RADIOMETRIC CALIBRATION OF AIRBORNE LIDAR INTENSITY DATA FOR LAND COVER CLASSIFICATION

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Commission I, WG I/2

KEY WORDS: Radiometric Calibration, Airborne LiDAR Intensity, Land Cover Classification, Radar Equation

ABSTRACT:
The rapid development of the airborne LiDAR systems paves the way for the use of the LiDAR technology in different bathymetric and topographic applications. LiDAR has been used effectively for digital terrain/surface modelling by measuring the range from the sensor to the earth surface. Information can be extracted on the geometry of the scanned features (e.g. buildings, roads) or surfaces elevation from the 3D point cloud. Yet, few studies explored the use of the LiDAR intensity data with the ranging data for land cover classification. LiDAR intensity is recorded as the amount of energy backscattered from objects. Generally, it requires certain radiometric calibration scheme to calibrate and correct the reflected intensity data of the land cover features to its physical spectral reflectance. Approximate approaches are proposed for the radiometric calibration of the LiDAR intensity including noise filtering, empirical modelling and cross-sensor calibration. Nevertheless, none of them demonstrates a viable solution for fast and accurate calibration. In this regard, some researches proposed to model the radar equation for radiometric calibration of the LiDAR intensity data. This study demonstrates how to radiometrically correct the LiDAR intensity data based on the range, the incidence angle of the laser beam, the laser footprint, the slope of the target, the ground object reflectance, and the atmospheric attenuation. The long term goal of the research is to devise a fast and accurate radiometric calibration scheme for the airborne LiDAR intensity data (both multi-echo and full-waveform) in order to maximize the use of the intensity data in large scale national land cover mapping. The objective of the calibration is to enhance the class separability amongst different land cover types before classifying the LiDAR data intensity. The range and incidence angle can be retrieved from the raw data of laser point cloud. The footprint area and the slope of the target are dependent on the topography of the study area. Homogeneous ground objects are identified in the study area in order to link them with the corresponding spectrum reflectance from the U.S. Geological Survey digital spectral library. The atmospheric attenuation can be derived by a sophisticated meteorological model obtained from Government weather station. All the parameters of the radar equation are applied to correct and calibrate the received energy for each laser pulse. After the radiometric calibration, a set of feature vectors (including the elevation data) is constructed derived from airborne LiDAR data. Both pixel-based and object-based classifiers can be applied on the calibrated data for land cover classification.

1. INTRODUCTION

Airborne Light Detection and Ranging (LiDAR) is a laser profiling and scanning system for bathymetric and topographic applications emerged commercially in the mid-1990s where NASA played a large part in pioneering and developing the requisite technology through its activities in Arctic topographic mapping from the 1960s onwards. The initial laser instrument in 1960s used gas laser and semiconductor laser for distance (range) measurements between the airborne platform and the ground surface. The limitation of the technique is that a single line of measurement can only be acquired during the flight. By early 1990s, the laser instruments and the global positioning system were developed rapidly which contributed to the generation of the existing multiple echo (multi-echo) airborne LiDAR instrument. This multi-echo system is able to record more than one echo for each emitted laser pulse, typically first and last returns. This allows collecting bulky and explicit 3D data which describes the topography of the earth surface.

Recently, the growth in the LiDAR market has been confirmed and justified by a 2009 survey, which indicated that between 2005 and 2008, there is an increase of 75% in the number of LiDAR systems in use, 53% in LiDAR operators, and 100% in the number of end users (Cary and Associates, 2009). According to the same survey, this growth trend is expected to continue in the next several years. Despite this positive outlook, the respondents to the survey indicated that there are some barriers that could hinder the expected growth. Two of the top three barriers are the quality of data and the shortage of experienced analysts. More specifically, the bulky and explicit 3D data obtained from the airborne laser scanning makes complexity in data processing and extracting useful information. The lack of intelligent processing algorithm also limits further exploration and applications.

Previously, applications and intelligent algorithms on airborne LiDAR focuses on the generation of digital elevation/surface model (Lohr, 1998), topographic mapping (Vosselman et al., 2004), building/road features recognition (Zhang et al., 2006), and 3D building reconstruction (Brenner, 2005). All the mentioned works mainly rely on the analysis of the geometrical components of the 3D point cloud (*x,y,z*). Few of the previous work explores the use of intensity data (*x,y,z,I*), which is based on the observation of the backscattered energy from the illuminated objects on the earth surface. The limited use of the intensity data can be explained by the existence of speckle noise due to the atmospheric and background backscattering as well as the relative position between the aircraft and the ground object. Low classification accuracy using LiDAR intensity data

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is always found when comparing the result to the results achieved by using near-infrared red band in optical remote sensing.

Despite the existence of the noise, it is still believed in the potential of the use of the airborne LiDAR intensity data for surface classification. The supported augments of using LiDAR 3D point cloud and intensity data for classification are: 1) the LiDAR data are in very high spatial resolution in three-dimensional space comparing to optical remote sensing images which are commonly provided in two-dimensional; 2) the LiDAR intensity data would not be affected by relief displacement and shadowing effect which are two of the problems faced in high resolution optical remote sensing image (e.g. GeoEye, IKONOS, QuickBird, and Worldview) classification; 3) high separability of surface reflectance is found in the spectrum range where commercial airborne LiDAR is operated under the infrared and short-wavelength infrared spectrum (1064 nm or 1550 nm) (Fig. 1).

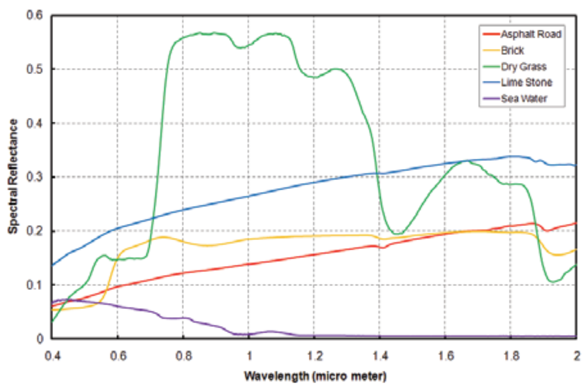

Figure 1. Spectral reflectance of different land cover features

Another argument is the bulky and explicit LiDAR data. Recently, the new airborne LiDAR technique is to record the complete waveform of the returned laser pulse signal instead of the discrete pulse return used previously (e.g. first and last return only). This technique was proposed in 1980s for bathymetric purposes and it entered the experimental stage before late 1990s (Mallet and Bretar, 2009). Although this new technique captures the whole return laser pulse in terms of the waveform signal which leads to the increase in data storage, it gives more control to the end user in the interpretation process. Advanced user can extract more information on full-waveform LiDAR data than multi-echo LiDAR data with the aid of the shape of the waveform, the range differences of peaks, the pulse width, and the amplitude. Full-waveform LiDAR thus provides additional information about the structure and the properties of the returned laser pulse of the illuminated surface. It is believed that such new format of data can enhance the capability of feature recognition and surface classification. With the demands on the airborne LiDAR mapping applications and the emerge of full-waveform technology, this study investigates the use of airborne LiDAR intensity data to determine the land cover classes by analyzing the returned laser pulses from different surface/material with appropriate radiometric calibration techniques.

2. RELATED WORK

2.1 Land Cover Classification

A number of recent researches proposed land cover classification using airborne LiDAR data. Previous classification techniques are mainly based on the geometry and elevation of the point cloud. Supervised parametric pixel-based classifiers are introduced on a set of feature vectors such as height, luminance, difference of multiple returns, intensity, etc (Charaniya et al., 2004; Bartels and Wei, 2006). Data fusion with other airborne or spaceborne remote sensing data are also suggested; for instance, fusion of LiDAR data with: CASI data for classification of floodplain vegetation (Geerling et al., 2007), multispectral images for classification of rangeland vegetation (Bork and Su, 2007), hyperspectral images for classification of complex forests (Dalponte et al., 2008), Quickbird data for mapping surface fuel models (Mutlua et al., 2008) or urban areas (Chen et al., 2009). The benefit from LiDAR data fusion with optical data is because airborne LiDAR data is not a multi-spectral data such as the optical remote sensing images, which provide high separability of spectral reflectance for different land cover features. Thus, classification using airborne LiDAR data mainly relies on its elevation-derived information in the role of sensor fusion in the previous experiments. To further explore the use of airborne LiDAR data in land cover classification, introduction of intensity data or even the entire full-waveform backscattered signal becomes a viable approach to improve the classification result.

Recently, a number of researches explored the use of airborne LiDAR intensity data for land cover classification. Using multi-echo LiDAR data, only the peak amplitudes are recorded in the laser backscattering beam return. Then, the intensity of the return pulse is utilized to determine the radiometric properties of the land cover classes. Song et al. (2002) converted the point cloud into grid data using interpolation method and then applied image filters to remove noise within the intensity image. The separabilities amongst four land cover classes (grass, house, road and tree) are assessed and low separability is found in between grass and tree. To enhance the performance, similar studies are conducted by incorporating ancillary data to classify intensity data. Beasy et al. (2005) classified nearshore materials at ocean bench using intensity data, luminance (average DN values of ortho-rectified aerial image) and texture data; fairly high separability was found in the experiment. Goodale et al. (2007) utilized intensity, and elevation derived data to classify coastal estuaries and beach habitat. It is found that LiDAR intensity data is useful in distinguishing coastal features. It is also found that elevation data is capable in separating certain classes such as mudflats from dune areas; however, texture data is not useful for flat coastal area without including roughness land surfaces like tall trees and shrubs.

Yoon et al. (2008) attempted to classify the intensity data from the singular returns of LiDAR signal of Optech ALTM 3070 equipment (nd:YAG 1064nm laser). The study compared the LiDAR intensity signal with the reflectance measured from field spectroradiometer (GER 2600). The findings show that there is no significant separability amongst land cover classes including vegetation and man-made structures. Comparing to the field spectroradiometer measurement, vegetation cover does not show higher reflectance than other land cover classes in the LiDAR intensity. Also, artificial structures like asphalt, unpaved roads, and concrete have similar reflectance pattern with low intensity. Conclusion is drawn that correction of intensity data should be applied with respect to the range information for each of the recorded laser pulse.

Referring to the previous attempts of classifying airborne LiDAR intensity data, all the previous methods are following statistical approaches to classify the intensity data without knowing the exact radiometric properties of the land cover classes and the physical properties of the laser intensity. Furthermore, complex design of object-based classifier is used to achieve high level accuracy (Brennan and Webster et al., 2006; Antonarakis et al., 2008; Chen et al., 2009). Data fusion approaches is also used; however, it requires similar date/season airborne/spaceborne data which will increase the cost of classification. Although some of the previous experiments achieve high classification accuracy; most of them include elevation-derived feature vector in the classification whereas the variable importance of the intensity as a feature vector in classification is low (Chehata et al, 2009). Moreover, most of the experiments demonstrated with high classification accuracy are only worked with distinguishable land cover classes. To improve the classification accuracy and enhance the ability to classify details land cover types, knowing the physical property of the land covers classes and the radiometric calibration of LiDAR intensity data is necessary (Bretar et al, 2008).

2.2 Radiometric Calibration

Radiometric correction of optical remote sensing images (particularly satellite images) is required for analyzing multi-temporal data or retrieving vegetation parameters using either absolute or relative calibration approach (Jensen, 2005). Due to the atmospheric refraction, scattering and absorption, the energy received from the earth surface includes certain level of noise. In this regard, radiometric correction can be used to calibrate the satellite sensor data based on the atmospheric condition, topography, acquisition time and ground topography (Paolini et al., 2006). Although the airborne LiDAR intensity data has been proven as a useful information for feature recognition and surface classification in a number of studies (Beasy et al., 2005; Brennan and Webster, 2006; Hopkinson et al., 2006; Hopkinson and Chasmer, 2007; Goodale et al., 2007; Antonarakis et al., 2008; Yoon et al., 2008; Wang and Glenn, 2009), none of the work can demonstrate the use of intensity data as a single band of digital image with near-infrared red spectrum. Some attempts have been conducted to radiometrically calibrate the airborne LiDAR intensity data so that it can be used as a reliable source to improve the feature recognition and extraction.

Lai et al. (2005) investigated mean filtering algorithm to fuse the LiDAR intensity range data to remove the signal noise (Gaussian noise, impulse noise and speckle noise). The results show that the proposed filtering algorithm improves merely the quality of the data. Boyd and Hill (2007) attempted to validate the LiDAR intensity data with HyMap (airborne hyperspectral remote sensing) sensor data band 42, which operates close to the wavelength of the LiDAR sensor. It was found that reflectance of band 42 provides similarity to the backscatter of the laser scanning. However, certain calibration for individual flight line is still desired to make the intensity data useful.

Some attempts are conducted to acquire homogeneous land cover features for radiometric calibration of the LiDAR intensity data using in situ field measurements (Kaasalainen et al., 2005; Yoon et al., 2008; Kaasalainen et al., 2009a), laboratory calibration (Kukko et al., 2008; Kaasalainen et al., 2008), commercial brightness reference targets (Kaasalainen et al., 2009a), and field available reference targets (Vain et al., 2009). The objective of the work is to investigate the effects of sensor operation parameters (e.g. range, incidence angle), the backscattering properties, and the relationship between recorded intensity data from the field and the laboratory / in situ measurement with the known reference targets.

In the findings of Kaasalainen et al. (2005), reference targets with higher nominal reflectance have higher recorded intensity values from both laser scanner with 633 and 1064 nm. The intensity is recorded with peak amplitude in phase angle 0° and it decreases smoothly in an exponential curve to 5° before it comes to steady. Decrease of the backscattered intensity is also found when the wavelength increases. Kukko et al. (2008) investigated the effects of incidence angle on the intensity with different reflective targets in the laboratory. The effect is obvious on the laser backscattered energy for high reflectance targets (e.g. > 50% Spectralon reflectance targets) but there is no difference for low reflectance targets even up to 30° of incidence angle. Finally, a strong relationship is found in the intensity data measured between the calibrated laboratory and airborne LiDAR measurement on the reference targets with only 4% difference (Kaasalainen et al., 2008).

To prepare reference targets for radiometric calibration, different sand and gravel samples and brightness tarps made of PVC were used as reference targets for the airborne LiDAR survey. The reflectance of the targets was measured by Spectralon using 785-nm terrestrial laser scanner (TLS) and 1064-nm Nd:YAG laser instrument and CCD camera in the laboratory. The significant findings in the study are: 1) variation of intensity data is found for targets like redbrick with rough surface (Kukko et al. 2008); 2) the effect of moisture on the targets becomes an issue in outdoor environment (may vary 30 to 50% of the reflectance measurement in Kaasalainen et al. (2009a); 3) the derivation of reference targets between the field and laboratory measurement should be minimized, e.g. measurement geometry, selection of gravel samples, the uniformity of the color and surface roughness of the samples, etc. After considering all these factors, the results between the field and laboratory measurements were found more consistent owing to the consideration of the above factors in the second round of the experimental testing.

Concerning the effects of distance between the laser scanner and the targets, Kaasalainen et al. (2009b) measured the intensity recorded by FARO and Leica TLSs with different distance towards the known reference targets. Reduction of backscattered intensity is found when the measurement distance increases. Yoon et al. (2008) conducted similar field spectrum reflectance measurement in field, range effect is obvious only in road features (concrete, unpaved and asphalt roads) whereas vegetation cover got high standard deviation of intensity. This can be explained by the effects of observation geometry and the surface properties (e.g. roughness, moisture) are much obvious towards materials with higher reflectance in near-infrared red spectrum (1064 nm).

All the above experimental testing focus on the LiDAR sensor parameters, other factors including the atmospheric attenuation, the topography of the survey area, and the spectral reflectance of different land cover features should also be considered. Therefore, the physical properties of the backscattered laser energy should be understood and modelled.

3. MODELLING THE RADIOMETRIC PROPERTIES OF AIRBORNE LIDAR DATA

The physical properties of the laser energy are considered with respect to the sensor configuration and the environment parameters using the radar (range) equation. It is proposed to model the received signal power for airborne laser scanning data (Baltsavias, 1999). The radar equation models the received signal power, regarded as the LiDAR intensity, by the below equation:-

$$P_r = \frac{P_t D_r^2}{4\pi R^4 \beta_t^2} \eta_{sys} \eta_{atm} \sigma \quad (1)$$

where the received signal power P_r is a function of the transmitted signal power P_t, the receiver aperture diameter D_r, the range from the sensor to the target R, the laser beam width β_t, a system factor η_{sys} and atmospheric transmission factor η_{atm}. The target (backscattering) cross-section σ consists of all target characteristics, is defined as:-

$$\sigma = \frac{4\pi}{\Omega} \rho\, A_s \quad (2)$$

where Ω is the scattering solid angle, A_s is the target area and ρ is the target reflectance. The receiver aperture diameter D_r is regarded as constant factor during the flight survey. The range data R of each laser pulse is the distance between the instantaneous location of the sensor and the ground. This factor should be considered as lower reflectance value will be recorded if the distance in between is longer (Yoon et al., 2008 and Kaasalainen et al., 2009b). The incidence angle is derived as the angle between the surface normal and the direction of the laser pulse. The transmitted laser energy P_t, though is usually unknown, can be assumed as constant or can be related to the pulse repetition frequency (PRF) (Vain et al., 2009). The atmospheric attenuation η_{atm} depends on the temperature, pressure and humidity during the flight survey.

Although previous researches use the radar equation for radiometric calibration (Coren and Sterzai, 2005; Höfle and Pfeifer, 2007; Vain et al., 2009; Kaasalainen et al., 2009), some of the factors such as the transmitted signal power P_t, the system factor η_{sys} and the atmospheric transmission factor η_{atm} are either neglected or assumed to be constant factors. In addition, most of the experimental works are performed in flat area instead of rugged terrain where the target (backscattering) cross-section σ is assumed to be in proportion to the scan angle. Therefore, there are some factors that should be considered in developing a physical model for radiometric calibration of the LiDAR data.

Calibration of the intensity data of each laser shots by considering the range, the scan angle, and the topography of the illuminated objects can be applied to the raw airborne LiDAR data. The atmospheric parameters and the surface moisture of the objects have not been considered in the previous research; therefore, it will be deeply investigated in the radiometric calibration. Atmospheric factors include the relative humidity, pressure, and temperature during the flight. To deal with the atmospheric effect, the radiative transfer model, which is commonly used in satellite remote sensing, will be considered. Computational meteorological software such as MODTRAN can be utilized to calculate the atmospheric adjustment parameters for each laser shot, and make it as an input in the radar equation. Other equipment factors such as the laser transmission energy, the system parameters, and the area of the aperture receiver will be discussed with the system manufactures.

The final factor to be discussed in the radar equation is the target reflectance ρ of the illuminated objects. For the experimental LiDAR data which are already acquired, field measurement using spectroradiometer cannot be achieved. Therefore, existing digital spectrum library from the USGS (Clark et al., 2007) or the NASA JPL is acquired in order to obtain the surface reflectance of different land cover features.

After providing all the parameters of the radar equations in some selected homogeneous targets, the relationship between the calculated LiDAR intensity data and the recorded LiDAR intensity data can be retrieved. Then, each of the laser intensity data should be calibrated and corrected based on this relationship. Then the LiDAR point cloud and the intensity data can be interpolated into digital elevation model and digital intensity image (Bater and Coops, 2009). Selection of interpolation technique to integrate multiple flight data may also affect the usefulness of the derived product (Boyd and Hill, 2007). Feature spaces can be constructed from these LiDAR-derived data for land cover classification. Pixel-based or object-based classifiers can be applied on the feature spaces for classification after the selection of training data. It is expected that the speckle noise of the intensity data can be reduced after the radiometric calibration. Thus, the effects of between-class confusion and within-class variation can then be minimized for the land cover classification problem. As a result, the benefit of using airborne LiDAR intensity for object segmentation and classification can be maximized and the classification accuracy of it can be significantly improved.

4. DISCUSSION

A growing body of researches recently focus on the use of airborne LiDAR intensity data for the land cover classification. Nevertheless, most of the studies classified homogenous land cover classes and incorporated ancillary sensor data to improve the classification accuracy. To maximize the benefit from using the airborne LiDAR intensity data, certain radiometric calibration scheme is desired to calibrate the intensity of the land cover features into its physical spectral reflectance. In this paper, the use of the radar (range) equation to model the physical properties of the laser energy is reviewed. Moreover, the research areas that have not been studied previously are discussed. Factors including range, incidence angle, footprint area, slope of the target, ground object reflectance, atmospheric and system parameters should be considered for each of the laser pulse for the radiometric modelling. Future study will conduct experimental testing on different topography and weather condition for radiometric calibration. In addition, land cover classification will be applied on both calibrated and original intensity data in order to compare the differences of classification accuracy. The long term goal of the study is to propose and demonstrate the use of the radiometric calibration for both multi-echo and full-waveform LiDAR data in order to maximize the benefit in using airborne LiDAR intensity data for object segmentation and classification.

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ACKNOWLEDGEMENTS

This research work is supported by the Discovery Grant from the Natural Sciences and Engineering Research Council of Canada (NSERC) and the GEOIDE Canadian Network of Excellence, Strategic Investment Initiative (SII) project SII P-IV # 72.