THE EVALUATION OF THE INTERNAL QUALITY OF LASER SCANNING STRIPS USING THE INTERACTIVE ORIENTATION METHOD AND POINT CLOUDS

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Commission III, WG III/3

KEY WORDS: Laser scanning, Adjustment, Quality, Inspection, Photogrammetry, Orientation, and Visualization

ABSTRACT:

The quality of laser scanning point clouds has become a topical research issue. The quality has been determined by the sum of several error sources caused by various factors affecting accuracy. In this paper, it is proposed that overlapping laser strips are favourable for inspecting the quality of the point clouds. The internal quality of five almost completely overlapping strips from TopoSys Falcon was investigated using the interactive orientation method. The orientation was solved in several small test sites located in different parts of the complete overlapping area. Each relative orientation between two laser point clouds revealed possible height or planimetric shifts at the examination area. When this procedure was repeated in various locations within laser scanning strips, internal deviations of laser data strips became visible. The comparison was done relatively. Therefore, no ground control points were used. As a result, the repeatability in heights was excellent, whereas the planimetric repeatability, however, included more systematic and non-systematic errors. Interestingly, the flight direction was the main error source, and visible in the observed bias and random errors.

1. INTRODUCTION

The development of airborne laser scanning has been rapid within last ten years. The LIDAR can capture 3-D point samples from our environment. The strength of the LIDAR is good over-sampling of the target – not necessarily the individual measurements. The laser frequency and point density tend to increase, when new generations of laser scanners are introduced. In laser scanning technology, the focus area has been the performance of laser scanning, including the implementation of laser emitter and receiver, data handling and direct orientation with GPS and INS.

Besides the technical development, another important issue is to develop reliable and accurate methods to verify the quality of laser scanning data. Several sub-factors can affect the quality. According Baltsavias (1999), for example, time offsets, failed system calibration, errors of GPS and INS, flying height, scan angle, coordinate transformations, laser power, beam divergence, atmospheric transmission, weather conditions, target reflectivity, detector sensitivity and density of point cloud can dilute the quality of the final laser point cloud.

Recently, promising results to inspect and improve the quality of laser scanning data have been obtained using the adjustment of overlapping strips (e.g. Kilian et al., 1996; Burman, 2000; Crombaghs et al., 2000; Kager & Krauss, 1999; Maas, 2002). The error sources of laser data due to flying or measurement parameters, integration of the instruments, GPS, INS, laser systems and processing errors has been reported by Schenk (2001), Vosselmann (2002), and Burman (2000). Many of these errors can be corrected using shift and drift parameters (Burman, 2002). Ahokas et al. (2004) have studied the repeatability of laser scanning strips, which is important to verify in order to judge the usability of the data. However, the focus of prior work in adjusting the overlapping strips has been on fitting smooth surfaces.

The objective of this paper was to study the repeatability of laser scanning strips, using the interactive orientation method and five completely overlapping laser strips. The interactive orientation method is based on visual interpretation of the data obtained by superimposing 3-D laser point clouds on 2-D images (Rönnholm et al., 2003). The method allows direct relative orientation between laser scanning data and digital images or between another laser point clouds. The strength of the interactive orientation method over computational methods is that the human intelligence can understand, interpret and fit the entity quite easily even when working with difficult source data, such as airborne laser scanning data. The advantage of the proposed approach is that both the elevation and planimetric errors can be defined and the complexity of the object studied with overlapping strips can be high.

The comparison between laser scanning strips was done directly in several small test sites of the entire overlapping strip area, and without using ground control points. The orientation method can be classified rather as an area-based matching than to any point-to-point method, although sometime small details of the tie features can be in key role for the orientation. The original point clouds were used and no filtering or classification is involved. The tie areas were inspected from several different viewing angles – in central perspective. Therefore, both the vertical and horizontal structure of the targets was available for orientations. The interpretability was usually improved using color-coding according the height value or distance from the inspecting location.

One relative orientation between two subsets from different laser scanning strips reveals possible height or planimetric shifts between data sets at the examination area. If this procedure is repeated in various locations within laser scanning strips, internal deviations of laser data become visible.

2. MATERIAL

The test site in the Espoonlahti was flown with TopoSys Falcon in May 2003 from the altitude of 400 m resulting in more than 10 measurements per m^2 (Figure 1). The data was pre-processed by TopoSys. Five of the strips (numbers 2, 3, 4, 5 and 6) were overlapping almost completely. The flight direction was almost from southeast to northwest for the strips 2, 4 and 6. Two strips, 3 and 5, were flown to opposite direction.

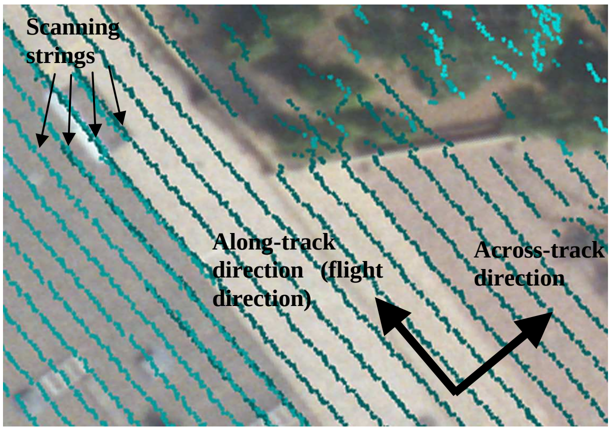

Figure 1. TopoSys Falcon laser scanner provides dense point sampling at the flight direction. However, there is a gap between scanning strings causing uncertainty in local planimetric registration in across-track directions.

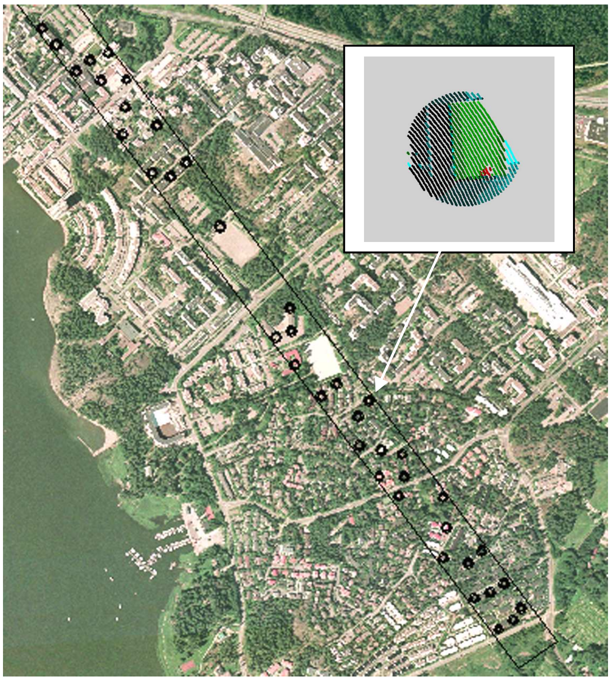

Figure 2. Thirty-nine small orientation sites cover an area of 1500 m x 100 m. Each site is visible from five different laser strips. Aerial image courtesy to FM-Kartta Ltd.

Thirty-nine circular test sites, with radius from 12 to 15 meters, were selected from the overlapping area of five laser strips. The sites were chosen in the way that some buildings or part of the buildings could be seen in each site. The buildings were expected to be the most robust features for relative orientation between the laser point clouds. Only the first pulse was used from the laser scanning data.

The whole test area and small test sites can be seen in Figure 2. The buildings in the test areas had both saddle roofs and flat roofs. The size of the building varied from small one-storied building to high apartment houses. The orientation of many buildings in the test sites was unfortunately either parallel or perpendicular to the flight direction, which caused some problems when the across-track direction was inspected.

3. METHODS

The interactive orientation method (Rönnholm et al, 2003) was used to find the direct relative orientation between two laser point clouds. The interactive orientation method was originally designed to be a tool for solving direct orientation between an image and 3D reference data, like in the case of Figure 3. The reference data for orientations can be 3-D control points, vectors, objects or even laser point clouds, for example.

The interactive orientation method is based on visual interpretation of superimposed 3-D data in the image. The superimposing is done using the collinearity equations

$$
\begin{aligned}
x &= -c\frac{r_{11}(X-X_0)+r_{21}(Y-Y_0)+r_{31}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)}+x_0 \\
y &= -c\frac{r_{12}(X-X_0)+r_{22}(Y-Y_0)+r_{32}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)}+y_0
\end{aligned}
\tag{1}
$$

where c = camera constant
x, y = 2-D image coordinates
X_0, Y_0, Z_0 = coordinates of projection center
X, Y, Z = 3-D ground point
x_0, y_0 = principle point
$r_{11} \ldots r_{33}$ = elements of 3-D rotation matrix

After superimposing laser point cloud with some initial orientation parameter values an operator is able to see, whether the data is fitting correctly or not. If not, the image orientation is not correct. The image orientation parameters contain three independent shifts and rotations. With tools presented in Rönnholm et al. (2003), these six parameters can be interactively modified. After every correction, the laser point cloud is superimposed again in the image, with the new orientation parameters. The method leads to an iterative process, until the orientations cannot be improved any more.

One disadvantage of the interactive method is that there is no automation involved. On the other hand, this is as well an advance, because human intelligence can understand and handle quite complex data sets. For example, there is no need to filter laser point clouds before orientations, because an operator can interpret and fit the entity, even if some details do not seem to correspond to each other. However, sometimes even small details, if identifiable from both data sets, can be used as a tie features. Actually, more important than filtering, is to improve visual interpretability of laser point clouds with color-coding.

Typically, the color-coding is done according the distance from the camera location or according the altitude.

The interactive method requires enough visible features on the image footprint. These features can be buildings, road signs, fences and even trees, for example. Specially, if the close-range images are used, the image footprint is usually quite limited and may contain too few distinguishable targets for accurate orientations. The panoramic images provide ultra-wide viewing angle and therefore better ensures finding reliable set of features within the image. Figure 3 is a part from panoramic image mosaic, created from concentric image sequences. This method of mosaicing is described in Haggrén et al. (1999) and Pöntinen (2000).

The interactive orientation method is applicable also for direct relative orientation of two laser point clouds. Firstly, the first point cloud is superimposed to the plain image plane, leading the situation that actually equals to a normal central perspective image. Secondly, the interactive orientation method is applied to find relative orientation between this image of the first point cloud and the other laser data set.

With synthetic images, there are no limitations for the perspective of inspecting. Therefore, angle of view can be chosen in a way the tie features are most visible. Typically, the reference area should be investigated, at least, at two perpendicular directions to ensure good accuracy in each direction. In this research, the test sites were inspected from two to six different angles of view. The described method to adjust two laser point clouds directly into the common coordinate system was applied the first time in Hyyppä et al. (2003) in the forestry areas.

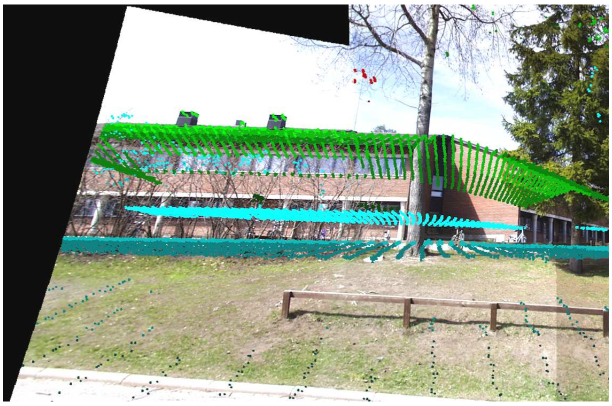

Figure 3. Laser scanning data provide good coverage of the building. However, some small deformations are detectable. This image covers about 23 % of the original panoramic image and laser point cloud.

Comparison between laser strips was done in all thirty-nine small test sites (Figure 2). The laser strip 2 was selected as a reference strip and the other strips were oriented to that. Because the test sites were quite small ones, only the shifts between point clouds were solved. If there was any detectable shift (e.g. in Figure 4), the difference was measured. Each orientation was done independently, without knowing the differences in surrounding test sites.

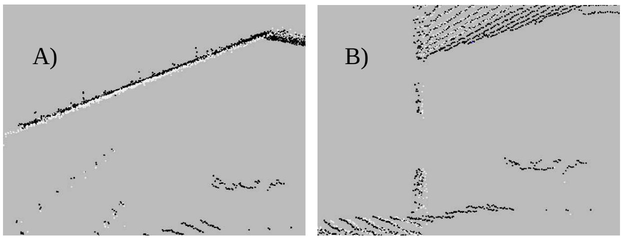

Figure 4. The planimetric shift of the building between laser strips 2 (black) and 5 (white) is visible from two different central perspectives. A) The shape of the roof. B) The wall and the edge of the roof.

4. RESULTS

During the orientation process, it became obvious that the differences should be presented in the along-track, across-track and height direction. This is primarily, because the gaps in scanning geometry (Figure 1) caused problems in many test sites for orientations in across-track direction. In this research, the corrections were measured only, if some differences were detectable. Therefore, the distinct shift could be easily underestimated, if it was not possible to improve orientation due the scanner properties. To reduce this problem, some of the worst test sites were discarded from the across-track direction. The results are presented in Tables 1, 2 and 3.

	Strip 2-3	Strip 2-4	Strip 2-5	Strip 2-6
Mean [m]	0.050	-0.005	0.064	-0.010
Std [m]	0.039	0.018	0.041	0.023
Max [m]	0.150	0.025	0.136	0.045
Min [m]	-0.009	-0.041	-0.010	-0.078

Table 1. Differences in flight direction (39 samples per strip)

	Strip 2-3	Strip 2-4	Strip 2-5	Strip 2-6
Mean [m]	-0.012	0.003	-0.019	-0.005
Std [m]	0.027	0.015	0.034	0.019
Max [m]	0.018	0.037	0.025	0.035
Min [m]	-0.085	-0.020	-0.099	-0.039

Table 2. Differences in across-track direction (20 samples per strip)

	Strip 2-3	Strip 2-4	Strip 2-5	Strip 2-6
Mean [m]	0.001	-0.003	-0.002	-0.014
Std [m]	0.011	0.008	0.011	0.011
Max [m]	0.027	0.014	0.025	0.002
Min [m]	-0.025	-0.027	-0.022	-0.043

Table 3. Differences in elevations (39 samples per strip)

The flight direction of the strips affects remarkably in the obtained planimetric errors both in along- and across-track directions. However, such phenomenon is not visible from the heights. If the differences between strips 3 and 5 are examined, the bias of only -0.014 m and standard deviation of 0.032 m in flight direction can be found. Correspondingly, the bias in across-track direction is 0.006 m with standard deviation of 0.027 m.

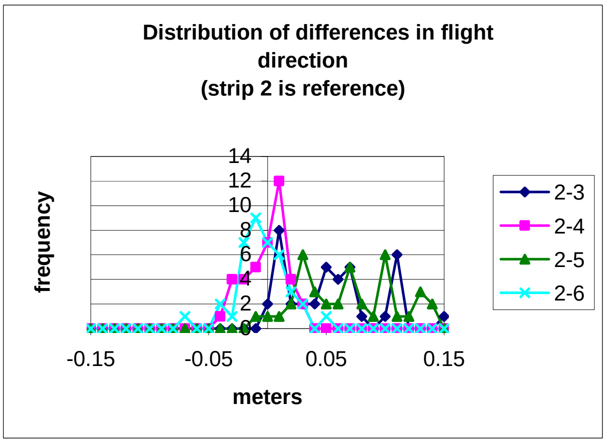

Figure 5. Distribution of differences in flight direction, 39 samples per strip.

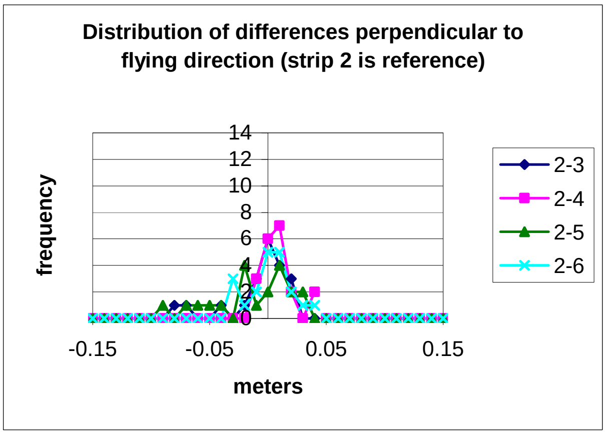

Figure 6. Distribution of differences in across-track direction, 20 samples per strip.

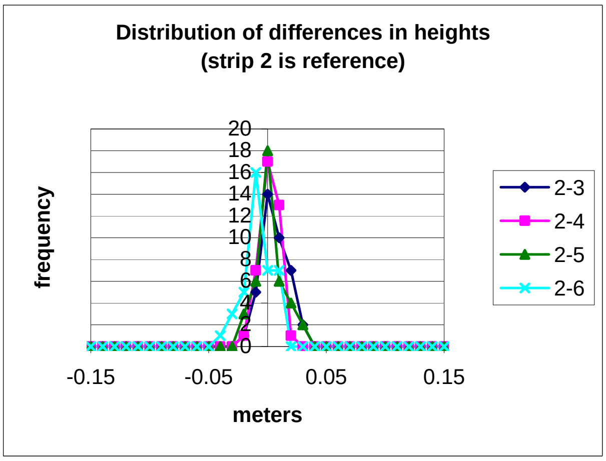

Figure 7. Distribution of differences in heights, 39 samples per strip.

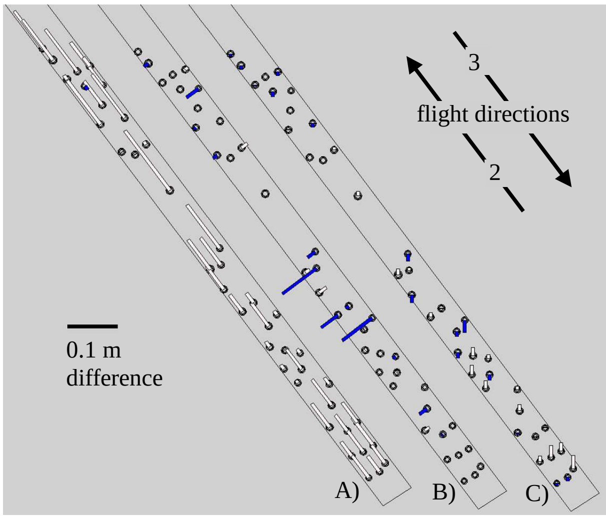

Figure 8. Differences between laser strips 2 and 3 in A) along-track, B) in across-track and C) in elevation.

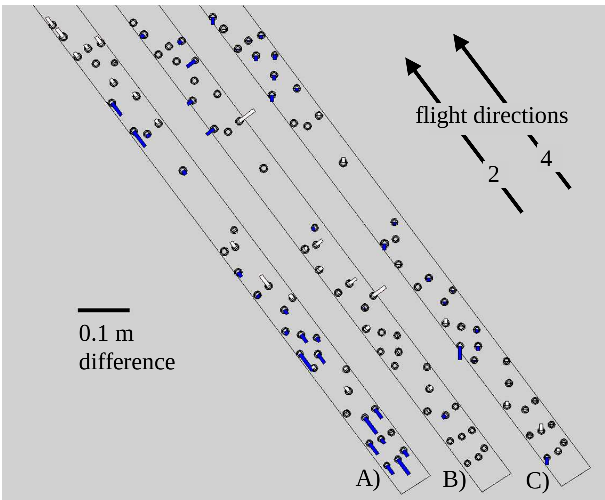

Figure 9. Differences between laser strips 2 and 4 in A) along-track, B) in across-track and C) in elevation.

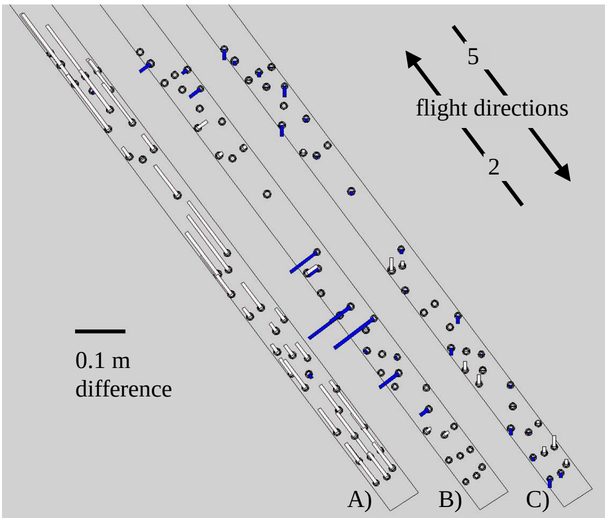

Figure 10. Differences between laser strips 2 and 5 in A) along-track, B) in across-track and C) in elevation.

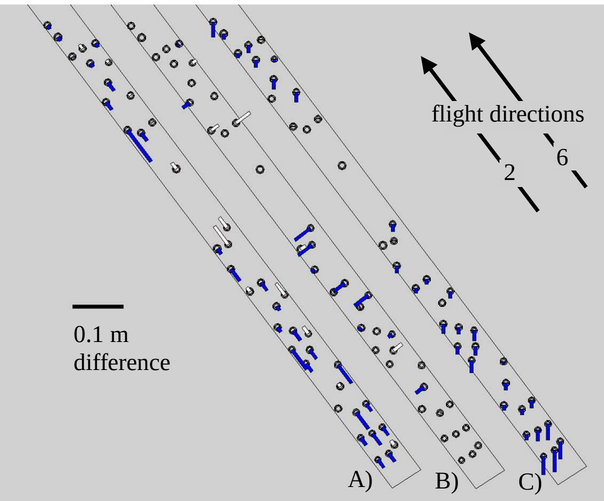

Figure 11. Differences between laser strips 2 and 6 in A) along-track, B) in across-track and C) in elevation.

5. DISCUSSION

The test sites for orientations (Figure 2) were chosen randomly without ensuring beforehand the suitability of the tie features for orientations. During the orientation process, it turned out that in many areas the quality of tie features was inadequate in across-track direction. In most of cases, the problem was the orientation of the features. In some cases, the size of the test site was insufficient, causing the lack of interpretable features. However, the interactive orientation turned out to be suitable method to detect even small differences between point clouds, if the target area included enough visible tie features.

This research focuses on repeatability. Therefore, when the results are read, it must be remembered the LIDAR can measure some targets repetitively in an incorrect way. For example, the material of the target can cause systematic bias (Hyyppä & Hyyppä, 2003). Nevertheless, it is important to ensure the good repeatability before any target-based corrections are applied.

The measured differences between laser strips concern the entity within small test sites. Therefore, a repeatability of single laser measurement cannot be directly derived from the results. According visual impressions during the orientations the repeatability of details vary a lot. The most crucial parameter seemed to be the gap between scanning strings (Figure 1), because small details are modelled from different planimetric location, leading the different results. In general, the cognition leads to simplified pastoral conclusion that the point density is critical for accurate orientations.

If the differences are examined graphically (Figures 8-11), some wave-like behaviour is found in all inspected directions. Likely, this phenomenon is caused mainly by the small inaccuracies with GPS and INS combined to fluctuation of the aeroplane. Beforehand, also some systematic rotation between laser strips was expected. However, visual study (Figures 8-11) did not reveal any clear rotations. If necessary, the rotation parameters could have been calculated using solved differences from test sites as corresponding points in the last squares adjustment.

6. CONCLUSIONS

The repeatability of the laser measurements was investigated using five almost completely overlapping laser strips measured with TopoSys Falcon. The differences between strips were measured in thirty-nine small test sites from the test area covering 1500x100 meters. One strip was selected as a reference strip and four others were compared to that one. In each test site the entity of two laser point clouds were oriented directly to the same coordinate system using interactive orientation method.

The repeatability of elevations, according the test sites, was excellent. The largest systematic bias was -0.014 m. With other strips no significant systematic bias was found. In addition, the standard deviation was 0.011, or less, for every comparison confirming the homogeneity of elevation measurements. Even maximum differences were only 0.02-0.04 m depending on the strip. The flight direction did not make any noticeable difference to repeatability.

The planimetric repeatability was not as good as with heights. However, the maximum systematic biases of 0.064 meters in along-track direction and -0.019 meters in across-track direction are still quite reasonable. The bias and deviation in across-track direction may have been underestimated, because there were less suitable tie features for that direction and because of the properties of TopoSys Falcon scanning footprint (Figure 1).

The flight direction was the most distinguishable reason of systematic planimetric errors. When the strips, flown from the same direction, are compared among each other, the maximum bias was only -0.014 m in the along-track direction and 0.006 m in across-track direction.

Some non-systematic errors were found within the laser strips. Typically, these errors were accumulated making wave-like pattern, leading to the conclusions the main source of these errors is inaccuracies of GPS and INS. Against the assumptions, there were no clear differences, whether the test area located in the middle or in the either side of the strip. Obviously, the system calibration has been sucessed well with TopoSys Falcon.

The laser strips are not completely homogenous. The repeatability in altitudes is excellent, but the planimetric variations slightly reduce the usability of this information. Therefore, the main concern when improving the quality of laser data is, how to get the planimetric accuracy into as uniform quality as possible.

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8. ACKNOWLEDGEMENTS

The author is grateful to the Academy of Finland (projects: Spherical Imaging (201053) and Novel Mapping (201376)) and the Jenny and Antti Wihuri Foundation for financial support, and to Juha Hyyppä and Harri Kaartinen from the Finnish Geodetic Institute for proving the laser data and co-operation, to FM-Kartta Ltd for aerial imagery, and to Hannu Hyyppä and Henrik Haggrén from the Institute of Photogrammetry and Remote Sensing (HUT) for assistance and guidance.