ISPRS Journal of Photogrammetry and Remote Sensing 128 (2017) 298–313

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Object-based analysis of multispectral airborne laser scanner data for land cover classification and map updating

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ARTICLE INFO

Article history:
Received 21 November 2016
Received in revised form 7 April 2017
Accepted 10 April 2017
Available online 21 April 2017

Keywords:
Laser scanning
Lidar
Multispectral
Land cover
Updating
Change detection

ABSTRACT

During the last 20 years, airborne laser scanning (ALS), often combined with passive multispectral information from aerial images, has shown its high feasibility for automated mapping processes. The main benefits have been achieved in the mapping of elevated objects such as buildings and trees. Recently, the first multispectral airborne laser scanners have been launched, and active multispectral information is for the first time available for 3D ALS point clouds from a single sensor. This article discusses the potential of this new technology in map updating, especially in automated object-based land cover classification and change detection in a suburban area. For our study, Optech Titan multispectral ALS data over a suburban area in Finland were acquired. Results from an object-based random forests analysis suggest that the multispectral ALS data are very useful for land cover classification, considering both elevated classes and ground-level classes. The overall accuracy of the land cover classification results with six classes was 96% compared with validation points. The classes under study included building, tree, asphalt, gravel, rocky area and low vegetation. Compared to classification of single-channel data, the main improvements were achieved for ground-level classes. According to feature importance analyses, multispectral intensity features based on several channels were more useful than those based on one channel. Automatic change detection for buildings and roads was also demonstrated by utilising the new multispectral ALS data in combination with old map vectors. In change detection of buildings, an old digital surface model (DSM) based on single-channel ALS data was also used. Overall, our analyses suggest that the new data have high potential for further increasing the automation level in mapping. Unlike passive aerial imaging commonly used in mapping, the multispectral ALS technology is independent of external illumination conditions, and there are no shadows on intensity images produced from the data. These are significant advantages in developing automated classification and change detection procedures.

1. Introduction

1.1. Background on multispectral laser scanning applications

Airborne laser scanning (ALS) has shown its high feasibility for automated mapping processes. During the last 20 years, the accurate 3D data, often combined with spectral information from digital aerial images, have allowed the development of methods for automated object extraction and change detection. In particular, important advancements have been achieved in the mapping of elevated objects such as buildings and trees (see, for example, Hug, 1997; Rottensteiner et al., 2007; Brenner, 2010; Guo et al., 2011). Some researchers have concentrated on roads (e.g., Hu et al., 2004; Clode et al., 2007), and numerous studies related to more general land cover mapping have also been carried out (Yan et al., 2015).

The role of laser intensity has been relatively small in the development. Intensity information, increasingly also from full-waveform data, has been used in many classification studies (e.g., Hug, 1997; Guo et al., 2011), but generally the geometric information of the laser scanner data has been more important. In 2008, EuroSDR (European Spatial Data Research) initiated a project 'Radiometric Calibration of ALS Intensity' led by the Finnish Geospatial Research Institute FGI and TU Wien in order to increase the awareness of intensity calibration. It was expected that someday multispectral ALS would be available and then the intensity of

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http://dx.doi.org/10.1016/j.isprsjprs.2017.04.005
0924-2716/

ALS will be of high value. Thus, earlier intensity studies (e.g., Luzum et al., 2004; Kaasalainen et al., 2005; Ahokas et al., 2006; Wagner et al., 2006; Höfle and Pfeifer, 2007; Wagner, 2010) showing the concepts for radiometric calibration of ALS intensity have been preparations for multispectral ALS.

Laser scanning systems providing geometric and multispectral information simultaneously provide interesting possibilities for further development of automated object detection and change detection methods. Experiences on this field have been obtained, for example, from studies with a hyperspectral laser scanner developed at the FGI (Chen et al., 2010; Hakala et al., 2012). The system is a terrestrial one and has been successfully applied for vegetation analyses and separation of man-made targets from natural ones (e.g., Puttonen et al., 2015). Multiple wavelengths also allow detection of detailed spatiotemporal changes in vegetation (e.g., Hakala et al., 2015; Puttonen et al., 2016).

Pfennigbauer and Ullrich (2011) discussed the development and potential of multi-wavelength ALS systems. Briese et al. (2013) realised such an approach by using three separate ALS systems. The study concentrated on radiometric calibration of intensity data from an archaeological study area. Wang et al. (2014) used two separate ALS systems to acquire dual-wavelength data for classifying land cover. They found that the use of dual-wavelength data can substantially improve classification accuracy compared to single-wavelength data. More extensive discussions and reference lists on these earlier developments of multispectral laser scanning can be found, for example, in Vauhkonen et al. (2013), Puttonen et al. (2015), Wichmann et al. (2015) and Eitel et al. (2016).

The first operational multispectral ALS system was launched by Teledyne Optech (Ontario, Canada) in late 2014 with the product name Titan. With this scanner, active multispectral information is for the first time available for 3D ALS point clouds from a single sensor. The channels of the sensor are: infrared 1550 nm (channel 1, Ch1), near-infrared 1064 nm (Ch2) and green 532 nm (Ch3). Each of the channels produces a separate point cloud. The look directions of the channels are: Ch1: 3.5° forward, Ch2: nadir, Ch3: 7° forward. Due to the separate point clouds, multispectral intensity values are not originally available for single points. Some preprocessing is thus needed before the multispectral information can be utilised.

The first studies based on Optech Titan data have been published, most of them in conference proceedings and based on Optech sample data acquired from Ontario in 2014. Wichmann et al. (2015) evaluated the potential of Titan sample data for topographic mapping and land cover classification. They analysed spectral patterns of land cover classes and carried out a classification test. The analysis was point-based and used a single point cloud that was obtained by merging three separate point clouds from the three channels by a nearest neighbour approach. Wichmann et al. (2015) concluded that the data are suitable for conventional geometrical classification and that additional classes such as sealed and unsealed ground can be separated with high classification accuracies using the intensity information. They also discussed multi-return and drop-out effects, drop-outs referring to cases where returns are not obtained in all channels. For example, the spectral signature of objects such as trees becomes biased due to multi-return effects. Bakuła (2015) created digital surface models (DSMs) and digital terrain models (DTMs) separately from the different channels and analysed them. Differences occurred in vegetated areas and building edges due to various distributions of points. For DTMs, the differences were small. The potential of the data for land cover mapping was also discussed. A further land cover classification experiment was presented in Bakuła et al. (2016). An overall accuracy of about 91% was achieved in classifying six classes: water, sand and gravel, concrete and asphalt, low vegetation, trees, buildings. This classification was raster-based and used spectral data, elevation, and textural data. Morsy et al. (2016) applied three normalized difference feature indices calculated from the Titan channels for land–water and vegetation–built-up separation. Classification experiments with data from the same area were also reported by Miller et al. (2016).

Zou et al. (2016) used Titan data acquired from Ontario in 2015. They applied an object-based classification approach. Segmentation was based on the multispectral intensity data and classification rules were constructed by using four indices based on intensity, return count and elevation information. The overall accuracy achieved in classification with nine classes was about 92%. The classes included water bodies, bare soil, lawn, road, building, low vegetation, medium vegetation, high vegetation and power line. Hopkinson et al. (2016) investigated the characteristics of Titan data and multisensor data acquired with the same wavelengths in a forested test site in Canada. Differences in proportions of returns at ground level, vertical foliage distributions and gap probability were observed across the wavelengths. A multispectral classification test with rasterised intensity data was also carried out. Eight classes were included in the Titan data classification: corn, gravel, hay, asphalt, larch, hardwood, pine/spruce and sand. The highest overall accuracy from training site accuracy statistics was about 88%. The overall accuracies achieved with the multisensor data were lower, although the number of classes in that case was only five. Hopkinson et al. (2016) also found that the overlap in single-channel intensity values between different land cover classes was so high that it prevents accurate classification from one channel data. Fernandez-Diaz et al. (2016) discussed the performance of a Titan system on the basis of test campaigns during two years. Among many other topics, results of a land cover classification test from a university campus area in Houston, Texas, were reported briefly. Intensity images and structural images derived from the elevation data and return counts were used in supervised classification. The resolution of the rasterised data was 2 m, and five classes were included in the study: grass/lawn, road/parking, trees and short vegetation, commercial buildings, and residential buildings. The best overall accuracy was about 90%, and it was obtained when structural images and two intensity channels (Ch2 and Ch3) were used. In most of the Titan studies discussed above, radiometric calibration of intensity data has not been reported. Morsy et al. (2016) mentioned an intensity correction mainly for the range and the scan angle in land–water mapping. Fernandez-Diaz et al. (2016) made an intensity correction by normalising raw intensities by range.

Some other recent studies with multiple wavelength ALS data can also be found. Leigh and Magruder (2016) investigated the use of dual-wavelength, full-waveform data for surface classification. The data were acquired with Leica Chiroptera sensor (Leica Geosystems AG, Switzerland), which has been planned for shallow water and coastal mapping. The sensor has green and near-infrared channels. Leigh and Magruder (2016) used a voxelisation approach to utilise the full-waveform information and to extract features for random forest classification. The best overall accuracy was about 81%, and it was achieved when both wavelengths were used. The classes under study included pavement, cleared paths, grass, scrub (two classes), rock, pine, and cypress.

1.2. Objectives and contribution of our study

Our article discusses the potential of the new single-sensor multispectral ALS technology in land cover classification and map updating. Our main interest is in nationwide mapping and updating of databases in the future. In addition to 3D modelling of objects, an important application area of ALS data has been automated change detection, especially for buildings. Despite promis-