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Evaluation of simulated bands in airborne optical sensors for tree species identification

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ABSTRACT

Airborne multispectral remote sensing devices have been used in automatic identification of tree species, and the spatial and spectral properties of the sensors affect the remote sensing measurement results. Previous work based on a simulation model with ground-level measured reflectance data of pine (*Pinus sylvestris L.*), spruce (*Picea abies* (*L.*) *H. Karst.*), and birch (*Betula pubescens Ehrh.* and *Betula pendula Roth*) tree species and idealized Leica ADS80 sensitivities suggested that the addition of a fifth sensitivity band in the red edge wavelength region to the existing Leica ADS80 system significantly improves the classification performance. In this paper, we extend this analysis using a simulated model with accurate spectral sensitivity information and airborne AisaEAGLE II hyperspectral data for these three tree species. We simulated multispectral responses using spectral sensitivity characteristics of the Leica ADS40, the Vexcel UltraCam-D, the Intergraph-Z/I Digital mapping camera and the Leica ADS40 system with an added band in the 691–785 nm region. We evaluated the tree species classification performance of these simulated responses using Discriminant Analysis and Support Vector Machine classifiers. The classification experiment result showed that the simulated responses of the 5-band multispectral system yielded the most robust classification performance with approximately 98% accuracy. This result was similar to the accuracy obtained with the hyperspectral data. Although differences were observed in the sensitivity functions of the 4-band systems, there were no large differences observed in the classification performances between them. With the simulated 5-band system, there was an increase of 5–13% points in classification accuracy when compared to the accuracies of the 4-band systems. The results obtained via proposed 5-band system support results from previous studies suggesting that there is a need for a sensitivity band in the red edge wavelength region for applications in tree species classification.

1. Introduction

Remote sensing data acquired via airborne and spaceborne optical sensors (multispectral or hyperspectral) with wavelength range from visible to infrared has been used in forest inventories. Recent advancements in sensor technology have included airborne pulsed LiDAR sensors (emitted laser pulse reflected from the earth surface are sensed) and passive optical sensors. The first sensing modality is efficient in probing the vegetation structure and density (e.g. Latifi, Fassnacht, & Koch, 2012), while passive optical sensor (solar energy reflected from the earth surface are sensed) responses are needed for target classification (e.g. Korpela, Heikkinen, Honkavaara, Rohrbach, & Tokola, 2011). One important application of remotely sensed data is tree species classification and it is crucial for economical, ecological and technical reasons (Korpela, 2004).

In passive optical remote sensing the radiance information from a forest canopies can be linked to a tree species. With the launch of civilian earth observing satellite in 1972 the passive spaceborne multispectral images have been used to study forest classification and mapping (Schowengerdt, 2007). Likewise, the small scale aerial photographs were used in experimental studies in forestry. Since the late 1980s digital image analysis methods have been used for the interpretation of a digitized color infrared (CIR) aerial images for forestry (e.g. stand delineation, tree species classification) (Korpela, 2004). With the advancement of digital airborne photogrammetric multispectral sensors its potential for forest and tree species classification has been studied (Korpela et al., 2011; Waser, Klonus, Ehlers, Küchler, & Jung, 2010). Widely used photogrammetric multispectral sensors include the Vexcel UltraCam-D (Kropfl & Gruber, 2006), the Intergraph-Z/I imaging Digital Mapping Camera (Rayn & Pagnutti, 2009) and the Leica ADS40 (Beisl, 2006). These sensors have been used in single-tree species classification and analysis in (e.g. Heikkinen, Korpela, Tokola, Honkavaara, & Parkkinen, 2011; Holmgren, Persson, & Söderman, 2008; Korpela & Rohrbach, 2010; Korpela et al., 2011; Packalén, Suvanto, & Maltamo, 2009). In these studies,

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80–93% overall classification accuracies were reported in single-tree species classification of Scot pine, Norway spruce and deciduous birch. It has been suggested that the species classification accuracy should reach 90–95% to be adequate for practical use (Korpela & Rohrbach, 2010). The multispectral sensor systems mentioned above are mainly intended for photogrammetric purposes and have only four spectral bands (and a PAN band) for one viewing direction.

The limitations of multispectral devices with respect to a limited number of spectral bands can be addressed using hyperspectral imaging with tens or hundreds of bands. Airborne hyperspectral imaging sensors such as the HyMap (Cocks, Jenssen, Stewart, Wilson, & Shields, 1998), Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) (Green et al., 1998), Compact Airborne Spectrographic Imager (CASI) (Anger, Mah, & Babey, 1994) and the Airborne Imaging Spectrometer for Applications (AISA) (Makisara et al., 1993) have been used in remote sensing and tree species classification study (Bunting & Lucas, 2006; Clark, Roberts, & Clark, 2005; Dalponte, Bruzzone, Vescovo, & Gianelle, 2009).

A hyperspectral sensor can capture informative data using hundreds of spectral bands and the use of these data yield satisfactory classification results (Becker, Lusch, & Qi, 2007; Clark et al., 2005; Dalponte et al., 2009). However, these sensor systems might be impractical or too costly for certain forestry applications. Currently, these sensors capture lower spatial resolution imagery when compared with photogrammetric multispectral sensors (Green, Tukman, & Finkbeiner, 2011; Korpela et al., 2011). Despite this limitation, hyperspectral data are important for constructing and simulating efficient sensor bands for multispectral sensors. Thus, identification of a small number of wavelength regions should increase the possibility to construct a practical sensor system for a given application. Existing photogrammetric multispectral sensors are broadband and widely used in remote sensing, but there are limited studies where (real or simulated) photogrammetric multispectral sensor responses were compared for tree species classification. Using a simulation model Heikkinen, Tokola, Parkkinen, Korpela, and Jääskelainen (2010) simulated the responses for the at-sensor radiance using the ground-level measured hyperspectral reflectance data of three tree species (Jääskelainen et al., 1994) and the idealized Leica ADS80 sensitivities. Heikkinen et al. (2010) suggested that the addition of the fifth sensitivity band red edge to the existing 4-band Leica ADS80 system could increase the classification accuracy significantly (5–15% point). Likewise, in band selection studies for tree classification in tropical rain forests, Costa Rica (Clark et al., 2005), and Southern Alps, Italy (Dalponte, Bruzzone, & Gianelle, 2012; Dalponte et al., 2009) have shown that the red edge region is important.

The objective in this study is to evaluate the effect of spectral bands for classification of three commercially important species (pine, spruce and birch) in Finland. We used a simulation model to simulate spectral responses with accurate sensitivity information from airborne photogrammetric multispectral sensors and remotely sensed airborne hyperspectral AisaEAGLE II (SPECIM, 2012a) data from tree species plots (pure, single-tree species with 2–10 trees). We compared the remotely sensed hyperspectral data from a tree species plot (pine, spruce and birch) with the ground-level measured hyperspectral data that were used in previous simulations in Heikkinen et al. (2010) for the same tree species. Using the AisaEAGLE II data, we simulated and evaluated the performance of spectral sensitivity characteristics of three photogrammetric sensors (the Leica ADS40, the Vexcel UltraCam-D, and the Intergraph-Z/I Digital Mapping Camera) for tree species classification. In addition, we simulated and evaluated 5-band sensor responses based on the sensitivity characteristics of the Leica ADS40 with an additional fifth band in the red edge region. All the evaluations for simulated responses were aimed only to give information about relative performance of spectral sensitivity characteristics and therefore do not represent complete sensor performance. The classification results from the simulated responses were evaluated against the real hyperspectral responses from the AisaEAGLE II.

2. Material

2.1. Remote sensing data

The basis of our research is the AisaEAGLE II (SPECIM, 2012a) hyperspectral data from a flight campaign conducted over the Hyytiälä forest area (Fig. 1a), southern Finland (61.50′ N, 24.20′ E) organized on 22nd July 2011. The study area is described in detail on paper by Korpela, Ørka, Maltamo, Tokola, and Hyyppä (2010). The forest data that were used here consists of Scot pine, Norway spruce and birch (*Betula pubescens Ehrh*. and *Betula pendula Roth*) tree species.

The AisaEAGLE II is an airborne hyperspectral sensor based on the pushbroom principle and manufactured by SPECIM Ltd. The sensor operates in the visible to near-infrared spectral range (400–1000 nm) with a 1024-pixel swath width with 12 μm pixel size. The camera field of view at the time of measurement was 35.8°. The sensor electronics operate using 12 bits and the optimal spectral resolution of the sensor is 3.3 nm. Our measurements were performed using an 8× binning mode, resulting in 64 channels with a Full-Width-at-Half-Maximum (FWHM) of 9.3 nm (at a 100-Hz sampling rate). The details of the measurement conditions are presented in Table 1.

The acquired images were first radiometrically corrected to radiances using the CaliGeo software (SPECIM, 2012b) by SPECIM. These imaged strips were geometrically rectified into the WGS84 UTM zone 35 coordinate system using PARGE (Schläpfer, Schaepman, & Itten, 1998) software from the ReSe company. A one-meter grid-sized digital elevation model (DEM) was used in the geometrical rectification (Korpela et al., 2010). The data were processed to a ground sampling distance (GSD) of 0.5 m, and the expected geometric accuracy is below 2 m. The RGB representation of a hyperspectral imaged strip after image preprocessing is shown in Fig. 1b.

2.2. Field data

During the flight campaign, the Hyytiälä forest area was imaged in nine imaging strips: B1, B2, B3, B4, B5, B6a, B6b, B7 and B8 (Fig. 1a). Details of the strips are presented in Table 1. In the B4 imaged strip, a 50% reflecting white reference plate was placed at the ground. After preprocessing of the imaged strips, the tree species plots (forest area) in the strips were identified by photo interpretation expert, combining visual inspection with additional ground information. The photo interpretation was based on the Vexcel UltraCamXp RGB images acquired on June 28th 2010, at 16.00 local time from a flight altitude of 2.5 km. The identified plots contain only single-tree species. The details of the plot data acquisition process are as follows.

1. A grid (100 m × 100 m) of sample points was created over the Hyytiälä 2010 LiDAR DEM (2160 points in total). Polygons were created to define the DEM extent and the area of hyperspectral imaging.
2. For each grid point, a surrounding neighborhood (100 m × 100 m) was assessed for single-tree species plots of pine, spruce or birch, and a single-tree plot was circled (radius of 10 m). This search was conducted beginning with a 20-cm resolution, with accurately oriented aerial images (Vexcel UltraCamXp images) centered at the grid point, and the images were visually interpreted. If a suitable plot was found, the center of the plot (tree top) was measured (XYZ) photogrammetrically, and the species was recorded. The tree tops were used as centers, since they provided accurate photogrammetric measurement.
3. LiDAR estimates of the stand's dominant height (95th percentile of the height distribution) and stand density (proportion of ground returns, $h < 2$ m) were calculated, using the 2010 and 2011 LiDAR data separately. The mean and maximum heights of the LiDAR points were calculated and compared to exclude the plots in which harvesting operations began after 2010. These plots were searched