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CALIBRATION OF LASER SCANNING INTENSITY DATA USING BRIGHTNESS TARGETS. THE METHOD DEVELOPED BY THE FINNISH GEODETIC INSTITUTE

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Abstract. The paper examines a radiometric calibration method used at the Finnish Geodetic Institute (FGI). The brightness calibration targets and calibration scheme of airborne laser scanner intensity data is observed. For calibrating laser scanner intensity data, FGI has developed a system that contains portable brightness targets (tarps) with nominal reflectance from 5% to 70%. Also commercially available gravels and sands were tested for the use of calibration. A laboratory system was set up to measure intensity values under controlled conditions. The paper introduces a concept of calibrating ALS intensity data developed at FGI.

Keywords: intensity, laser scanning, calibration, brightness tarps, reflectance, backscatter, laboratory measurements.

1. Introduction

ALS is a remote sensing system that uses an active sensor with monochromatic laser. This technique is commonly used for measuring surface topography and characterizes different 3D objects (Kraus and Pfeifer 1998; Wehr and Lohr 1999; Haala and Brenner 1999; Wever and Lindenberger 1999; Hyypä *et al.* 2001; Rivas *et al.* 2006). It is based on laser (LIDAR) range measurements between the aircraft and the observed object. Precise orientation is achieved combining GPS (*Global Positioning System*) and IMU (*Inertial Measurement Unit*). The final product is a point cloud (*x, y* and *z*) representing the coordinates of the reflecting object. Also intensity (I) value is collected for each point. Even though intensity values are recorded, they are rarely used, e.g. as predictor in object classification (i.e. tree species (Holmgren and Persson 2004) or for matching laser scanner data with aerial images. There has been no systematic calibration method developed or presented. However, the usage of laser scanner intensity values have recently become a topic of interest (Lutz *et al.* 2003; Moffiet *et al.* 2005; Kaasalainen *et al.* 2005) and calibration methods are currently being called for.

There are a number of applications where brightness values with topographic information would substantially increase information about the target. In some cases, brightness values could be the major or the only information source from the observed area. Measurements may also be difficult to obtain (e.g. in glaciers) or the resolution of satellite imagery may not be sufficient. Also active remote sensing system brightness measurements are less dependent on weather conditions.

This paper presents a method for ALS intensity data calibration developed by FGI. Using laboratory measurements and brightness targets laid out during the flight campaign, intensity values can be corrected and used for processing laser data.

2. Physics of ALS Calibration

The recorded intensity is related to the received power that can be given in form (Wagner *et al.* 2006):

$$P_r = \frac{P_t D_r^2}{R^4 \beta_t^2 \Omega} \rho A_s, \tag{1}$$

where P_r and P_t are received and transmitted power, respectively. Dr is the receiver aperture size, R is the range, β_t is beam divergence, Ω corresponds to the bidirectional properties of scattering, ρ is the reflectivity of the target surface and A_s is the receiving area of the scatterer. The recorded intensity is proportional to R^2 for homogenous targets filling the full footprint, to R^3 for linear objects (e.g. wire) and to R^4 for individual large scatterers (Ahokas *et al.* 2006).

Atmospheric conditions also affect intensity values. Then, the real received power would be (Ahokas *et al.* 2006):

$$P_{r,real} = T^2 P_r, \tag{3}$$

where T is atmospheric transmittance. For T value, FGI has used the program called MODTRAN4. For simulation, correct wavelength, atmospheric model, flying altitude, visibility and path length should be selected. The content of different gases and moisture mainly affect intensity values. Moist air particles are bigger and diffuse laser light which means that the received power of the single shot reduces which has an effect on the range and intensity values.

The laser beam does not hit the ground only at the nadir point. The angle between airplane normal and laser beam is called the incidence angle. The greater is the incidence angle, the larger effect it has on the range and intensity values. For the effect of the incidence angle, intensity values were multiplied by $1/\cos \alpha$, where α is the incidence angle.

3. Laboratory Measurements

To get exact backscattering properties for tarps and commercially available gravels and sand, laboratory measurements were carried out. The picture of laboratory setup is shown in Fig. 1.

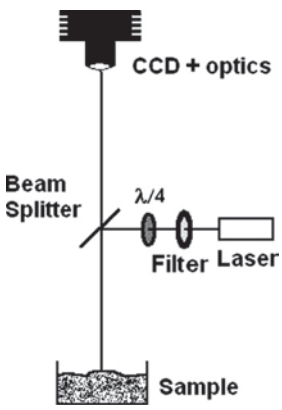

Fig. 1. Setup of laboratory measurements (Kaasalainen *et al.* 2008a)

The intensities of the collected samples were measured employing a laboratory instrument and a reference plate calibrated with 99% Spectralon (Labsphere Inc.). Similar measurement geometry to the laser scanner was accomplished using a beam splitter (see Fig. 1). The backscattered laser beam was observed through the beam splitter by a charge-coupled device (CCD) camera and intensities can be acquired from the CCD image. A usual wavelength of ALS measurements is 1064 nm. Thus, a 1064 nm continuous-wave neodymium-yttrium aluminum garnet (Nd:YAG) laser of 10 mW output power was used. Because the laser scanner mostly measures with non-polarized lasers, the linear polarization of Nd:YAG was scrambled with a quarter-wave plate placed in front of the source (Kaasalainen *et al.* 2008).

The sample was placed on a rotating plate to smooth out laser speckle effect and also to cover a larger sample area when the laser spot moved along the rotating surface. Speckle effect was also reduced by averaging over several exposures: five exposures are taken, 10 seconds for every exposure (Kaasalainen *et al.* 2005).

4. Brightness Calibration

4.1. Brightness Tarps

The demand for targets large enough for airborne measurements have become evident after small-size targets were tested in aerial camera imaging. The material for such targets should be strong enough to endure hard field conditions over several years of occasional use. The brightness targets that are used in FGI were manufactured by Suojasauma Oy in 2000. The size of one target is 5×5 m. They are portable and can be arranged in a straight line on a test field (see Fig. 2 for more detail).

Fig. 2. Brightness targets in Espoonlahti, Dec 2006 (Kaasalainen *et al.* 2007)

Eight targets, for which reflectance was optimized at a wavelength range of 400-800 nm, were manufactured (5%, 10%, 20%, 25%, 30%, 45%, 50% and 70%). Because reflectance values given by the manufacturer were approximate, laboratory calibration was crucial. The targets are made of polyester 1100 dtex with polyvinyl chloride (pvc) coating. They were coated with titanium dioxide and carbon black paint mixing pigment. A delustrant agent was added to the paint to get the mat surface and to decrease non-Lambertian reflectance effect. Moreover, the dirt attaches to the mat surface more easily and the tarps have to be cleaned before every campaign (Kaasalainen *et al.* 2008a).

There has been a study in FGI on how the tarps can be used in ALS intensity data calibration. Test flights in Sjökulla were carried out using Optech ALTM 3100 laser scanner. Flying heights were 200 m, 1000 m and 3000 m above the ground level. During these flights, the above mentioned tarps were used (eight targets with nominal reflectance from 5% to 70%). Radiometric calibration was carried out according to the following scheme: (i) intensities from various altitudes were assumed to follow (range) R^2 relationship; (ii) if incidence angle is > 20°, it has a significant effect on intensity values and has to be corrected (Kukko *et al.* 2008); (iii) the transmitted power was assumed to be changed according to Chasmer *et al.* (2006); (iv) the effect of atmospheric attenuation was neglected in the preprocessing phase.

Scaled intensity values with selected reference height were calculated (Ahokas *et al.* 2006):

$$I_{scaled,j} = I_j \frac{R_j^2}{R_{ref}^2} \frac{E_{Tref}}{E_{Tj}}, \quad (3)$$

where j is strip number, I_j is intensity in strip j, R_{ref} is reference distance, R_j is distance in strip j, E_{Tref} is the transmitted reference pulse energy and E_{Tj} is the transmitted pulse energy for strip j (Ahokas *et al.* 2006).

Following the made corrections, intensity values were directly relative to target reflectance from all altitudes. An effect on fading in intensity corresponds to the typical variation of about 10% with the applied reference targets from 200 m altitude. Flying heights of 200 m and 1000 m are suitable for intensity calibration using artificial or natural test targets due to the size of the calibrator. 0.3 mrad beam divergence gives a footprint of 90 cm which is large for practical calibration. 3000 m flight altitude had no signals recorded with the reflectance of less or equal to 10% (Ahokas *et al.* 2006).

The study showed that intensity values needed to be corrected for: (i) range; (ii) incidence angle (>20°); (iii) atmospheric transmittance; (iv) atmospheric attenuation using dark object addition and (v) transmitted power.

The calibration of intensity data makes the usage on intensity values more reliable. The values are strongly dependant on range as well as on PRF. Variation in PRF changes the transmitted values, which also has an influence on intensity.

4.2. Commercially Available Reference Targets

There have been studies done on how commercially available samples would work. Two campaigns have been organized where commercial samples have been used. They took place in Espoonlahti, Dec. 2006 and Nuuksio, Jul. 2007. Fig. 3 shows the setup of gravels in Nuuksio and Espoonlahti.

Fig. 3. Gravel setup in Nuuksio, Jul. 2007. Clockwise from top left: crushed redbrick (C Brick), sandblasting sand (Sand01), black gabbro (Gabbro), crushed LECA (LECA), and sandblasting sand (Sand05). Right: gravel samples in Espoonlahti, Dec. 2007 campaign, from top downward: Gravel, Qartz, Diabase and LECA (Kaasalainen *et al.* 2008b)

The first set of gravel was measured in Espoonlahti with TopEyeII (see Fig. 3 and Table 1). The results showed a poor repeatability (except for LECA) between measurements. An improved set of gravels was chosen for the Nuuksio flight (see Fig. 3 and Table 1). Leica ALS50 laser scanner was used. The results showed somewhat better agreement, especially between 1064 nm Nd:YAG and Leica ALS50 results (Kaasalainen *et al.* 2008b).

The artificial gravel samples were measured with FARO (785 nm) terrestrial laser scanner and under laboratory conditions with Nd:YAG 1064 nm laser. The results are summarized in Table.

Table. Measurements from Espoonlahti and Nuuksio, compared with laboratory measurements (FARO TLS and Nd:YAG)

Sample	Campaign	ALS	FARO	Nd:YAG(0°)
LECA	Espoonlahti	0.40	0.42	0.52
Gravel	Espoonlahti	1.0	1.0	1.0
Diabase	Espoonlahti	0.67	0.59	1.45
Quartz	Espoonlahti	1.15	1.59	1.36
LECA	Nuuksio	0.36	0.47	0.40
Gabbro	Nuuksio	0.30	0.38	0.45
C Brick	Nuuksio	2.16	1.12	1.91
Sand05	Nuuksio	0.75	1.02	0.70
Sand01	Nuuksio	1.0	1.0	1.0
Bunker	Nuuksio	0.93	0.99	0.74

Espoonlahti measurements are relative to (sanding) gravel and Nuuksio measurements are relative to Sand01 sample. The wavelength difference between FARO and other measurement has not been corrected, which causes differences between FARO and other instruments.

The samples in Table are as follows: Light Expanded Clay Aggregate consisting of the lightweight particles of burn clay (LECA); coarse gravel used for sanding roads (Gravel); black diabase (Diabase); yellow quartz (Quartz); black gabbro (Gabbro); crushed redbrick (C Brick); sandblasting sand with grain size 0.1–0.6 mm (Sand01) and grain size with 0.5–1.2 mm (Sand05); bunker sand from golf course (Bunker).

The results showed that commercially available sands and gravels could be used in laser scanner intensity calibration but control over the target properties is essential for laboratory validation to be feasible and meaningful. Detailed information on, e.g. target footprint size and point density is also important. Besides, the obtained results indicate that the relative calibration method is possible in comparing reflectance values measured during different campaigns. For more detailed information see (Kaasalainen *et al.* 2008b).

5. Conclusions

The paper introduced a concept of ALS intensity data calibration developed at FGI. Intensity values need to be corrected with range, incidence angle, atmosphere conditions and transmitted power. Reference targets were developed in FGI and laid out during the flight campaigns. The results were promising and intensity values were directly relative to target reflectance from all altitudes. Also a test with commercially available sands and gravels was carried out. They can be used in the calibration process; however, there must be control over target properties and information about target footprint size and point density is also important.

References

Ahokas, E.; Kaasalainen, S.; Hyypä, J. and Suomalainen, J. 2006. Calibration of the Optech ALTM 3100 laser scanner intensity data using brightness targets, in P*roc. ISPRS Commission I Symp. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, Marne-la-Vallee, France, Jul. 3–6, 36 (A1) [CD-ROM].

Chasmer, L.; Hopkins, C.; Smith, B. and Treitz, P. 2006. Examining the Influence of Changing Laser Pulse Repetition Frequencies on Conifer Forest Canopy Returns, *Photogrammetric Engineering & Remote Sensing* 72(12): 1359–1367.

Haala, N. and Nrenner, C. 1999. Extraction of buildings and trees in urban environment, *ISPRS J. Photogramm. Remote Sens.* 54(2/3): 130–137. doi:10.1016/S0924-2716(99)00010-6

Holmgren, J. and Persson, A. 2004. Identifying species of individual trees using airborne laser scanner, *Remote Sens. Environ.* 90(4): 415–423. doi:10.1016/S0034-4257(03)00140-8

Hyypä, J.; Kelle, O.; Lehikoinen, M. and Inkinen, M. 2001. A segmentation-based method to retrieve stem volume estimates from 3-D tree height models produced by laser scanners, *IEEE Transactions on Geoscience and Remote Sensing* 39(5): 969–975. doi:10.1109/36.921414

Kaasalainen, S.; Kukko, A.; Lindroos, T.; Litkey, P.; Kaartinen, H.; Hyypä, J.; Ahokas, E. 2008. Brightness measurements and calibration with airborne and terrestrial laser scanners, *IEEE Transactions on Geoscience and Remote Sensing* 46(2): 528–534. doi:10.1109/TGRS.2007.911366

Kaasalainen, S.; Hyypä, J.; Litkey, P.; Hyypä, H.; Ahokas, E.; Kukko, A. and Kaartinen, H. 2007. Radiometric calibration of ALS intensity, in *Proc. ISPRS Workshop on Laser Scanning and SilviLaser, Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci*., Espoo, Finland, Sep. 12–14, Vol. 36: 210–205. (Part 3/W52). [CD-ROM].

Kaasalainen, S.; Ahokas, E.; Hyypä, J. and Suomalainen, J. 2005. Study of surface brightness from backscattered intensity: Calibration of laser data, *IEEE Geosci. Remote Sens. Lett* 2(3): 255–259. doi:10.1109/LGRS.2005.850534

Kraus, K. and Pfeifer, N. 1998. Determination of terrain models in wooded areas with airborne laser scanner data, *ISPRS J. Photogramm. Remote Sens.* 53(4): 193–203. doi:10.1016/S0924-2716(98)00009-4

Kukko, A.; Kaasalainen, S. and Litkey, P. 2008. Effect of incidence angle on laser scanner intensity and surface data, *Applied Optics* 47(7): 986–992. doi:10.1364/AO.47.000986

Lutz, E.; Geist, T. and Stotter, J. 2003. Investigations of airborne laser scanning signal intensity on glacial surfaces – Utilizing comprehensive laser geometry modeling and orthophoto surface modeling (a case study: Svartisheibreen, Norway), in *Proc. ISPRS Workshop 3-D Reconstruction Airborne Laserscanner INSAR Data*, 143–148.

Moffiet, T.; Mengersen, K.; Witte, C.; King, R. and Denham, R. 2005. Airborne laser scanning: Exploratory data analysis indicates potential variables for classification of individual trees or forest stands according to species, *ISPRS J. Photogramm. Remote Sens.* 59(5): 289–309. doi:10.1016/j.isprsjprs.2005.05.002

Rivas, B. M.; Maslanik, A. J.; Sonntag, G. J. and Axelrand, P. 2006. Sea ice roughness from airborne LIDAR profiles, *IEEE Transactions on Geoscience and Remote Sensing* 44(11): 3032–3037. doi:10.1109/TGRS.2006.875775

Wagner, W.; Ullrich, A.; Ducic, V.; Melzer, T. and Studnicka, N. 2006. Gaussian decomposition and calibration of a novel small-footprint full-waveform digitizing airborne laser scanner, *ISPRS J. Photogramm. Remote Sens.* 60(2): 100–112. doi:10.1016/j.isprsjprs.2005.12.001

Wehr, A. and Lohr, U. 1999. Airborne laser scanning – An introduction and overview, *ISPRS J. Photogramm. Remote Sens.* 54(2/3) 68–82. doi:10.1016/S0924-2716(99)00011-8

Wever, C. and Lindenberger, J. 1999. Experiences of 10 years laser scanning, in *Proc. Photogramm. Week*, 125–132.

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