RADIOMETRIC CALIBRATION OF ALS INTENSITY

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ABSTRACT:

We have developed a new concept of empirical calibration scheme for airborne laser scanner (ALS) intensity by means of portable brightness calibration targets, which can be laid out in the flight target area. The accurate radiometric calibration of these targets is based on laboratory measurements with CCD-based laser backscatter instrument and terrestrial laser scanner reference measurements in laboratory and field conditions. We also discuss the extension of this method into the usage of commercially available industrial gravels or other (natural-type) targets available *ad hoc*. We demonstrate that airborne laser intensity calibration is feasible using this type of targets, but one must take carefully into account the physical parameters related to the experiment and the targets.

1. INTRODUCTION

1.1 The Radiometric Calibration of Laser Intensity

The previous use of uncalibrated laser intensity has mainly focused on estimation of planimetric shifts between ALS strips (Burman, 2000; Maas, 2001, 2002), segmentation of ALS data (Oude Elberink and Maas, 2000), and object classification (Song et al., 2002; Matikainen et al., 2003; Clode and Rottensteiner, 2005; Luzum et al., 2005; Moffiet et al., 2005). The first attempts to calibrate laser intensity have been presented by Luzum et al., (2004); Kaasalainen et al., (2005); Coren and Sterzai, (2006); Ahokas et al., (2006); Donoghue et al., (2006). Luzum et al., (2004) assumed a signal loss related to squared distance. In Donoghue et al., (2006) a linear correction approach for intensity was found adequate. Kaasalainen et al., (2005) proposed the intensity calibration by means of a known reference target. Coren and Sterzai, (2006) suggested a method that takes into account the loss of intensity with the diverging beam, the incidence angle, and the atmospheric attenuation. An asphalt road was used as homogeneous reflecting area. Ahokas et al., (2006) proposed a more general correction method, i.e., the intensity values need to be corrected with respect to range, incidence angle (both bidirectional reflectance distribution function (BRDF) and range correction), atmospheric transmittance, attenuation using dark object addition and transmitted power (because difference in the pulse repetition frequency (PRF) will lead to different transmitter power values).

Recently, it was proposed that the future ALS could be a hyperspectral sensor (Kaasalainen et al., 2007a). Under such circumstances the classification of laser hits could be highly automated if the used hyperspectral intensity responses could be radiometrically calibrated. The development of automatic data processing algorithms for, e.g., full-waveform digitizing lidars would also require calibrated intensity information. Therefore a systematic radiometric calibration method would have direct implications in more precise surface and target characterization.

1.2 Physics of ALS calibration

The recorded ALS intensity is related to the received power, which can be given in the form (Wagner et al., 2006; modified from Ulaby et al., 1982):

$$P_r = \frac{P_t D_r^2}{R^4 \beta_t^2 \Omega} \rho A_{s.} \quad (1)$$

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

The laser pulse illuminates a given surface area that consists of several scattering points. Thus, the returned echo comprises a coherent combination of individual echoes from a large number of points (as with radars, see Elachi, 1987). The result is a single vector representing the amplitude V and phase f (I~V2) of the total echo, which is a vector sum of the individual echoes. This means that as the sensor moves, the successive beam intensities (I) will result in different values of I. This variation is called fading. Thus, an image of a homogeneous surface with constant reflectivity will result in intensity variation from one resolution element to the next. The speckle effect gives the images acquired with laser light a grainy texture. According to Ahokas et al., (2006), the original variability of the beam intensities was about 10% for the rough calibration target.

The effect of the incidence angle, i.e., the scanning angle, depends on the roughness of the surface. For rough surfaces, the variation with respect to incidence angle change is significantly smaller than for smooth surfaces and the main variation occurs for near-nadir measurements. Since surface smoothness is defined using Fraunhofer criterion (Schanda, 1986), most

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natural targets are considered to have low variation of intensity as a function of incidence angle compared to microwave radars, where the variations with the incidence angle are significantly larger. However, recent experiments with laboratory and terrestrial lasers show that the intensity variation with the angle of incidence needs to be taken into account (see also Kaasalainen et al., 2005; Kukko et al., 2007).

1.3 Calibration Scheme for ALS

The Finnish Geodetic Institute has managed a permanent photogrammetric test field in Sjökulla, Kirkkonummi since 1994. The test field contains permanent and transportable test targets for radiometric and geometric calibration of analogue and digital aerial cameras. Since 2000, airborne lidar testing has also been carried out using a set of eight portable 5x5 meter brightness targets (tarps) with calibrated reflectances of 70% (A), 50% (B), 40% (C), 26% (D), 20% (E), 16% (F), 8% (G), and 5% (H) (Kaasalainen et al., 2007b). These tarps have been used in airborne laser campaigns as well as laboratory and field reference measurements. This article presents the results from flight campaigns carried out in 2005-2006, and evaluates the feasibility of using these targets in brightness calibration and the accuracy of the results.

The radiometric calibration scheme of the Finnish Geodetic Institute, presented first in Ahokas et al. (2006), was based on using these brightness calibration tarps. The brightness targets were calibrated in the laboratory at two different wavelengths and repeated reference measurements have been carried out with both terrestrial laser scanner and a laboratory laser instrument (Kaasalainen et al., 2005, 2007b). The brightness targets act as a near-Lambertian reference, which are needed for the development of the radiometric calibration scheme for ALS.

Because of the inconveniences and limitations of the effective use of the large-size tarps, we also discuss the ongoing investigations of the usage of gravel and natural targets in radiometric measurement and calibration.

2. EXPERIMENTS

2.1 Airborne Laser Flights

The brightness calibration method based on the calibration tarps has been tested in several laser scanner flight campaigns. The first complete radiometric calibration of all the eight targets was carried out during the Optech ALTM 3100 airborne laser scanner surveys (July 12th and 14th, 2005) at the Sjökulla photogrammetric test field (Ahokas et al., 2006). The measurements were carried out at flight altitudes of about 200, 1000, and 3000 meters with a 1064 nm laser source. A more detailed description is in (Ahokas et al., 2006). At this campaign, the lowest flight altitudes (200 m and 1000 m) were found most suitable for intensity calibration.

The tarps were also used in the Espoonlahti full waveform flight campaign (Aug 31st, 2006), which used the TopEye MKII 1064 nm laser scanner. The flight altitude was 300 meters and the test area consisted of the Espoonlahti boat harbour and beach. The Topeye instrument recorded the entire waveform. Four of the targets (8%, 16%, 50%, and 70%, see also Fig. 1) were measured during these flights (Kaasalainen et al., 2007b). Another TopEye MK-II campaign occurred at the same site in December 2006, where the 5%, 20%, 26%, and 40% targets were measured. Four targets (5%, 16%, 40%, and 70%) were also measured at the Nuuksio flight campaign (14-15 May 2006). The data were acquired at the altitude of 1097 m with the Optech ALTM laser scanner. The most important parameters of all the flight campaigns are summarized in Tables 1 and 2.

Figure 1. Four of the brightness calibration targets arranged for airborne laser measurement in Espoonlahti, Dec 2006. Each target is 5x5 m in size.

Location & Date	Instrument	Wavelength (nm)	Altitude (m)
Sjökulla Jul 05	Optech	1064	200
Nuuksio May 06	Optech	1064	1097
Espoonlahti Aug 06	Topeye	1064	300
Espoonlahti Dec 06	Topeye	1064	100 200 300 500 700

Table 1. Summary of some laser scanner flight parameters from different calibration flight campaigns. See also Table 2.

Altitude	Tarp 5 %	Tarp 20 %	Tarp 26 %	Tarp 40 %
100 m	702	645	413	1679
200 m	280	237	251	125
300 m	62	85	325	402
500 m	11	14	13	17
700 m	18	18	95	73

Table 2. Number of sample points at the Espoonlahti Dec 2006 campaign. The intensities were then sampled as an average of the entire set of points for each tarp. The hits near the edges of the targets were excluded (i.e., if there was a significant change in intensity in the vicinity of a data point, it was interpreted to be near the edge of the target and excluded).

2.2 Validation Measurements in the Laboratory

Laboratory measurements are the only means of correcting the directional effects from backscattered laser intensity, which have been found to be common and affect substantially to the lidar intensity. They also provide an accurate reference for the intensity measurement. The laboratory laser instrument has been constructed to operate in the similar illumination/observation geometry as in laser scanning (i.e., exact backscatter where the source and detector light paths coincide). The instrument (Fig. 2) comprises a 1064 nm Nd:YAG laser (wavelength similar to most airborne scanners), and 16-bit monochrome CCD-camera, which is a commonly used detector in laboratory (laser) measurements in, e.g., optical physics (Yoon et al., 1993). More details on the laboratory experiment are found in (Kaasalainen et al., 2007). We averaged five 3-second images for each target. The backscattered laser intensities were measured from the CCD images by means of standard photometric techniques.

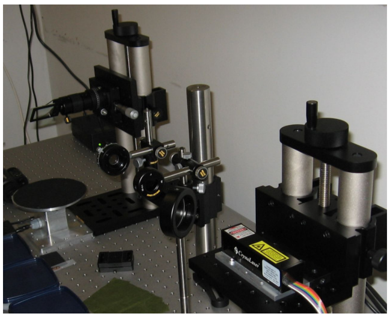

Figure 2. The laboratory laser measurement. The laser beam is reflected into the sample from a plate beam splitter (top left) and observed through the beam splitter with the CCD camera mounted above the instrument. Neutral density filters and a quarter-wave (λ/4) plate are used to avoid saturation of the detector and to scramble the linear polarization of the laser, respectively.

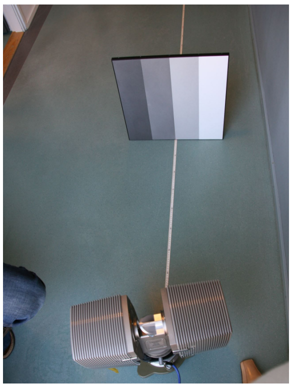

Figure 3. The FARO terrestrial laser scanner measuring a 4-step (12%, 25%, 50%, and 99%) Spectralon reflectance calibration plate (Labsphere Inc.).

The reflectance of a calibration target must be independent of the measurement technique and instrument, i.e. the relative intensities measured in different campaigns must be in agreement. To test this, we carried out laboratory reference measurements with the 785nm FARO LS HE80 terrestrial laser scanner. The scanner uses phase angle technique for the distance measurement with the accuracy of 3-5 mm and 360°×320° field of view. The detector of the FARO scanner is not optimized for intensity measurement: there are modifications in the detector that affect the intensity, e.g., a brightness reducer for near distances (<10 m) and a logarithmic amplifier for small reflectances. These all required an extensive and systematic distance and reflectance calibrations, which were carried out in the laboratory using the test targets and a calibrated 4-step Spectralon reflectance panel (see Fig. 3). We also made experiments for the calibration of distance and incidence angle effects (e.g., Kukko et al., 2007) and found the most suitable laboratory measurement distance to be about 1 m for brightness measurements.

3. RESULTS AND DISCUSSION

3.1 Comparison of laser intensities

The most important feature that makes a target suitable for intensity calibration is that its relative intensity is independent of the measurement system, i.e., the instrument, flight altitude, etc. To investigate this, we present a comparison of the relative intensities of the test tarps from different measurements in Table 3. The intensities of the 20% and 50% target are presented relative to the 70% target. It appears that the reflectances are generally well reproduced, but occasional deviations occur, because of random (laser) measurement errors (such as the saturation of the detector) and the contamination of the target itself due to, e.g., weather conditions. Furthermore, the angle of incidence turns out to be a crucial factor in laser intensity (Kukko et al., 2007) and causes variation in the measured intensities, which must be taken into account in surface models and intensity calibration. There is also a wavelength difference between FARO (785 nm) and the other measurements (1064 nm), which affects the relative intensities. There is a decrease in intensity towards longer wavelengths (see Fig. 4), which partially explains the differences for the targets measured with the FARO.

It is obvious that more data are needed for further testing and investigation of the materials most suitable for calibration, but these results indicate that the relative intensity calibration is possible by means of calibration targets.

Measurement (date & flight altitude)	Test tarp (%)	
	16/70	50/70
Sjökulla, Jul 05, 300 m	0.24	0.69
Espoonlahti, Aug 06, 200 m	0.37	0.72
Nuuksio, May 06, 1097 m	0.21	0.58*
Laboratory, 785nm FARO	0.25	0.89
Laboratory, 1064nm Nd:YAG	0.23	0.73

Table 3. Comparison of the test target intensities from ALS flight campaigns and laboratory measurements. The intensities are scaled with the brightest (70%) target. *=The Nuuksio value is for the 40% target, implying a response of 0.66 for 50 % target (by interpolating the missing 50% value). (Also note that the corresponding 40%/70% value in Sjökulla measurements was 0.60.)

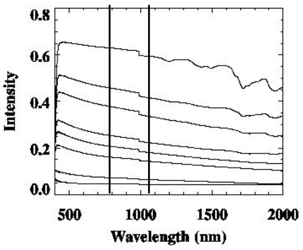

Figure 4. Reflectance spectra of the brighness tarps, measured using a flashlight illumination placed right on top of each sample (i.e. the zenith) and the detector placed at about 30º from the zenith (Kaasalainen et al., 2005). The intensities are relative to the 99% Spectralon reference plate. The 785 nm (FARO) and the 1064 nm (airborne and laboratory) wavelengths are marked with vertical lines.

We also made a further experiment on the effect from different flight altitudes on the calibration. The results are from a Topeye flight campaign in Espoonlahti, December 2006. The intensities, scaled at 100 m altitude, and relative to the brightest target (40% at this campaign) at four different flight altitudes, are presented in Table 4 and Fig. 5. (The scaling to the 100 m altitude was done by means of multiplying the original intensity by the ratio of the squared distance and the squared reference distance (100 m). The result was then divided by the squared atmospheric transmittance calculated with the MODTRAN software.) The intensity levels at different altitudes are in good agreement, i.e., the relative brightness calibration is independent on flight altitude. The relative results in Table 3 and Fig. 4, on the other hand, imply that the calibration would be independent on the instrument.

More data and a more accurate investigation on the effects of different parameters are needed to develop this concept into a well-established calibration procedure.

Altitude	Tarp 5 %	Tarp 20 %	Tarp 26 %
100 m	0.14	0.55	0.68
200 m	0.12	0.48	0.61
300 m	0.13	0.47	0.60
500 m	0.13	0.49	0.62
700 m	0.13	0.48	0.61

Table 4. Espoonlahti Dec 2006: Test target intensities relative to the brightest (40%) target. (Scaled in 100 m altitude.) The intensities are plotted in Fig. 5.

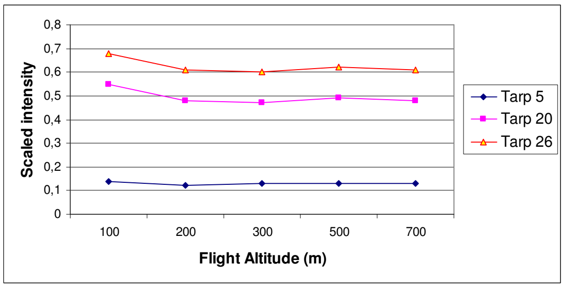

Fig. 5. Comparison of the intensities of the Espoonlahti (Dec 06) test targets (5%, 20%, 26%, and 40%) at different flight altitudes, scaled with the brightest (40%) target. (Cf. Table 4).

3.2 Discussion and Future Work

The calibration tarps provide a means to calibrate the laser scanner intensity in airborne flight measurements. They are, however, sensitive to errors caused by the weather effects, such as rain or wind changing the surface properties. The intensity signal from the wet or rugged and uneven surface may be substantially different from that of the flat and smooth or dry tarp. Because of these limitations, we are investigating the use of standard industrial gravels in brightness calibration. They would be less sensitive of, e.g., wind effects, and there could also be a possibility to calibrate, at some reduced accuracy at least, for the effects of moisture on their intensity. They have also proven more practical in field use because of easier logistics and mounting process, and their commercial availability.

The prospects of *in situ* calibration of the brightness targets (with the aid of, e.g., portable laser instruments) during a laser scanner flight are also under study. This might enable the usage of natural targets (such as beach sands or roads) in the brightness calibration. Another alternative is to bring a sample of a natural calibration target into laboratory for more controlled reference measurement. More information is needed especially on the target reflectance properties in different weather conditions, especially because the actual targets to be calibrated also include complex vegetation surfaces. There is little information available on the laser-based reflectance calibration of vegetated surfaces, but strong directional effects have been found in the backscattered intensity of, e.g., forest understorey (Kaasalainen and Rautiainen, 2005).

In May 24, 2007, the European Spatial Data Research (EuroSDR) approved the proposal of the Finnish Geodetic Institute and the Technical University of Vienna to develop a practical ALS intensity calibration method for national mapping and cadastre agencies and companies during 2007-2008.

3.3 Applications

The intensity calibration procedure has applications in, e.g., the utilization and processing of the data from full-waveform lidars (which have recently become common) into calibrated backscatter cross-sections. This would offer a possibility of classifying the data based on the shape of the returned laser pulse and the cross-section amplitude, and thus facilitate the development of more accurate digital terrain models and more effective classification of targets. The calibration technique will also enhance the methods of monitoring and mapping of forests (e.g. tree growth), construction, and agriculture. There are also prospects for environmental change detection and monitoring, such as snowmelt or snow/glacier albedo variation, hydrolgical processes and climate change.

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