TOPOGRAPHIC AND DISTANCE EFFECTS IN LASER SCANNER INTENSITY CORRECTION

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ABSTRACT:

The effect of incidence angle on the intensity of laser backscatter has been studied in photonics and optics, but the applications of these results to remote sensing of natural land targets are limited, as well as the availability of experimental validation data for airborne and terrestrial laser scanning, where the incidence angle correction using the Lambertian scattering law is common. We have investigated the role of topographic (incidence angle) and distance effects in the radiometric calibration of monostatic terrestrial and airborne laser scanner data. Our results show that the Lambertian (cosine) correction is practically valid at incidence angles up to 20º, whereas at greater angles of incidence, the accuracy of data is still very limited to estimate the performance of any correction method. We also discuss the mixed effects of distance and target reflectance on terrestrial laser scanner intensity calibration, for which the number of applications is constantly increasing. As there are differences in the intensity detectors of different instruments, it is important that the effects of distance and target reflectance are well defined before using any terrestrial laser scanner in intensity measurement.

1. INTRODUCTION

1.1 Background: Radiometric Calibration of ALS Intensity

The radiometric calibration of airborne laser scanner (ALS) intensity has been actively studied in recent years (Coren and Sterzai, 2006; Ahokas et al, 2006; Hopkinson, 2007; Höfle and Pfeifer, 2007; Briese et al. 2008; Wagner et al., 2008; Kaasalainen et al., 2009a; Yoon et al., 2009). The intensity, recorded by current laser scanners either in the form of the echo amplitude or full waveform of the backscattered signal (Wagner et al., 2006), is being applied along with the 3D point cloud (x,y,z) in various studies of, e.g., object classification (see Höfle and Pfeifer, 2007) for an extensive review and more references). Even though more data are constantly becoming available, there are still many issues that need to be solved in order to establish and evaluate the performance of radiometric calibration methods. There is a current EuroSDR (http://www.eurosdr.net) project aiming at feasible and cost-effective ALS radiometric calibration techniques, which addresses both the absolute and relative approaches to the calibration of ALS intensity data.

Applications and usage of terrestrial laser scanner (TLS) intensity data are also increasing in, e.g., environmental studies (Prokop, 2008; Luzi et al., 2009), either to improve the accuracy of distance measurement or to be used in, e.g., target characterization. This emphasizes the need for accurate radiometric calibration methods also for TLS. These methods would also enhance the use of TLS in the validation and testing the performance of ALS applications, especially those related to the study and uses of calibrated intensity in data processing and interpretation algorithms (such as automatic extraction of certain targets from laser point clouds).

1.2 The ALS Intensity Calibration From Point Clouds

The Finnish Geodetic Institute has developed a practical approach for ALS and TLS intensity calibration of monostatic lidars, based on pre-calibrated *in situ* reference targets used in the ALS flight area or the TLS field of view (Ahokas et al., 2006; Kaasalainen et al., 2009a; Vain et al., 2009). The correction of the intensity values (raw data) from ALS point data, which is extracted using the TerraScan (TerraSolid Ltd.) software, is carried out in terms of the following equation (Ahokas et al., 2006; Höfle and Pfeifer, 2007):

$$I_{corrected} = I_{original} \cdot \frac{R_i^2}{R_{ref}^2} \cdot \frac{1}{\cos\alpha} \cdot \frac{1}{T^2} \cdot \frac{E_{Tref}}{E_{Tj}} \qquad (1)$$

where $I_{original}$ is the raw intensity value, R_i is the slant range (see Fig. 1) from the sensor to the ground, R_{ref} is the chosen reference range, α is the incidence angle (for horizontally flat surfaces, the incidence angle equals the scan angle, see Sect. 1.3), T is the total atmospheric transmittance, E_{Tref} is the chosen reference pulse energy value and E_{Tj} is the pulse energy value in a current flight line. The atmospheric effect ($1/T^2$) is modelled using the MODTRAN (ver. 3) software (see also Vain et al., 2009) for more details on the procedure). In practice, the pulse energy is not known or reported by the manufacturer. Therefore it is usually omitted in the calculations, especially when reference targets in the same target area (or flight line) are used.

The term *reflectance* (or the *albedo*) mostly refers to the total fraction of the incident (collimated) power on unit surface area

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scattered into upper hemisphere by unit area of surface. Laser scanners measure only the fraction of reflectance scattered into the direction of illumination (0° angle between light source and detector), i.e., the backscattered (directional) reflectance. Using reference targets in calibration, the backscattered reflectance R of the target is then given by (cf. Hapke, 1993):

$$R(\text{target}) = \frac{I_{\text{corrected, target}}}{I_{\text{corrected, reference}}} R(\text{reference}), \qquad (2)$$

where $I_{\text{corrected,reference}}$ is calculated similarly for the reference, according to Eq. (1), and $R(\text{reference})$, i.e., the (backscattered) reflectance of the reference target, is obtained from *in situ* or laboratory reference measurements (Kaasalainen et al., 2009a).

1.3 The Incidence Angle Effect

The Lambert's law is an empirical expression of reflectance (R) of a surface being proportional to the cosine of the incidence angle α (Hapke, 1993), i.e.,

$$R = k_L \cos\alpha \qquad (3)$$

where k_l is a constant. Even though this is a simplified mathematical law, and the light scattering behaviour of most natural surfaces is not Lambertian, the incidence angle dependence for many surfaces is approximated to follow the cos α relation. This is why it is also being used in ALS intensity calibration applications (such as that in Eq. 1). The effect of incidence angle on backscatter has been studied in photonics and optics (e.g., Ruiz-Cortés and Dainty, 2002; Jutzi et al., 2003), but the applications of these results to remote sensing of natural surfaces are limited, as well as the availability of experimental validation data (cf. Kukko et al., 2008).

The incidence angle is defined in ALS as the angle between surface normal and the laser beam incident on the surface, and can be calculated from the coordinates of the laser point and the scanner position. In the case of flat surfaces (i.e., surfaces in horizontal level), the scan angle and incidence angle coincide (see Fig. 1 for definitions). The effect of the incidence angle on the laser point intensity value is called the topographic effect, and the cosine correction, assuming the surfaces to be Lambertian, has become a practise (Höfle and Pfeifer, 2007; Wagner et al., 2008), especially in ALS. The experimental validation, however, is difficult to obtain. For TLS, the radiometric calibration in the first place has been little studied, but the role of the incidence geometry can in some cases be even stronger than that in ALS. In this paper we present systematic TLS measurements to evaluate the impact and the correction of the topographic effect by comparing the cosine law (Eq. 3) reflectances to the laser backscatter reflectances measured with terrestrial and airborne laser scanners.

The distance has an effect on the recorded intensity values. We also present some preliminary results on a study of distance effects on the calibration of TLS intensity data, and discuss the issues that have to be taken into account in the applications using TLS intensity, such as the recently increasing vehicle based laser scanning techniques (Jaakkola et al., 2008).

R_i – slant path from sensor to the ground

$1/T^2$ – atmospheric correction over the slant path

$1/\cos\alpha$ – incidence angle correction

R_i^2 / R_{ref}^2 - spherical loss. Reference height is used when comparing laser data from different heights.

α_s – scan angle
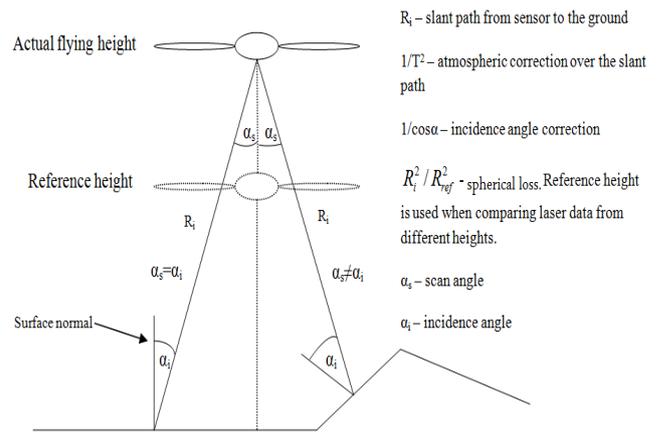
α_i – incidence angle

Figure 1. The incidence angle and the scan angle. Some of the ALS intensity atmospheric correction parameters are also shown (cf. Eq. 1).

2. METHODS AND DATA

2.1 Terrestrial Laser Scanner (TLS) Measurements

The TLS measurements used in this paper were carried out by Kukko et al. (2008) to study the incidence angle effects on some typical ALS land targets. The instrument was a 785nm FARO LS 880HE80 (FARO LS) 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. Because the detector is optimized for distance rather than intensity measurement, the intensity data (counts) have been modified by a logarithmic amplifier of small reflectances and a brightness reducer at near distances. Additional calibration of the intensity data is needed for the effects of the amplifier and reducer to get a linear brightness scale, based on instrument calibration experiments for varying distance and reflectance. For a more accurate description on the FARO LS intensity calibration see (Kukko et al., 2008; Kaasalainen et al., 2009b) and references therein. The incidence angle measurements were carried out for samples of artificial tarps of known reflectance and commercially available gravel used in the radiometric calibration of ALS and aerial images (Ahokas et al., 2006; Kaasalainen et al., 2009a). The targets were placed on a goniometer at 1-meter distance from the scanner (Fig. 2). The laser backscatter reflectance was calibrated at each incidence angle using a 99% Spectralon® (Labsphere Inc.) panel as a reference, measured at 0° incidence. The raw intensity value of a target was extracted by averaging points over a selected surface area in a point cloud image. The standard deviation of these averages is typically the order of 0.5-1% for the FARO intensities.

The distance effect was studied by mounting the FARO TLS on top of a scissor lift. The targets were then scanned in 50cm increments from about 2m to 10m height. Spectralon targets of 12%, 25%, and 50% reflectance were measured, and the 99% Spectralon plate was used as reference.

Fig. 2. The FARO TLS incidence angle measurement for gravel samples. The scanner is mounted on a tripod about 1m above the sample placed on a goniometer, which could be tilted for incidence angle variation.

2.2 Airborne Laser Scanner (ALS) Data

The study area is situated in South Finland near Helsinki in Espoonlahti Harbour. Airborne laser scanning (ALS) data from Espoonlahti 2007 flight campaign using Leica ALS50-II scanner were used in this study. Data were extracted from two altitudes: 500m and 2200m. Intensity data at both flight altitudes were collected from asphalt roads at scan angles up to 22°. The corrections described in Section 1.2 were carried out for the intensity raw data (see more details in Vain et al., 2009). No brightness reference is used for these data, because we only investigated the relative decrease in brightness as the incidence (scan) angle increases.

3. RESULTS AND DISCUSSION

3.1 The Incidence Angle Effect in TLS and ALS

3.1.1 TLS: Figures 3 and 4 present the calibrated backscatter reflectance (measured with the FARO) as a function of incidence angle, compared with the prediction from the cosine law (Eq. 3, where k_l is the reflectance at 0° incidence).

The cosine dependence of reflectance is visually clear for the brightness tarps (Fig. 3), especially towards the bright end of the scale, which is expectable since these targets can be considered approximately Lambertian (cf. Hapke, 1993). For sand and gravel (Fig. 4), more deviation exists in the data, but the greatest discrepancy with the cosine law appears at large angles of incidence (typically >20°). Some outliers (such as the last data point for the play sand sample) are caused by inaccuracy due to the spilling of the gravel at large tilt angles. The cosine law still provides a good approximation of the topographic effect, especially up to about 20° of incidence, where most of the ALS data for land targets (i.e., those on the ground) are collected and recorded for calibration. Larger angles may appear for, e.g., slopes and buildings. More data would, however, be needed to study further the incidence angle behaviour of different surfaces at angles greater than 20°, as well as to evaluate the possible need for more accurate (physical) correction methods, or the feasibility of intensity calibration of those surfaces in the first place. More detailed methods would first require more accurate data to be used in the validation of models. This requires an improvement in the calibration and manufacturer provided information on the performance of the TLS intensity detectors to minimize the deviation in TLS intensity data. For even surfaces such as the

walls or roofs of buildings (resembling the tarp surfaces) the Lambert's law could still provide a good approximation of the incidence angle dependence.
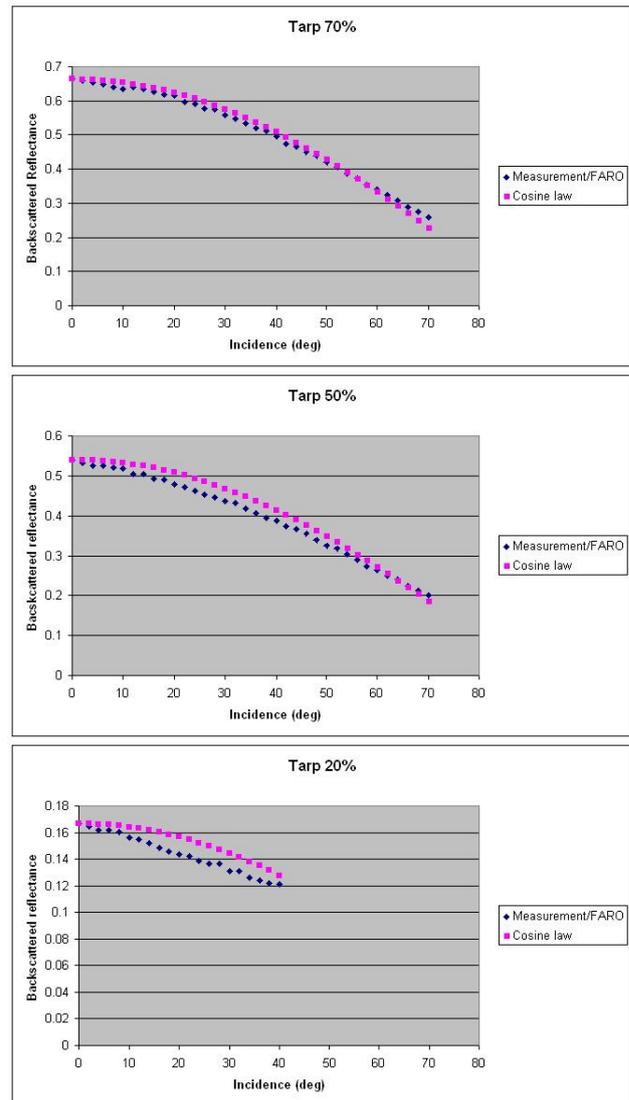

Figure 3. TLS results for brightness tarps of 70% (top), 50% (middle), and 20% (bottom) nominal reflectance.

3.1.2 ALS: Fig. 5 presents the ALS intensity for an asphalt road surface, compared to the (theoretical) prediction from the cosine law (similarly to the TLS results). The data points represent an average of all points with the same scan angle, corrected using Eq. 1. This figure also illustrates the large ranges of deviation (large errors) in current ALS intensity data (cf. Kaasalainen et al., 2009a).

To visualize the effect of the cosine correction on the intensity values in overall scale, we plotted the average difference (in percentages) between the raw and cosine corrected data points in Fig. 6. Compared to the error range in the data points in Fig. 5, the difference is still quite small. This means that the accuracy of the cosine law is sufficient to predict the reflectance with increasing incidence angle at this level of accuracy. As the radiometric calibration applications and hence the availability of calibrated data in ALS increase, there will be more opportunities to evaluate the correction effects.
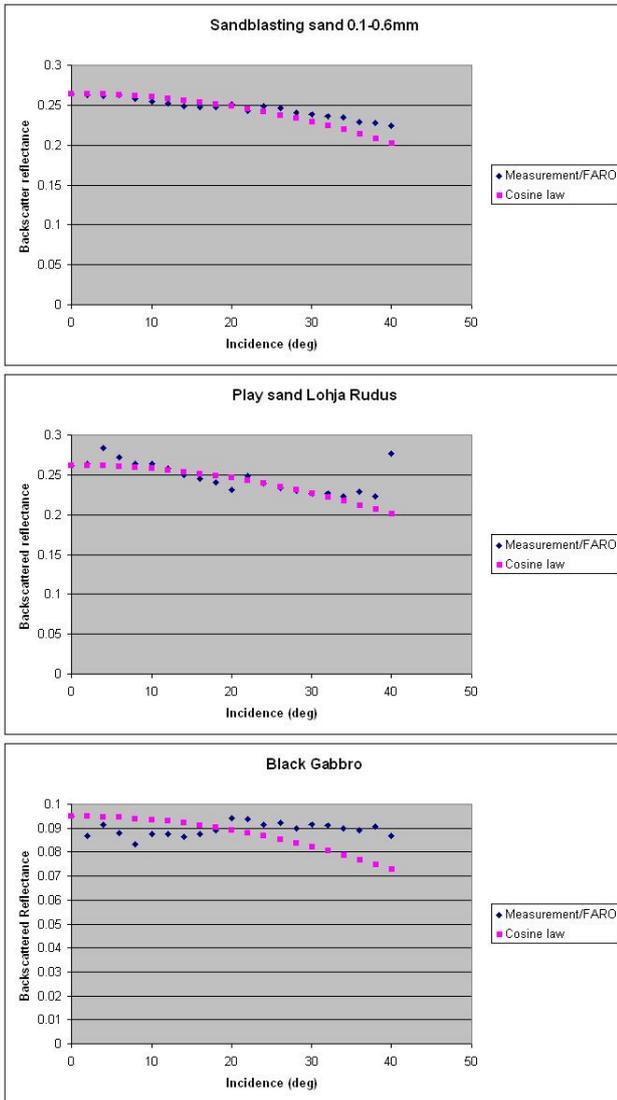
Figure 4. TLS results for sand and gravel targets: sandblasting sand with 0.1-0.6mm grain size (top), play sand (Lohja Rudus Ltd.) (middle), and black gabbro gravel (bottom).
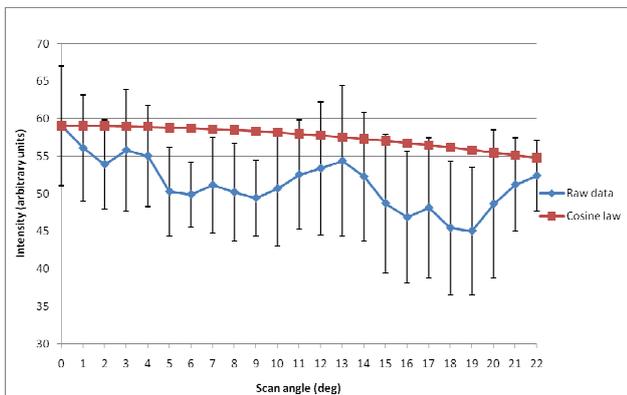

Figure 5. ALS results for asphalt road in the Espoonlahti harbour. The blue line is the raw data at 500m altitude, each point is an average of several points having the same incidence angle. The error bars represent the standard deviations of the average.
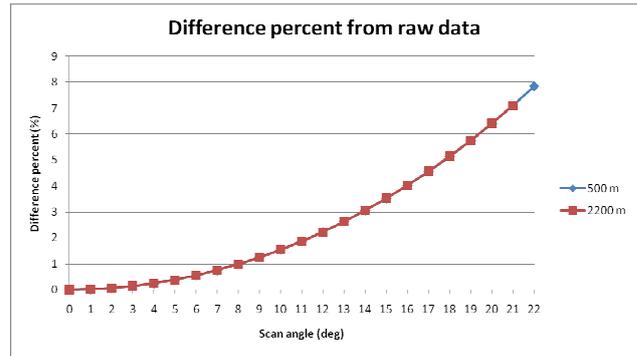

Figure 6. Effect of the cosine correction on intensity values (difference between raw and cosine corrected data).

3.2 Distance effect

The distance effect was studied from TLS data (FARO). The backscattered reflectance of the 12%, 25%, and 50% Spectralon panels, calibrated with the 99% panel, are shown in Fig. 7. The effects of the small-reflectance amplifier and the near distance reducer are clearly visible: the reflectances are not constant at distances less than 3m, after which the nominal reflectance values of the three panels are not reproduced. The former is likely to be caused by the brightness reducer, whereas the latter may be due to the 99% panel having been more reduced by the brightness reducer than the other (lower reflectance) panels. It is also obvious that the effects of these two are somewhat mixed. Nevertheless, the data are still useful for classification and change detection purposes, which are important in, e.g., the automatic target recognition procedures in vehicle based laser scanning, where large amounts of data are produced in a single data acquisition or campaign.

A search for more accurate calibration on one hand, and testing the use of other types of TLS (with linear brightness scale) are in progress to solve the nonlinearity problem in the intensity measurement. Since the use of intensity information is however important in many applications, including those using a reducer/amplifier based scanner, it is important to know the accuracy and limitations of the intensity data they produce.
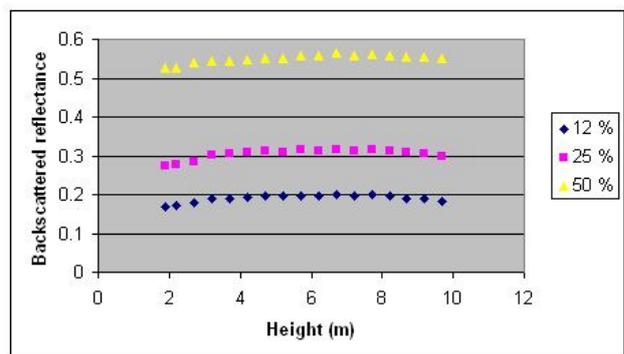

Figure 7. Backscattered reflectances measured with the FARO LS in a scissor lift at different heights. The results are presented for Spectralon targets of 12%, 25%, and 50% reflectance.

4. SUMMARY

At the current levels of accuracy of ALS intensity data, the cosine correction of the incidence angle effect works reasonably well for most surfaces, even in the cases that the surface could

not be approximated to be Lambertian. Together with earlier results (Kukko et al., 2008), it can be concluded that for most targets the incidence angle effect is practically within the error limits of the data at incidence angles up to about 20°. The computational cosine effect is about 6% in this range, which is well in the error limits of the intensity data produced by current ALS instruments (this is clearly seen in Fig. 5 and Kaasalainen et al., 2009a). It must also be taken into account that some surfaces may present a specular reflection at 0° (normal incidence), which may cause a peak in the intensity at this angle. More data with better accuracy than that provided by the current airborne scanners would be needed in cases where the incidence angle is greater than 20°, to be able to distinguish any difference between surfaces for which the Lambertian approximation does or does not work adequately.

The intensity and distance effects in TLS are mixed, at least for some scanners. A further study on distance effects in TLS is in progress, with a comparison with data from other instruments (Kaasalainen et al., 2009b). This is particularly important in the applications where TLS are used in mobile (vehicle based) mapping systems and other (stationary) applications, where the distance of the target varies in a large scale. It is important that the detector effects are well known (to provide a correction scheme) before using any terrestrial laser scanner in intensity measurement.

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