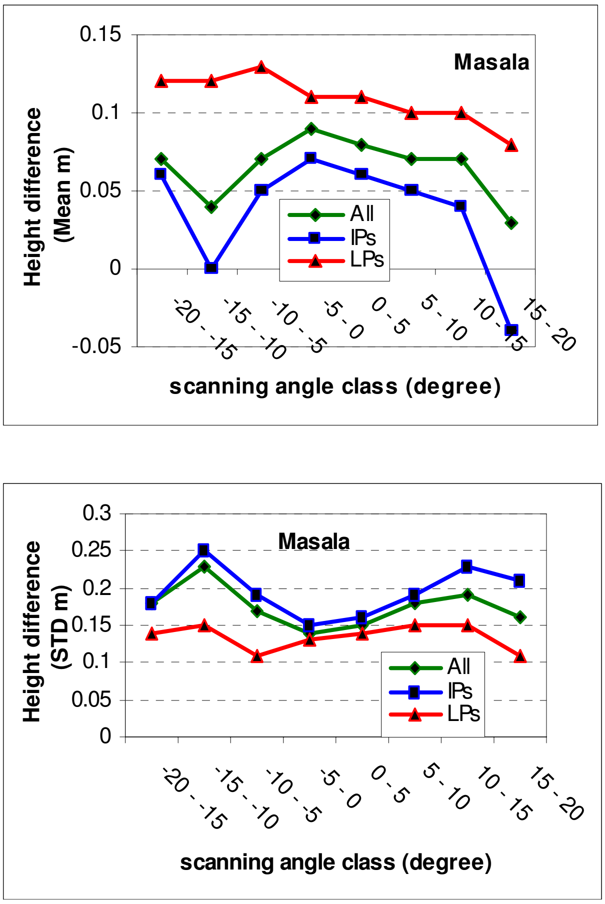

Figure 1. The elevation errors as a function of scanning angle for Masala test areas. All=all points, IPs=interpolated points, LPs=laser points.

4.2 Scanning angle effects at Sammatti

At Sammatti, low density data was collected from high altitude (2000 m). From three different areas (each approx. 350 by 1100 m in size) and from two strips, five cases of tests were calculated to give an overall understanding about the quality of low density data. Flight strip 1 was flown from east to west. Flight strip 4 was flown from north-west to south-east.

Table 1. Calculated deviation of low-density laser scanner data compared with high-density laser scanner data in Sammatti. Means and standard deviations (std) presented.

Test Area	Type	Mean and std of differences (cm)
Strip 1, Area 1	Field	9.0±15.4
Strip 1, Area 2	Forest	-2.9±16.4
Strip 1, Area 3	Forest	-5.8±15.8
Strip 4, Area 1	Field&Forest	2.0±18.1
Strip 4, Area 2	Forest	-7.7±24.3

Positive values in difference refers that Optech DSM is higher than Toposys DSM.

In general Optech data coincides well with Toposys Falcon data.

The effect of the scanning angle was studied for agricultural field and forests. Scanning angles are positive to the right side of the aircraft and negative to the left side.

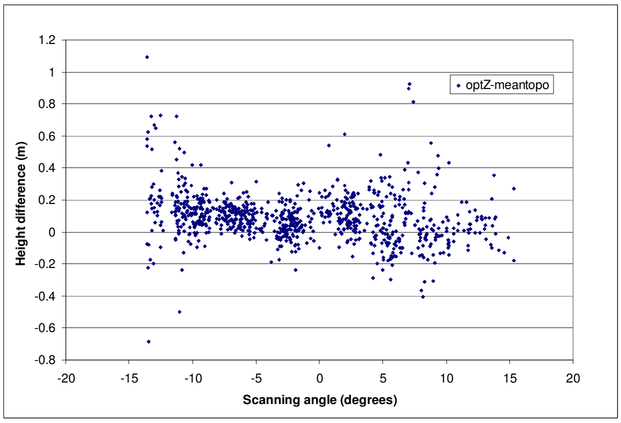

Figure 2. Height differences for agricultural field (strip 1, area 1). The amount of compared Optech points is 853.

In Figure 2 are shown the difference of high altitude derived laser points (classified as ground points) compared to average value of more than 5 laser points (classified as ground points) from high density measurements in an agricultural field. The results imply that at higher scanning angles (shown especially of the left side of the scan) errors can increase.

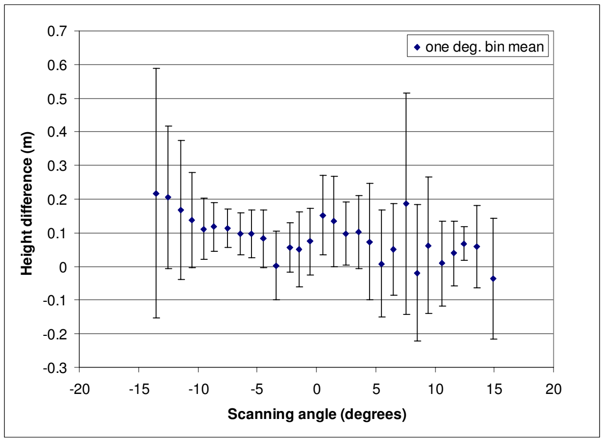

Figure 3. Calculated systematic and random errors for case (agricultural area) shown in Figure 2.

The calculated systematic and random errors are shown in Figure 3 as a function of scanning angle. The trend of the systematic errors (blue squares) can be interpreted as the time-invariant error due to the misalignment of strips. The variation of systematic errors can be considered as systematic differences with the two acquisitions at different times. The random errors at each scanning angle should explain the errors due to the scanning angle, landscape cover and misclassification. By comparing the left sides of Figures 2 and 3, it seems that the number of misclassification increases as a function of scanning angle. The interpretation of the right side is more complex. It shows that scanning angle effect can still be moderate until 15 degrees and there are other error sources higher than the scanning angle error.

Figure 4 shows a similar test with forest. Basically, there does not seem to be any misalignment of the strip. On both size the systematic error changes near 15 degrees scanning angle. Additionally, at the left, the random error increases.

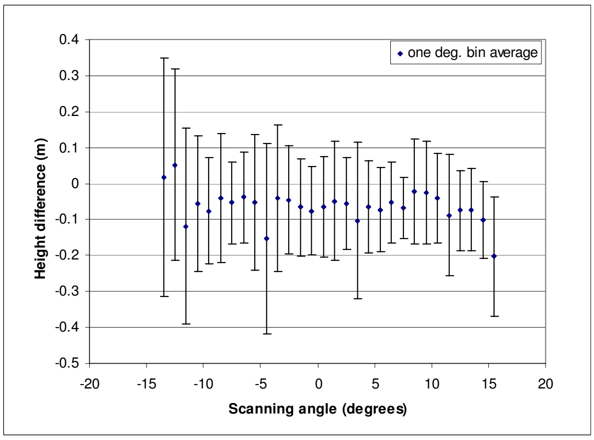

Figure 4. Calculated systematic and random errors for forest area. Strip 1, Area 3. 4683 verified points.

Figure 5 shows the number of ground hits (TerraScan classified ground hits) obtained as a function of scanning angle for the forest shown in Figure 4.

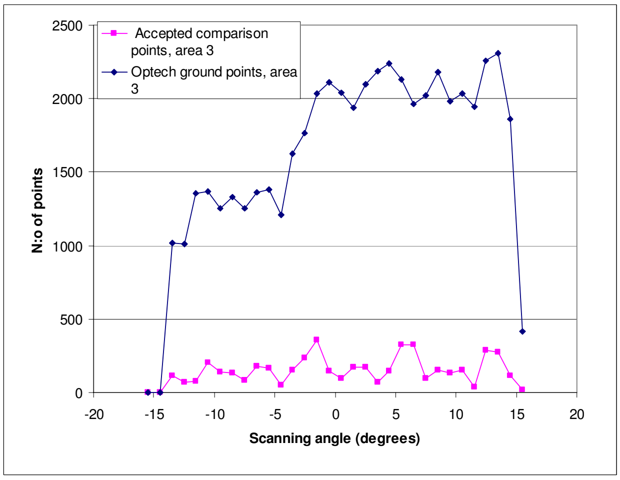

Figure 5. Amount of Optech ground points (above) and points used for verification (below). The drops at scanning angles more than 13 degrees (on the left) and more than 14 degrees (on the right) are caused by the loss of original data at these angles and it should not be taken into account.

Figure 5 shows that the obtained ground points for DTM generation stays relatively reasonable until it drops at scanning angles more than 13 degrees, which is caused by the loss of original data at these angles and it should not be taken into account. The number of classified ground points is also affected by the density of the forests as seen in the left side of the Figure 4. That effect is dominant. The lower curve shows the number of good reference 1-m plots by Toposys II.

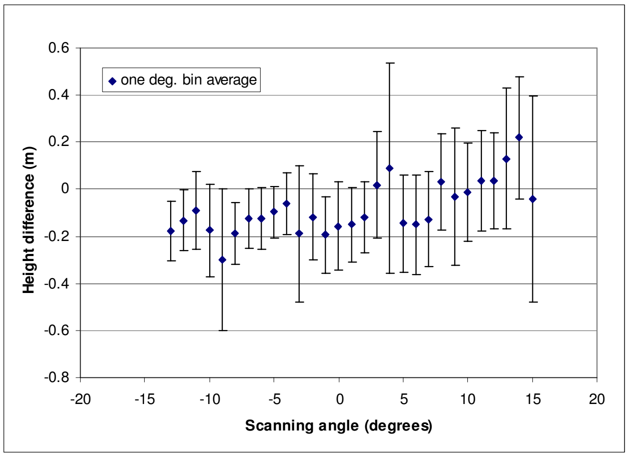

Figure 6. Calculated systematic and random errors for forest area. Strip 4, Area 2. 4084 verified points.

Figure 7 shows the number of TerraScan classified ground hits obtained as a function of scanning angle for the forest shown in Figure 6. The amount of classified ground points drops also at the scanning angles near nadir (2 local minima) because of the high density of the forest.

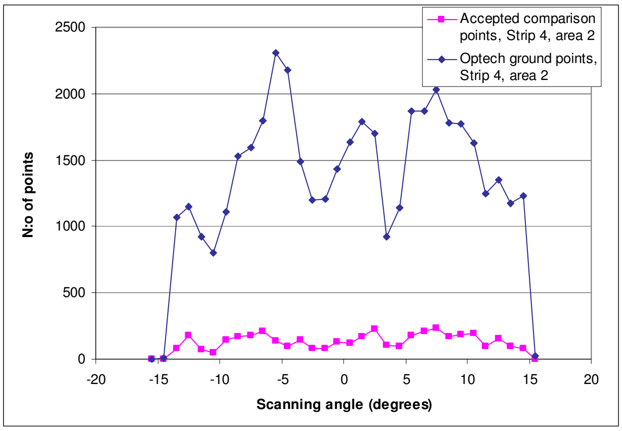

Figure 7. Amount of Optech ground points (above) and points used for verification (below).

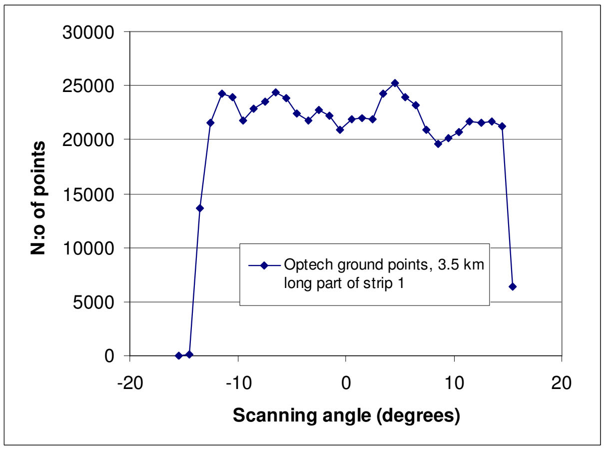

Figure 8. Amount of Optech ground points, Strip 1.

A 3.5 km part of strip 1 contained 645 963 classified ground points. There is again a loss of data at the edges but ground points are distributed quite evenly at the angles where they in fact should be. See Figure 8.

Finally, a raster difference image (roughly 7 km by 2.5 km) with 2.5 m pixel size was created. Sparse Optech derived DTM was subtracted by Toposys II derived DTM. The difference image did not show significant effect of the scanning angle. The largest differences between two flights were obtained in the agricultural field due to the growth of the crops. The standard deviation of pixels was calculated within all along track pixels and is shown as a function of distance in the across track direction, Figure 9.

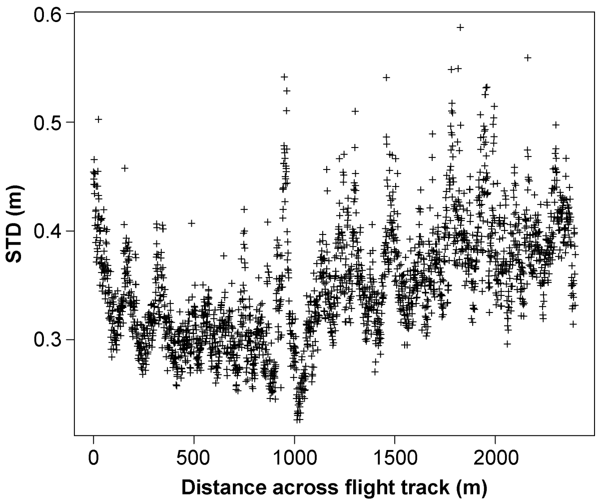

Figure 9. The standard deviation of pixels of the difference image of two laser based DTMs was calculated within all along track pixels and is shown as a function of distance in the across track direction.

The data consisted of three strips, therefore, the effects of scanning angle are mainly seen from the edges of image. The results show, however, that some other misclassifications dominate the process.

5. DISCUSSION AND CONCLUSION

The optimization of the scanning angle is important part of countrywide laser scanning. Significant savings can be obtained by increasing the scanning angle and flight altitude. The very first results obtained with scanning angle analysis showed that there is an effect of the scanning angle on the precision, but other factors, such as density of the forests, dominate the process. Scanning angles up to 15 degrees seems to be usable for high altitude laser scanning in boreal forest zone. High altitude laser scanning gives precision that is about ±20 cm (std), which is good enough for most terrain models required in forested areas.

It should be stressed that the effects of the scanning angle should be further studied. The use of five Toposys ground classified point requires a good visibility of the terrain from above and thus it is possible that this kind of analysis has reduced the effect of the scanning angle. Also, the number of the TerraScan classified points could be replaced by the number of true ground points. Also, strip adjustment capable to remove time-variant changes should be included in the analysis. Since accuracy of the DTM does not deteriorate rapidly when number of ground points decreases, then final effect of the scanning angle can be relatively low, at least in boreal forest areas. The studies should be continued with larger scanning angles.

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