CALIBRATION OF THE OPTECH ALTM 3100 LASER SCANNER INTENSITY DATA USING BRIGHTNESS TARGETS

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Commission I , WG I/2

KEY WORDS: LIDAR, Calibration, Targets, Quality, Radiometric, Calibration field, Laser scanning

ABSTRACT:

In this paper the calibration of Optech ALTM 3100 laser scanner intensity is reported using airborne experiments and known brightness targets. The Finnish Geodetic Institute has had a permanent photogrammetric test field in Sjökulla Kirkkonummi since 1994. This test field contains permanent and transportable test targets for radiometric calibration, permanent ground control points for small, medium and large-scale geometric calibration and also test bar targets for spatial analysis of analogue and digital aerial cameras. Since 2000 LIDAR testing has also been carried out, the latest being Optech ALTM 3100 campaign in 12-14 July 2005. Eight portable brightness targets with nominal reflectance of 5 %, 10 %, 20 %, 25 %, 30 %, 45 %, 50 % and 70 % were in use for LIDAR testing. Flying heights were about 200, 1000 and 3000 m above ground level. Intensity values need to be corrected with respect to range, incidence angle (both BRDF and range correction), atmospheric transmittance, attenuation using dark object addition and transmitted power (because difference in PRF will lead to different transmitter power values). After these corrections, the intensity values were directly relative to target reflectance. Flight heights of 200 m and 1000 m are suitable for intensity calibration using artificial test targets due to the practical aspects of the calibration (size of the calibrator). With the 3000 m altitude signals with reflectance of less or equal of 10% could not be recorded most probably due to insufficient signal-to-noise ratio. Thus, the test target reflectance should exceed 10% to give a reliable distance measurement from 3000 m altitude.

1. INTRODUCTION

The ALS (airborne laser scanning) data processing would be more automated if ALS systems would measure, in addition to range, further physical observables that can be used for object classification (Wagner et al. 2006). Most of the systems record the intensity value of each echo, but it is seldom used in the analysis. Examples where intensity has been used include the use as a predictor e.g. for tree species classification (Holmgren et al. 2004) or for matching aerial imagery and laser scanner data. The more effective use of intensity values is missing due to the lack of techniques to calibrate them, the lack of knowledge to use it and also due to the reduced information content of intensity data compared to 3D data. There are also full-waveform digitising LIDAR systems that have been developed, first as preparation for future satellite systems to survey earth topography and vegetation cover, and later for airborne laser scanners. According to Wagner et al. (2004) the use of full-waveform in airborne laser scanner offers a possibility to classify the data based on the shape of the echo. Another important advantage is that the detection of the trigger pulses can be applied after data capturing. Both the intensity of the pulse and full waveform needs better ways in their calibration. In this paper the calibration of laser scanner intensity is discussed and airborne experiments are conducted.

2. THEORY

2.1 Receiver power, Intensity

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

$$P_r \; ? \; \frac{P_t D_r^2}{R^4 ?_t^2 ?} \, ? A_{s.} \qquad (1)$$

where P_r and P_t are transmitted and receiver power, D_r is the receiver aperture size, R is the range, $?_t$ is the beam divergence, ? corresponds to the bidirectional properties of the scattering, ? 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 filling the full footprint, to R^3 for linear objects (e.g. wire) and to R^4 for

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individual large scatterers. In Baltsavias (1999), a corresponding equation is given for homogenous targets.

The backscatter cross-section ? can be given in the form (Wagner et al. 2006):

$$? \;\; ? \frac{4?}{?} ?A_{s.} \qquad (2)$$

Bidirectional properties of the scattering, target reflectivity and the receiving area of the scatterer affect the backscattering characteristics of a target.

Additionally, atmosphere attenuates the transmitted signal. If T is the atmospheric transmittance, the received power $P_{r,real}$ after atmospheric attenuation is

$$P_{r,real} \;?\; T^2 P_r \qquad (3)$$

In the present systems, only one pulse is simultaneously propagating between that target and the sensor. This means that the pulse repetition frequency PRF is changed when higher altitudes are used. During this process also the transmitted power is changed (Chasmer et al., 2006).

2.2 Fading and Speckle

The laser pulse illuminates certain surface area that consists of several scattering points. Thus, the returned echo is the coherent addition of the 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 ?, ($I \sim V^2$) Fig. 1, of the total echo, which is a vector sum of the individual echoes. This means that the successive beam intensities I as the sensor moves will result in different values of I. This variation is called fading (Elachi, 1987). Thus, an image of a homogeneous surface with constant ? will result in intensity variation from one resolution element to the next. Speckle gives a grainy texture to images recorded with laser light (Hecht, 1992).

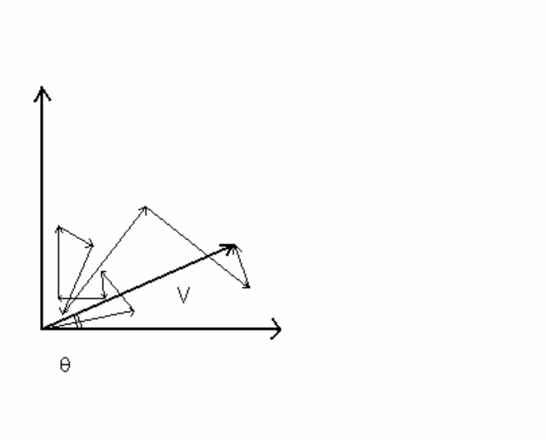

Figure 1. Total echo is a vector sum of individual echoes (modified from Elachi, 1987).

3. TEST

3.1 Test field

The Finnish Geodetic Institute has had a permanent photogrammetric test field in Sjökulla Kirkkonummi since 1994. Originally, it was built for testing analogue aerial cameras. Recently, it has been used extensively for calibration and testing of large format digital airborne cameras and also direct georeferencing systems. This test field consists of permanent and transportable test targets for radiometric calibration, permanent ground control points for small, medium, and large-scale geometric calibration and also test bar targets for spatial analysis. The testing of LIDAR systems has been carried out since 2000.

3.2 Brightness targets

Eight portable brightness targets with nominal reflectance of 5 %, 10 %, 20 %, 25 %, 30 %, 45 %, 50 % and 70 % were in use for LIDAR testing. Their reflectances were optimized at the wavelength range of 400-800 nm, but the intensity properties have been measured between 400-2000 nm using a portable field spectrogoniometer ASD FieldSpec Pro. These nominal reflectance values are approximate and the accurate laboratory calibration has been carried out in Kaasalainen et al. (2005). Target reflectance values at the 1064 nm wavelength defined from the laboratory measurements are 6.5, 11.5, 23, 29, 36, 53.5, 65 and 90% and these values are used in the following figures of this study.

Targets have been made of polyester 1100dtex with polyvinyl chloride (pvc) coating. Titanium dioxide and carbon black paint mixing pigments were used to coat the target surface. Delustring agent was added to the paint to get a mat surface and to decrease non-Lambertian reflectance effects. The fabric is quite heavy ($600 g/m^2$) and durable. The size of one target is 5 m by 5 m that is large enough to make high altitude (3000 m) measurements possible. Targets can be attached together and mounted to the ground with steel pegs and pulley tackles. The whole system requires more than 40 m space in one direction if assembled linearly. The number and combination of targets can be varied depending on the available space. Each target with accessories can be transported in its own carrying bag.

Figure 2. Targets at the Sjökulla photogrammetric test field in Kirkkonummi arranged for a digital aerial camera test. (Photo 4 Oct. 2004 by H. Kaartinen).

3.3 Test flights

Optech ALTM 3100 airborne laser scanner surveys were executed on July 12th and 14th, 2005. Flying heights, H, were about 200, 1000 and 3000 m above the ground level, Figure 3. Laser repetition frequencies were 100 kHz (for H=200 and 1000 m) and 33 kHz (for H=3000 m). Half of the scanning angle was 17 degrees. In the ALTM 3100, intensities can be captured in 12 bit dynamic range. Spot distribution is a saw tooth -like pattern. The laser wavelength was 1064 nm; the same wavelength was used in the reference measurements made in the ground laboratory (Kaasalainen et al. 2005). Two measurement strips with opposite directions were flown from 200 m flying height and from 1000 m flying height laser points were recorded from three strips on the targets. Laser points were recorded from four strips on the targets from the 3000 m flying height.

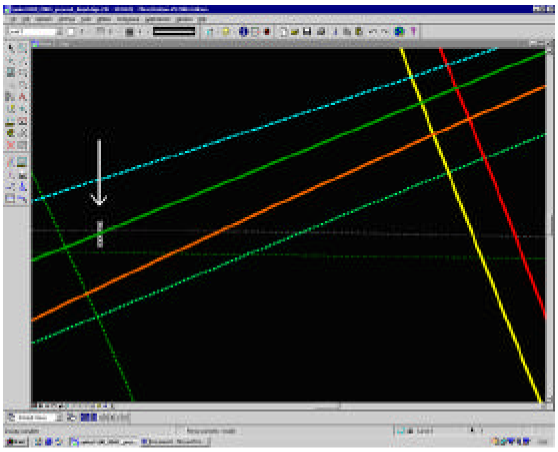

Figure 3. Trajectories over the Sjökulla test field. The arrow is pointing to the brightness targets. Solid lines describe 3000 m, dashed lines 1000 m and thin dotted lines 200 m flying height trajectories.

The gravel that partially covers the Sjökulla test field has a small-scale variation in topography. The brightness targets were at the same vertical level on the ground within 20 cm from each other. The angles between consecutive targets were less than 1 degree from horizontal level. Laser-based vertical profile of the targets is in Figure 4. There is a 5 cm systematic error in height observations between the strips.

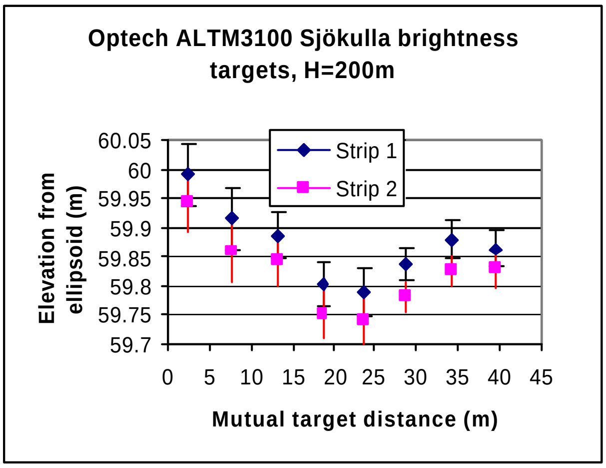

Figure 4. Averages and standard deviations of elevations of the targets.

A 4mx4m area inside the 5mx5m brightness target was used to avoid mixed intensities coming from the neighbouring target or the black gravel outside the target.

Only 2 to 5 laser points were registered from each target per strip from 3000 m flying height. Point amounts from 1000 m were accordingly 20 to 30 and from 200 m 130 to 170 laser points.

3.4 Calibration of intensity values

The recorded intensity is a function of target reflectivity, range (including incidence angle), and PRF (see Section 2).

The effect of the range is demonstrated in Figure 5, in which the intensity and observation angle dependence is affected by the range difference between two strips.

The recorded intensity values were corrected as follows:

- intensities from various altitudes were assumed to follow the (range) R^2 relationship;
- pulses with different incidence angles were corrected to account for the change of reflectivity as a function of incidence angle (Kaasalainen et al. 2005) and also to change of range;
- the transmitted power was assumed to be changed according to Chasmer et al. (2006). Transmitted pulse energy is 164 µJ for 33 kHz and 59 µJ for 100 kHz, and
- the effect of the atmospheric attenuation was neglected in the preprocessing phase.

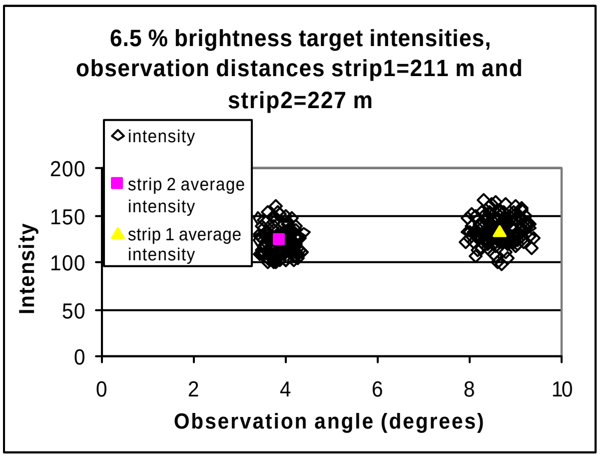

Figure 5. The relation between the intensity and observation angle is distorted by the range difference of the two strips.

Thus, the scaled intensity values (with selected reference height) were calculated as follows.

$$I_{scaled,j} \; ? \; I_j \frac{R_j^2}{R_{ref}^2} \frac{E_{Tref}}{E_{Tj}} \qquad (4)$$

where j is strip number, I_j is intensity in strip j, R_{ref} is reference distance (here 200 m), R_j is distance in strip j, E_{Tref} is the transmitted reference pulse energy (59 µJ) and E_{Tj} is the transmitted pulse energy for strip j.

4. RESULTS

4.1 Original intensity values

Average intensities of the brightness targets from different flight strips are in Figure 6. From 3000 m flying height, the two darkest targets (reflectance 6.5 and 11.5 %) did not give signals that could be separated from noise. Also, the dynamic range of intensity values is high due to R^2 dependence.

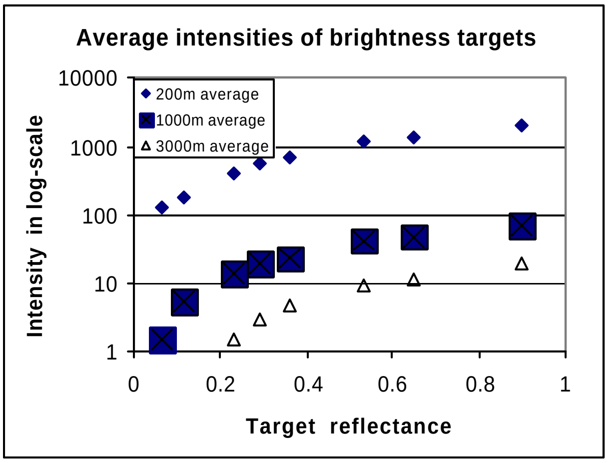

Figure 6. Average intensities of the brightness targets from three altitudes in log-scale.

4.2 Linearity of Intensity

The scaled intensity values for 200 m, 1000 m and 3000 m are depicted in Figures 7, 8 and 9. Coefficient of correlation, R^2, values for each flight strip give the goodness of fit between mean intensity (for each reflectance value) and scaled intensity. High R^2 values confirmed the use of the applied calibration targets for intensity calibration, Table 1.

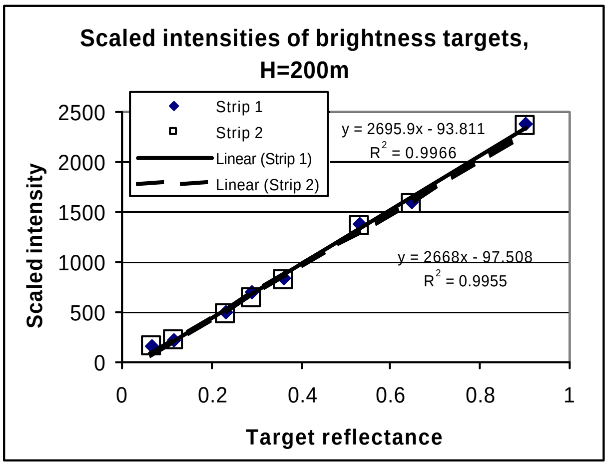

Figure 7. Intensities from strips 1 and 2 scaled to 200 m flying height.

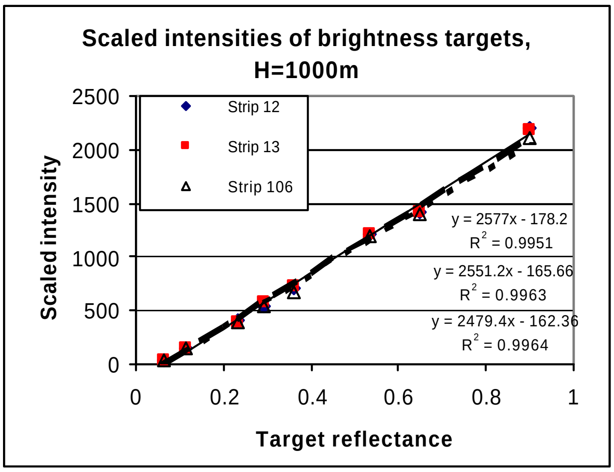

Figure 8. Intensities from strips 12, 13 and 106 scaled to 200 m flying height.

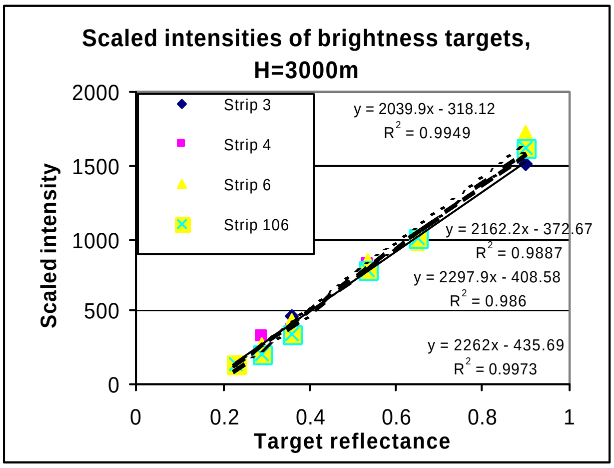

Figure 9. Intensities from strips 3, 4, 6 and 106 scaled to 200 m flying height.

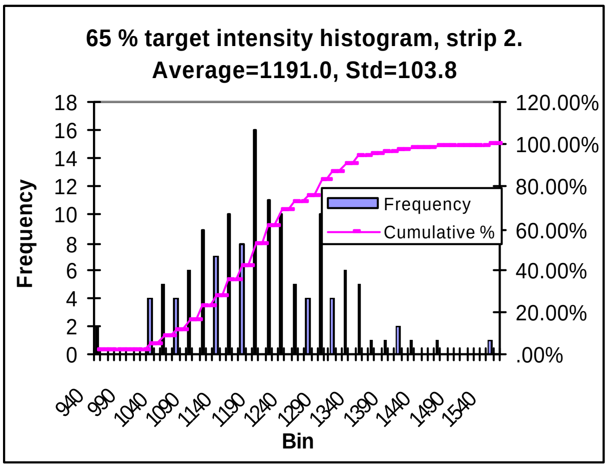

Figure 10. Histogram of beam intensity with 65 % target reflectance. Flying height 200m.

Table 1. Coefficient of correlation R^2, and standard error SE for every strip after intensity scaling.

Height (m)	Strip	R^2	SE
200	1	0.9966	48.42
	2	0.9955	54.83
1000	12	0.9951	55.28
	13	0.9963	47.57
	106	0.9964	45.68
3000	3	0.9949	41.42
	4	0.9887	65.37
	6	0.9860	77.37
	106	0.9973	33.17

These standard errors corresponded to roughly 5% relative error in the reflectance measurement. The variation of SE in the 3000 m results is due to the small number of intensity observations and possibly due to atmospheric inhomogeneity. It should be noticed that the standard error is also the function of fading (variance of the intensity), errors in the reference calibration (Kaasalainen et al. 2005) and errors in the calibration set up. In Kaasalainen et al. (2005), the errors were assumed to be in the range of 2%. Thus, the calibration set up error was assumed to be low.

4.3 Variability of beam intensities

The mean values of intensities were used in Figures 7 to 9. Due to the fading, there exist stronger variability of the individual beam intensities. That was studied using histogram analysis, Figure 10, and by calculating the standard deviation of intensity for each brightness target. The obtained std-% ranged between 9 and 14% from strip 1 and from 8 to 15% from strip 2 (H=200m). It could be concluded that the original variability of the beam intensities is roughly about 10 %.

4.4 Atmospheric considerations

The radiative transfer code MODTRAN4 was used for simulation of atmospheric transmittances at the 1064 nm wavelength. Mid-latitude summer atmospheric model with rural aerosols and 23 km visibility and observation distances 220 m, 1100 m and 3100 m were the input parameters in MODTRAN. Calculated total transmittances were 0.985, 0.94 and 0.890. To obtain transmittance corrected intensities the scaled intensities were divided by the squared atmospheric transmittances, according Equation (3). The results are shown in Figure 11.

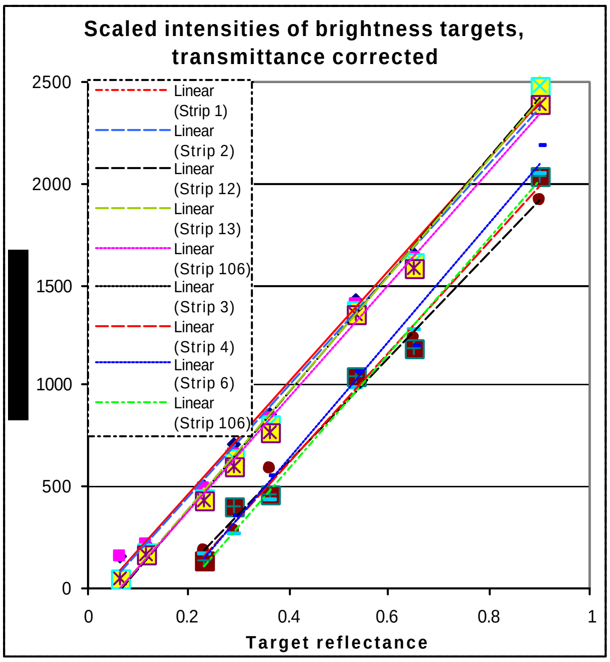

Figure 11. Intensity values corrected for atmospheric transmittance.

From Figures 7-9 and 11, it can be concluded that in principle that applied correction, which included range, incidence angle, atmospheric transmittance and transmitted power correction worked relatively well. All flights with altitudes equal of less than 1000 m could be relatively calibrated to same intensity level, which is linearly dependant on the target reflectance.

By comparing the regression lines of corrected intensities from various flight altitudes, we could notice that the slope of each line is almost equal. The variability between slopes of the same flight altitude is even higher than by comparing the slopes between different flight altitudes. Thus, the correction seems to work well concerning the slope.

On the contrary, the intercept point of the regression line seems to be more downwards as the flight altitude increases. This effect has to be corrected. A common technique for atmospheric correction of the multi-spectral imagery is to use dark objects as calibration targets (known as DOS technique, Chavez, 1988). It is assumed that the dark object has uniformly zero radiance. On the contrary to DOS-technique, a positive value needs to be added to correct for the observed phenomena.

After applying an additive value of +99 (from regression lines of Fig. 11) for 200 m flights, +191 for 1000 m flights and +485 for 3000 m flights, intensities of all flight lines could be calibrated against each other, Figure 12. Again the variability of the 3000m slopes was due to low number of hits, fading effect and possible inhomogeneity of the atmosphere.

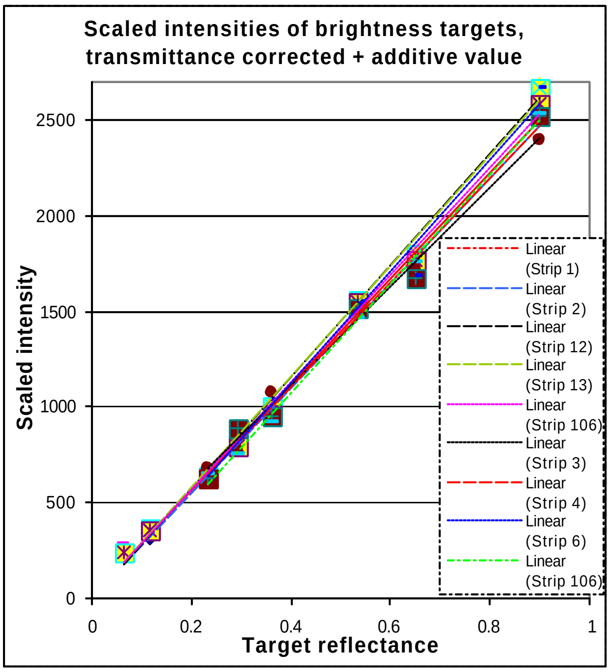

Figure 12. Intensity values corrected for atmospheric transmittance and additive values from regression lines.

5. CONCLUSIONS

In this study we showed the feasibility of portable brightness targets for the calibration of airborne laser scanner intensity from different flying altitudes, namely 200 m, 1000 m and 3000 m. High coefficient of correlation R^2 values (between mean intensity (for each reflectance value) and scaled intensity) confirmed the use of the applied calibration targets for intensity calibration.

It was shown the intensity values needs to be corrected with respect to 1) range, 2) with incidence angle (both BRDF and range correction), 3) atmospheric transmittance, 4) attenuation using dark object addition and 5) transmitted power (difference in PRF will lead to different transmitter power values). After these corrections, the intensity values were directly relative to target reflectance from all altitudes.

The effect of the fading in intensity corresponds to typical variation of about 10% with the applied reflectance targets from the 200 m altitude.

We found the flight heights of 200 m and 1000 m to be suitable for intensity calibration using artificial or natural test targets due to the practical aspects of the calibration (size of the calibrator). 0.3 mrad beam divergence gives a footprint of 90 cm that is large for the practical calibrator size. Due to the fading, relatively large number of beam hits is recommended to be recorded. Also nadir or small angle ALS observations make the utilization of laboratory measurements easier in the calibration process. At the moment the reflectance properties of the brightness targets are known at the angles smaller than 10 degrees. Cleaning of the brightness targets after a field campaign may change their reflectance properties, thus, revision laboratory measurements are needed and additional measurements with larger observation angles than 10 degrees. 5x5m targets allow intensity calibration observations from the altitude of 1000 m and below. Point densities will be large enough in such circumstances when PRF is 100 kHz.

In this study, the 3000 m data were used to show that after using the correction of the transmitted power due to PRF change, the absolute reflectance corresponding to intensities values could be calibrated

We also found with the 3000 m altitude, that signals with reflectance of less or equal of 10% could not be recorded most probably due to insufficient signal-to-noise ratio. Thus, the test target reflectance should exceed 10% to give a reliable distance measurement from 3000 m altitude. A black roof of a house is an example of a non-visible object from this altitude.

We recommend that this kind of correction or calibration of the intensity values should be done in the preprocessing part of the data in order to increase the usability of the intensity information. Even though it is evident for researchers that intensity values are strongly dependant on applied range to the target, and it may be evident for system developers that PRF change may change transmitter power, the users of the intensity values need better-calibrated intensity data for their application development.

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