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Retrieving forest structure variables based on image texture analysis and IKONOS-2 imagery

F. Kayitakire, C. Hamel, P. Defourny *

Department of Environmental Sciences and Land Use Planning, Université Catholique de Louvain, 2/16 Croix du Sud, B-1348 Louvain-la-Neuve, Belgium

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Abstract

Remote sensing techniques have been seen as valuable and low-cost tools for frequent forest inventory purposes. However, estimation errors of relevant forest structure variables remain too high for operational use of high spatial resolution satellite imagery, such as Landsat TM/ETM and SPOT HRV, in temperate forests. Very high spatial resolution images that have been acquired by new commercial satellites, such as IKONOS-2 or QuickBird, are expected to reduce estimation errors to a level that is acceptable by foresters. This study assessed the capability of 1-m resolution IKONOS-2 imagery to estimate the five main forest variables—age, top height, circumference, stand density and basal area—in even-aged common spruce stands. They were estimated on the basis of texture features that were derived from the grey-level co-occurrence matrix (GLCM). The coefficients of determination, R^2, of the best models ranged from 0.76 to 0.82 for top height, circumference, stand density and age variables. Basal area was found to be weakly correlated to texture variables ($R^2=0.35$). Relative prediction errors of four out of the five studied forest variables were comparable to the usual sampling inventory errors (top height: 10%; circumference: 15%; basal area: 16%; age: 18%), but the stand density estimation error (29%) remained too high for use in forest planning. The sensitivity analysis to the GLCM parameters showed that the most important parameters were the texture feature, the displacement and the window size. The orientation parameter had minimal effects on the R^2 values, even if it influenced the values of the texture features.

Keywords: Forest inventory; Texture; Co-occurrence matrix; IKONOS

1. Introduction

Estimating forest structure variables from remotely sensed data has been of interest since the early days of digital remote sensing. Aerial photographs have been used extensively in the mapping and inventory of forest stands. However, this procedure is time-consuming, subjective and highly dependent on interpreter experience, as it is based totally on visual interpretation. Automated image analysis techniques provide a faster, alternative method of retrieving forest parameters from space-borne and air-borne digital imagery.

Several studies have focused on using Landsat TM/ETM+ and SPOT HRV data to estimate forest inventory variables, such as stand volume, basal area, mean height, density and cover type (Franco-Lopez et al., 2001; Pax et al., 2001; Woodcock et al., 1997). However, the estimation accuracies achieved have not been satisfactory for operational use in forest management (Kilpelainen & Tokola, 1999; Hyyppa et al., 2000; Salvador & Pons, 1998; Trotter et al., 1997), but were appropriate for adding to the information regarding nationwide statistics. Indeed, these studies reported estimation errors higher than 30% in most cases, whereas the errors of a forest inventory for stand management planning purposes typically vary between 15% and 20% (Duplat & Perrotte, 1981; Holmgren & Thuresson, 1998).

Hyyppa et al. (2000) used various image sources, such as aerial photographs, SPOT Pan, SPOT XS and Landsat TM, and compared the accuracy of retrieving the following forest stand variables: stem volume, mean tree height and basal area. They found that the image types ranged according to their spatial resolutions, except for the SPOT Pan data, which performed worse than the SPOT XS data. Furthermore, the coefficients of determination were low for the satellite datasets, but were significantly higher for aerial photographs. This is due, in part, to the low spatial resolution of the satellite data in comparison to

* Corresponding author. Fax: +32 10478898.
E-mail address: defourny@enge.ucl.ac.be (P. Defourny).

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the stand size. Hyyppa and Hyyppa (2001) showed that standard errors of predicted variables were reduced as the stand size increased for a range of remote sensing data sources. According to Trotter et al. (1997), Landsat TM only provides an acceptable data source for estimating timber volume in plantation forests for areas of about 40 ha and larger.

As the spatial resolution of the satellite sensors mentioned above was found to be insufficient for accurate estimation of forest parameters, recent studies focused on the exploitation of aerial digital imagery. The range of automated interpretation approaches of such data is quite large and none seems to be adequate. Tree counting and species recognition (Culvenor, 2002; Gougeon et al., 1999; Key et al., 2001) are important because they deliver information on the tree level, as in field inventories. Stand structure variables—height, volume, circumference or diameter at breast height, basal area, crown closure and crown diameter—have been estimated using semi-variogram parameters (Levesque & King, 1999; Muinonen et al., 2001; StOnge & Cavayas, 1995, 1997; Wulder et al., 1998), statistical texture indices (Franklin & Mcdermid, 1993) and also through individual tree crown delineation (Gougeon & Leckie, 1999; Wulder et al., 2000).

According to the literature on forest structure variables estimation using texture measures from about 1-m spatial resolution images, it appears that semi-variogram parameters methods have been used the most. This approach has a solid theoretical background and the semi-variogram parameters are readily interpreted. However, there are a number of limitations to using the semi-variogram in large-scale operational applications; these limitations are due to data volume. On the other hand, texture features that are derived from the grey level co-occurrence matrix (GLCM), as proposed by Haralick et al. (1973), have often been used in texture classification or texture segmentation (Franklin et al., 2000, 2001a; Hay et al., 1996; Rao et al., 2002) but have very rarely been used for estimation of forest variables. Such measures carry information that may also be useful for prediction purposes.

The advent of commercial satellites that provide very high spatial resolution imagery, which is comparable in many ways to aerial photography, raised great interest in using such data for forest inventory purposes. The objective of this research is therefore to investigate the use of very high spatial resolution imagery from IKONOS-2 for estimating forest structure variables by means of texture features that are derived from the GLCM. In a second step, the sensitivity of these texture features to the GLCM parameters is studied to help to choose the appropriate parameter values.

2. Material

2.1. Study site

The study site was located in the Hautes–Fagnes region, eastern Belgium, at 50°35′ N; 6°03′ E. The elevation ranges from 390 to 610 m with a plateau at about 500 m in the most part of the site. The region is characterized by a cool and humid climate and poor soil that favours peat formation. The forest stands cover about 7900 ha and are dominated by three species: oak (*Quercus* spp.), which accounts for 15% of the forest stand; common beech (*Fagus sylvatica* L.), which accounts for 14%; and Norway spruce (*Picea abies* (L.) Karst.), which is the main species and accounts for 55%.

At the beginning of the twentieth century, the Norway spruce plantations were intensively established on poorly drained soils that are unsuitable for agricultural activities. Most of them have been intensively managed by clear-cut rotation so that they are dominated by monospecific even-aged stands. The tree-crown cover is usually more than 90% and the majority of remotely sensed stands seem to be homogeneous. The stands are often of small size: mean area of 1.8 ha and more than 80% of the spruce stands are less than 3 ha in size. The study focused mainly on these spruce stands because they dominate the landscape, as well as the commercial wood production, and because they require frequent inventories. Furthermore, as these stands are regular (i.e. monospecific and even-aged), the satellite remote sensing tools that are available today should be suitable for such inventories.

2.2. Remote sensing data

The remote sensing data consisted of IKONOS-2 multispectral and panchromatic images that were acquired simultaneously on 26 October 2001. Detailed information about the acquisition configuration are reported in Table 1. A panchromatic image subset that is representative of the forest types studied here is shown in Fig. 1.

To georeference the IKONOS images, 17 ground control points (GCPs) were collected. The *X* and *Y* coordinates of the GCPs were obtained from digital colour orthophotos with a spatial resolution of 0.40 m. A digital elevation model (DEM) was derived from contour lines based on a 1:50 000 topographical map, and had a spatial resolution of 30 m. This DEM was subsequently used to provide *Z* coordinates for the orthorectification process. The images were orthorectified using a rigorous model that was developed by Toutin (2003). The root mean square (RMS) residuals of the model were 1.97 and 2.19 m for the *X* and *Y* coordinates, respectively, on the panchromatic image, whereas the RMS residuals for the multispectral image were 2.16 and 2.19 m for the *X* and *Y* coordinates, respectively. The registration quality was also

Table 1
Acquisition parameters of the IKONOS-2 images

Date/time (GMT)	26-10-2001/10:51
Sun angle elevation (deg)	26.7
Sun angle azimuth (deg)	172.2
Sensor angle elevation (deg)	76.3
Sensor angle azimuth (deg)	338.8
Nominal ground sample distance of the panchromatic image (m)	
Cross scan:	0.85
Along scan:	0.87
Spectral bands wavelengths (μm)	0.45–0.52, 0.52–0.60, 0.63–0.69, 0.76–0.90, 0.45–0.90