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Waveform-based point cloud classification in land-cover identification

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ABSTRACT

Full-waveform topographic LiDAR data provide more detailed information about objects along the path of a laser pulse than discrete-return (echo) topographic LiDAR data. Full-waveform topographic LiDAR data consist of a succession of cross-section profiles of landscapes and each waveform can be decomposed into a sum of echoes. The echo number reveals critical information in classifying land cover types. Most land covers contain one echo, whereas topographic LiDAR data in trees and roof edges contained multi-echo waveform features. To identify land-cover types, waveform-based classifier was integrated single-echo and multi-echo classifiers for point cloud classification.

The experimental area was the Namasha district of Southern Taiwan, and the land-cover objects were categorized as roads, trees (canopy), grass (grass and crop), bare (bare ground), and buildings (buildings and roof edges). Waveform features were analyzed with respect to the single- and multi-echo laser-path samples, and the critical waveform features were selected according to the Bhattacharyya distance. Next, waveform-based classifiers were performed using support vector machine (SVM) with the local, spatial features of waveform topographic LiDAR information, and optical image information. Results showed that by using fused waveform and optical information, the waveform-based classifiers achieved the highest overall accuracy in identifying land-cover point clouds among the models, especially when compared to an echo-based classifier.

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Introduction

Airborne laser scanning (ALS) data (also called topographic LiDAR data for *Light Detection and Ranging* data) are being used increasingly to classify land use and land cover (Wagner et al., 2008; Alexander et al., 2010; Heinzel and Koch, 2011; Crosilla et al., 2013; Dalponte et al., 2008). ALS systems apply two distinct techniques in which the return signal that is recorded is either full-waveform or discrete-return (also called multiple-return) (Alexander et al., 2010). Traditional discrete-return systems provide individual return with only discrete time measurements (Mallet et al., 2011). Full-waveform LiDAR data, which furnish more object information in the path of the laser pulse than discrete-return LiDAR data, consist of a succession of cross-section profiles of the landscape. Based on the waveform-based data, we can easily identify vertical profile of 3D object in the laser-pulse path when compared to only using echo-based (discrete-return) data.

The waveform pattern is affected by the surface reflectance, geometric structure, and roughness of the laser footprint. Amplitude, echo width, cross section, and the number of echoes (returns) are valuable parts of the information obtained from full-waveform data, which have been used successfully to classify land use and land cover (Alexander et al., 2010). For example, whereas echo amplitudes vary with the radiometric and geometric properties of targets, echo widths describe the durations of the received signal and can be applied easily in classification. Because the echoes for fields of trees are generally wider than those for roads or meadows (Wagner et al., 2008), echo width provides critical information for identifying vegetation types and detecting roads (Mallet et al., 2011; Hollaus et al., 2011). From the distance between the sensor and the target and from the amplitude and the width of an echo, the backscatter cross section can be derived, which is suitable for describing the scattering properties of targets (Alexander et al., 2010). Alexander et al. (2010) used major features such as the cross section in the classifier to distinguish between grass and roads successfully. Moreover, Crosilla et al. (2013) analyzed the skewness

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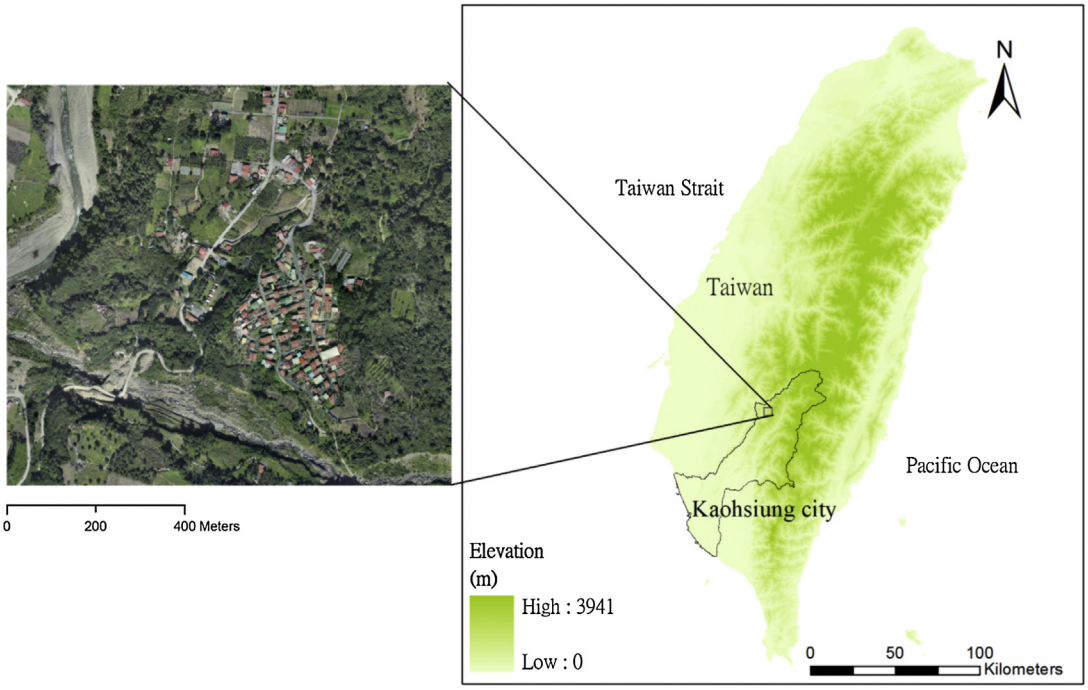

Fig. 1. Location of study area in Kaohsiung city of Taiwan.

and kurtosis of elevation and intensity-distribution values from LiDAR data for classification.

The extracted full-waveform features can be used for classifying land cover, especially for distinguishing vegetation from other land cover types. The first echo is often acquired from the vegetation and other surface features that can be penetrated, such as the crown and trunk of trees. The last echo is a return message indicating that the last laser pulse signal is attenuating to the end, which may contain ground information or non-ground points such as dense vegetation. Jutzi and Stilla (2003) showed that vegetation and roof edges contain features that generate multiple echoes, and thus echo numbers provide key information for classifying land cover. Therefore, LiDAR waveform information on land-cover types contains single-echo (number of echoes = 1) and multi-echo (number of echoes > 1) waveform features. To consider land cover with single-echo and multi-echo waveform features along the path of a laser pulse, waveform-based classifiers were applied that included both single-echo and multi-echo features in our current study.

LiDAR features also exhibit spatial autocorrelation, which indicates that the features in a sampling point are similar to those in a neighboring sampling point. The spatial (neighborhood) information on the features of each waveform is determined using the local waveform sets included in the cylindrical neighborhood centered on that waveform (Guo et al., 2011). In the study, the average or standard deviation of the waveform characteristics was selected in the neighborhood of each waveform as the spatial features in the classifier. Furthermore, LiDAR and optical image data are generally complementary (Guo et al., 2011; Mutlu et al., 2008). Multi-source data composed of full-waveform LiDAR data and orthoimages were used for point cloud classification. The orthoimage is composed of three spectral bands in the visible domain: Red (R), Green (G), and Blue (B). The RGB channels of an orthoimage are used as three independent optical features at the nearest locations of first-echo LiDAR points in this study.

Since waveform data can be divided into two categories, one contains single major echo such as the return waveforms from open ground. The other contains multiple echoes such as the return waveforms for trees and roof edges. Waveform features were analyzed with respect to the single- and multi-echo laser-path samples to investigate whether full-waveform data can provide effective information on land-cover classifications. In this study, waveform-based classifiers were performed using support vector machine (SVM) with the waveform LiDAR features, optical image information and the spatial features of LiDAR data. Finally, the classification accuracy of the waveform-based model was compared using the conventional echo-based classifier.

Study area and materials

Our study area was Namasha (Namaxia), which is a famous source of precious wood in Taiwan. Namasha is a suburban district in the northeastern part of Kaohsiung City that is located upstream from the Kao-ping river watershed (Fig. 1). Namasha suffered substantial destruction during Typhoon Morakot in 2009. The entire study area was 0.95 km^2, and the average elevation above the sea level and slope were approximately 722 m and 18°. Full-waveform LiDAR data were acquired from three LiDAR systems: Leica ALS60, Riegl LMS-Q680i, and Optech ALTM PEGASUS HD400. Three kinds of LiDAR data were used to prove the robustness of the

Table 1
Description of LiDAR data from Leica, Riegl and Optech systems.

Sensor	Leica ALS60	Riegl LMS-Q680i	Optech ALTM PEGASUS HD400
Wavelength (nm)	1064	1550	1064
Pulse rate (kHz)	55	220	150
Scan rate (Hz)	61	200	35
Field-of-view, FOV (degree)	6	60	40
Observation date	2011/10/30	2012/01/08	2011/10/07
Flight height (m)	2900	1900	2000
Beam divergence (mrad)	0.22	0.5	0.2
Footprint size (m)	0.64	0.95	0.4
Echo width (ns)	5	4	7
Point density (pts/m^2)	4.2	2.1	1.8

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