On the use of pulse reflectance data for laserscanner strip adjustment

Hans-Gerd Maas
Institute of Photogrammetry and Remote Sensing
Dresden Technical University
Helmholtzstr. 10
D-01062 Dresden, Germany
e-mail **hmaas@rcs.urz.tu-dresden.de**

Commission III, Working Group 3

KEY WORDS: Airborne laserscanning, accuracy, pulse reflectance.

ABSTRACT

The precision of airborne laserscanner data is strongly influenced by the limited accuracy potential of the integrated GPS/INS pose determination system. Errors of kinematic GPS height determination will often be in the order of one to two decimeters and propagate directly into the height coordinates of digital surface models, digital terrain models and 3-D object models derived from these data. The planimetric accuracy of ground points is influenced by the kinematic GPS accuracy as well as by drift effects of the INS system and is in the order of a few decimeters. Errors become evident at check points or as discrepancies between neighboring strips of laserscanner data. Vice versa, these discrepancies can be used to apply corrections to laserscanner data in a strip adjustment procedure.

Tie points for laserscanner strip adjustment can be determined with high precision by least-squares matching applied to the original non-interpolated ground point clouds organized in stripwise TINs. This procedure provides useful results in regions with sufficient surface slopes in both coordinate directions, but fails over flat terrain if both height and planimetry coordinate discrepancies are to be determined. In such situations, image contrast in the laserscanner pulse reflectance data, simultaneously recorded by some laserscanner systems and perfectly co-registered with the height data in the TIN structure, can replace non-existent height contrast and provide a solution. The paper describes the extension of least-squares-matching to the alternative use of height and reflectance values of irregularly distributed laserscanner points for the determination of laserscanner strip discrepancies in flat regions with existing local image intensity contrast. The practical applicability and precision potential of the technique will be discussed.

1. Introduction

Beyond its original application field in the generation of digital terrain models and digital surface models, airborne laserscanning is meanwhile being used for a number of general 3-D object modeling tasks. While early systems captured datasets with a typical resolution of one point per ten square meters, recent systems can acquire datasets with a resolution of one point per square meter and beyond.

The accuracy potential of airborne laserscanning is mainly influenced by laser range measurement, the deflecting mirror unit and the GPS/INS aircraft pose determination system. In many cases, the latter depicts the largest error source, typically influencing the height coordinate of laserscanner ground points with one to two decimeters and the planimetric coordinates with up to half a meter. While only the height accuracy is relevant in pure digital terrain model applications over terrain with limited steepness, the planimetric coordinates become equally important in high density datasets used for general 3-D object reconstruction tasks such as 3-D building modeling. These errors become evident at ground control points or as discrepancies between overlapping or crossing strips of laserscanner data. Several authors suggested the development of laserscanner data adjustment procedures based on ground control points and tie points between strips (Kilian, 1994; Crombaghs et al., 2000; Burman, 2001; Vosselman/Maas, 2001). While height discrepancy measurements are sufficient in adjustment procedures for use in digital elevation model applications, discrepancies in all three coordinates have to be determined in general applications.

A procedure for the precise determination of tie point discrepancies has been presented by (Maas, 2000). The method is applied to non-interpolated raw laserscanner data points organized in a TIN structure, thus avoiding biases in occlusion regions introduced by the interpolation to a regular grid. It requires the selection of patches containing significant height contrast in orthogonal coordinate directions. This requirement is for instance fulfilled by roof patches with more than one ridge direction. Typical laserscanner datasets will, however, contain large regions where no suitable patches for full 3-D discrepancy measurement can be found, leading to incomplete input to laserscanner strip adjustment routines.

In such regions of insufficient height contrast, an alternative may be provided by the intensity signal recorded by several laserscanner systems. This intensity signal depicts a monochromatic image in the wavelength of the laser, perfectly co-registered with the height data and in an orthogonal projection. This reflectance value is sometimes being used in segmentation tasks (e.g. Oude Elberink and Maas, 2000). An example of a laserscanner height and reflectance image, both interpolated to a 0.5m regular grid and scaled to 8 bit for visualization, is shown in Figure 1. If a flat patch of laserscanner data contains sufficient image contrast, the intensity information may be used for the determination of planimetric coordinate differences. Combined with height discrepancies obtained from the height data in the patch, this allows for the measurement of full tie point discrepancies even over flat terrain.
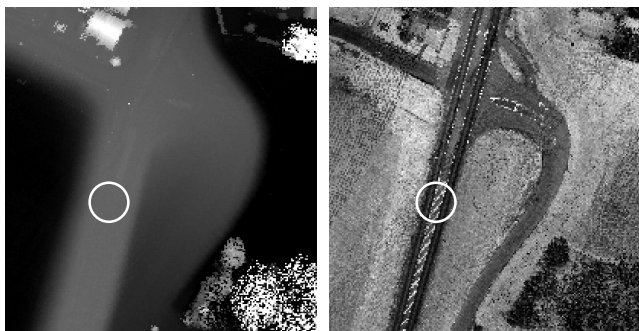

Figure 1: Height and reflectance image of a road crossing in a high-density laserscanner dataset

2. Least squares matching on laserscanner reflectance data

Least squares matching is used regularly in many applications in photogrammetry, for instance for the measurement of tie points in raster image data. The procedure for least squares matching applied to $2^1/_2$-D laserscanner height data in a TIN structure described in (Maas, 2000) uses the heights of laserscanner ground points as observations and derives patch gradients from the normals of TIN meshes. Matching is performed between discrete points in one patch and points interpolated in the corresponding mesh of a TIN structure in the other patch. One observation equations is written for every original data point of both patches, and the input for the observation vector is obtained by subtraction of a height computed by linear interpolation at the same location in the corresponding mesh of the TIN structure of the other patch. It can be shown, that this procedure is superior to matching applied to laserscanner data interpolated to a regular grid, as it allows extensions to avoid significant biases in occlusion regions (Maas, 2000).

In the case of reflectance matching, the reflectance value is used as an observation in least squares matching rather than the height value; this is in analogy to matching in optical greyvalue images with the difference that the data are not on a raster structure.

Obviously, the reflectance image will only allow for the determination of the two planimetric shift parameters. Therefore, a two-step procedure is introduced:

- Height discrepancies between patches are determined by least squares matching constrained to vertical shift determination by using height as observation and keeping the planimetric shifts fixed.
- Planimetric discrepancies between patches are determined by least squares matching constrained to horizontal shift determination by using reflectance as observation and keeping the height shift fixed.

Thus, the determination of all three components of the shift between two patches of neighboring or crossing laserscanner data strips becomes possible.

3. Practical results

The combined height and reflectance data matching technique was applied to a high-density dataset of an area in The Netherlands acquired by the FLI-MAP 1 airborne laserscanner system (Pottle, 1998), installed on a helicopter. The dataset consists of first-pulse height measurement and 6-bit reflectance data; the point density is in the order of five points per square meter. Figure 2 shows a part of the dataset in three strips, containing a road crossing with white markings. Due to the absence of sufficient height contrast, the height data in the test area along the road allows only for the determination of a vertical shift between strips. The reflectance image can be considered complementary to the height image and seems well suited for the determination of horizontal shift parameters. Matching was applied to a total of 20 tie points between the strips, choosing circular patches with a radius of three meters containing texture provided by the white road markings.
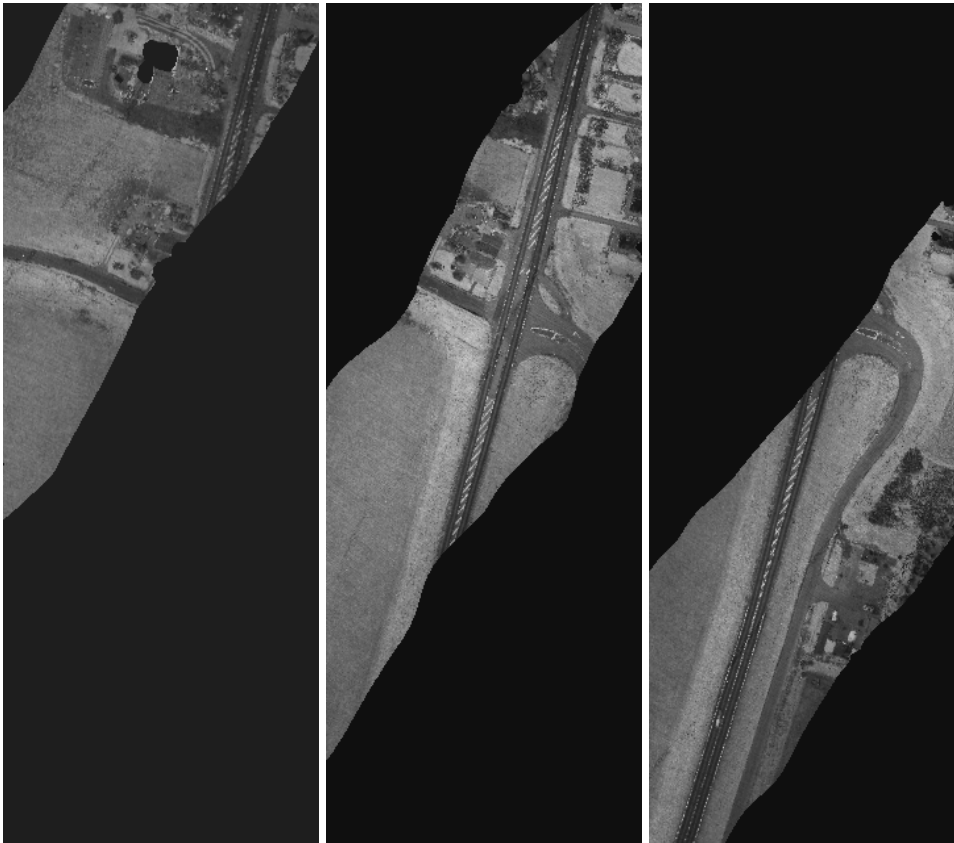
Figure 2: Reflectance image of a road crossing in three neighboring strips

The results of the application of the technique are listed in Table 1. The discrepancies over a 50 meter section of Figure 2 are shown in Figure 3. The amplitude of height discrepancies is in the order of 10-15 cm, while planimetric discrepancies of more than 40 cm occur. As discussed in (Maas, 2000), the estimated standard deviation of the planimetric shift parameters is too optimistic as a consequence of the stochastic properties in the covariance matrix – this is an inherent problem of least squares matching. Instead, variance measures in a local linear regression analysis based on a set of neighboring patches were used to obtain more realistic precision figures. Due to the fact that the data was obtained by a laserscanner system without INS, this assumption of linear strip deformation is probably not justified (cmp. Figure 3), so that the latter precision figure is contaminated by flightpath deviations and is thus too pessimistic as a measure for the accuracy potential of least squares matching. Roughly, the standard deviation of the horizontal shift parameters obtained from reflectance data can be estimated in the order of 10 cm, compared to an average point spacing of 40-50 cm in the dataset at hand. The estimation of the precision of the height shift parameter does not suffer from the limitations mentioned above; standard deviations of less than 1 cm can be obtained here.

Shift parameters [mm]			
	Planimetry (from reflectance)		Height
	X	Y	Z
strip M - L	-190 … 140	-460 … -100	-93 … -6
strip M - R	-180 … 220	-210 … +80	-46 … 91
Average standard deviation of shift parameters [mm]			
strip M - L	23	33	4
strip M - R	10	10	4
RMS from regression analysis of shift parameters [mm]			
strip M - L	123	136	36
strip M - R	70	80	33

Table 1: Results of height and reflectance matching from 20 patches in the section
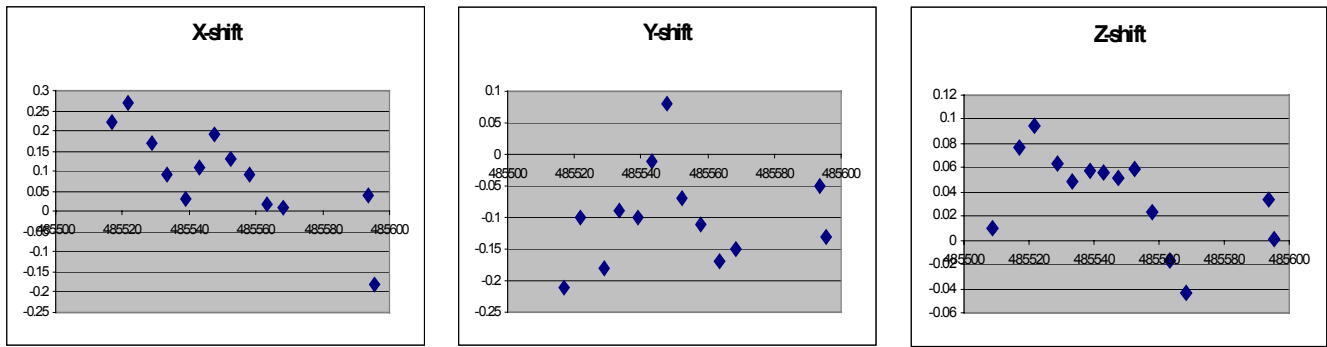
Figure 3: Patch shifts over 50 meter section in Figure 2

In addition to the road markings, a few well defined corners of fields and meadows were selected for reflectance-based matching. The results obtained from these points were only slightly worse than those of obtained from the road markings. The probe was, however, too small for secure statements.

4. Conclusion

Reflectance values of airborne laserscanner data may provide an interesting option for the determination of planimetric strip discrepancies in regions with poor height contrast. The possibility of simultaneous matching in height and reflectance data is especially relevant in flat areas, where the patch contrast situation in height data only allows the determination of the vertical shift parameter.

Limiting factors are given by the resolution of datasets and by the noise characteristics of laserscanner intensity data: The option is mainly relevant for high density datasets with point densities of at least one point per square meter. The high noise in laserscanner intensity data and the inherent undersampling of the technique will not allow to reach a precision potential which is comparable to the precision often achieved by matching applied to raster images obtained by solid state sensor cameras. Nevertheless, a precision significantly smaller than the average point spacing could be achieved in the practical tests, providing valuable input to laserscanner strip adjustment procedures.

More effort has to be spent on the suitability of different types of reflectance contrast and on the automatic selection of appropriate patches. Further research should also address the combined use of the full information of a laser pulse return in least squares matching, automatically balancing weight depending on height and reflectance contrast.

References:

- Crombaghs, M.J.E., R. Brügelmann, E.J. de Min, 2000. On the adjustment of overlapping strips of laser-altimeter height data. In: International Archives of Photogrammetry and Remote Sensing, Vol. 33, Part B3/1, pp. 224-231.
- Burman, H., 2001: Calibration and orientation of laser scanner data. OEEPE workshop on Airborne Laserscanning and Interferometric SAR for Detailed Digital Elevation Models, Stockholm
- Kilian, J., 1994: Calibration methods for airborne laser systems. International Archives of Photogrammetry and Remote Sensing, Vol. 30, Part 1, pp. 42-46
- Maas, H.-G., 2000: Least-Squares Matching with Airborne Laserscanning Data in a TIN Structure. International Archives of Photogrammetry and Remote Sensing Vol. 33, Part 3A, pp. 548-555
- Oude Elberink, S., Maas, H.-G., 2000: The use of anisotropic height texture measures for the segmentation of laserscanner data. International Archives of Photogrammetry and Remote Sensing, Vol. 33, Part B3
- Pottle, D., 1998: Helicopter-based observations replace traditional surveying. Geodetic Info Magazine 2/98, pp. 62-65
- Vosselman, G., Maas, H.-G., 2001: Adjustment and filtering of raw laser altimetry data. OEEPE Workshop on Airborne Laserscanning and Interferometric SAR for Detailed Digital Elevation Models, Stockholm