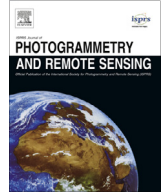




Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

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

Automated retrieval of forest structure variables based on multi-scale texture analysis of VHR satellite imagery



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ARTICLE INFO

Article history:

Received 5 February 2014

Received in revised form 28 April 2014

Accepted 8 July 2014

Keywords:

Forestry
Multiple regression
Feature selection
Texture
Multi-scale
Multi-resolution
Pléiades
Quickbird

ABSTRACT

The main goal of this study is to design a method to describe the structure of forest stands from Very High Resolution satellite imagery, relying on some typical variables such as crown diameter, tree height, trunk diameter, tree density and tree spacing. The emphasis is placed on the automatization of the process of identification of the most relevant image features for the forest structure retrieval task, exploiting both spectral and spatial information. Our approach is based on linear regressions between the forest structure variables to be estimated and various spectral and Haralick's texture features. The main drawback of this well-known texture representation is the underlying parameters which are extremely difficult to set due to the spatial complexity of the forest structure.

To tackle this major issue, an automated feature selection process is proposed which is based on statistical modeling, exploring a wide range of parameter values. It provides texture measures of diverse spatial parameters hence implicitly inducing a multi-scale texture analysis. A new feature selection technique, we called Random PRiF, is proposed. It relies on random sampling in feature space, carefully addresses the multicollinearity issue in multiple-linear regression while ensuring accurate prediction of forest variables. Our automated forest variable estimation scheme was tested on Quickbird and Pléiades panchromatic and multispectral images, acquired at different periods on the maritime pine stands of two sites in South-Western France. It outperforms two well-established variable subset selection techniques. It has been successfully applied to identify the best texture features in modeling the five considered forest structure variables. The RMSE of all predicted forest variables is improved by combining multispectral and panchromatic texture features, with various parameterizations, highlighting the potential of a multi-resolution approach for retrieving forest structure variables from VHR satellite images. Thus an average prediction error of ~ 1.1 m is expected on crown diameter, ~ 0.9 m on tree spacing, ~ 3 m on height and ~ 0.06 m on diameter at breast height.

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1. Introduction

Many studies have focused on estimating forest parameters from optical remote sensing data since the early years of satellite imagery. The methods consist usually in extracting one or several predictive variables for estimating tree or stand level variables that are useful for forest resources inventory and management such as tree height, stem diameter, density, basal area, stem volume or biomass (Kayitakire et al., 2006; Feng et al., 2010; Proisy et al., 2007;

Ozdemir and Karnieli, 2011; Song et al., 2010; Beguet et al., 2012). These studies are generally based on linear single regression modeling and only few multiple regression modeling. The accuracy in retrieving forest stand variables depends on the image spatial resolution. Hyypä et al. (2000) observed that medium or high resolution multispectral satellite imagery such as SPOT-4 (20 m resolution) or Landsat TM (30 m resolution) leads to a lower correlation performance, in comparison with sub-metric aerial photography. Using 5 m and 10 m SPOT-5 images, Wunderle et al. (2007), Wolter et al. (2009), Castillo et al. (2010) retrieved some forest stand attributes (such as crown diameter), exploiting image texture, with a good accuracy.

Over the last decade, a growing number of Very High Resolution (VHR) multispectral satellite images from various sensors has

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become available such as Pléiades, Quickbird, Geoeye, WorldView or Ikonos which provide sub-metric spatial resolution (0.5–1 m in panchromatic band, 2–4 m in multispectral bands).

VHR imagery provides a meaningful textural information. Various texture representations were proposed in literature and applied to the remote sensing data for a wide range of applications such as urban mapping (Soe and Tyler, 2004; Dell'Acqua and Gamba, 2003; Pacifici et al., 2009), image segmentation (Trias-Sanz et al., 2008; Gaetano et al., 2009) or vegetation structure mapping and habitat use (Wood et al., 2012; Tuttle et al., 2006).

Some recent studies (Kayitakire et al., 2006; Feng et al., 2010; Proisy et al., 2007; Ozdemir and Karnieli, 2011; Song et al., 2010; Beguet et al., 2012; Beguet et al., 2013; Gomez et al., 2012; Tuominen and Pekkarinen, 2005) have shown the potential of VHR imagery for forest inventory applications thanks to the strong relationship between forest spatial structure and image texture at stand level. Texture analysis of VHR satellite images generally applied to forest inventory can be divided into three main approaches (Maillard, 2003): wavelet or Fourier-based, variogram-based, and GLCM-based (Grey level Co-occurrence matrix) methods. Coueron et al. (2005), Proisy et al. (2007), Barbier et al. (2010) used a 2D Fourier periodogram to model canopy texture. Ruiz et al. (2004), Regniers et al. (2013), Van Coillie et al. (2007) used wavelets for forest structure analysis. A variogram is useful to explore the relationship between image texture and forest structure (Guyon and Riou, 1996; St-Onge and Cavayas, 1997; Franklin et al., 2001; Wolter et al., 1998; Song et al., 2010). Its main drawback is the requirement of a good non-linear model to fit the observed variogram before extracting texture indicators such as sill, range and nugget. The second order statistics derived from Grey Level Cooccurrence Matrix (GLCM) as defined by Haralick et al. (1973) are the most used texture features in forestry remote sensing literature (Franklin et al., 2001; Chehata et al., 2011; Boukir et al., 2013) and provide good performances for estimating forest parameters (Kayitakire et al., 2006; Wunderle et al., 2007; Wolter et al., 2009; Castillo et al., 2010; Ozdemir and Karnieli, 2011; Beguet et al., 2012). Generally, these parameters are set to fixed and hence unoptimal values. To tackle this major issue, an automated feature selection process that explores a wide range of texture parameter values is a worthwhile solution to investigate which, to the best of our knowledge, has not been proposed yet in literature. This automated spatial parameter tuning has an appealing property : it provides texture measures of diverse spatial parameters hence implicitly inducing a multi-scale texture analysis. It is well known that texture analysis is generally more relevant in a multi-scale context (Gonzales and Woods, 2008).

Moreover the existing studies generally involve only one spatial resolution, considering exclusively panchromatic or multispectral data. To our knowledge, only Wolter et al. (2009) have combined texture features from both kinds of data with different spatial resolutions, but via variograms and not GLCM.

Besides, the impact of image acquisition conditions on the forest structure retrieval from texture information is a critical issue. In fact, both view and sun angles influence the image texture, due to the interaction of radiation with vegetation structure. They particularly determine the length and the orientation of the shadows of crowns cast on ground, the fraction of sunny or shadowed crowns, and also the apparent radius or length of crown viewed by the sensor. Barbier et al. (2010) showed that the bidirectional variation in texture is to be accounted for when using a number of images with various angle configurations. In addition, image texture can significantly vary across the seasons due to phenological changes in vegetation structure, thus indicating that care is to be taken when measuring texture at different phenological stages (Culbert, 2009).

In this paper, we aim to fully exploit the potential of texture features extracted from VHR satellite images using a GLCM-based approach for estimating some typical forest stand variables, with a particular emphasis on automated parameter tuning, one of the major issues in texture analysis. The study focuses on the retrieval of the following forest structure variables: crown diameter, tree height and tree density or spacing which lead a spatial resolution-dependent image texture. The stem diameter at breast height is also considered, since it is easily measured on the field and it indirectly contributes to image texture via its correlation with the crown structure variables such as crown diameter. The top-tree height also contributes to image texture since it impacts on the length of crown shadows according to the solar elevation or the apparent crown length viewed by the sensor according to the view zenith angle.

The main objective of our work is to design and test an automated process for the selection of GLCM texture features and their optimal parameterization that is able to predict the forest variables with a satisfactory accuracy regardless of the season or the angle configuration of the remote sensing data. To achieve optimal results, numerous combinations of panchromatic and/or multispectral features were tested through multi-variable linear regressions involving field-measured forest variables. As collinearity is a very perturbing problem in multi-linear regression, this issue is carefully addressed through an innovative variable subset selection algorithm we called Random PRiF. A comparative analysis is carried out with other well-established variable subset selection techniques used in multi-variable regression, a classic dimensionality reduction: PCA (Principal Component Analysis) (Manly, 1994) and a recent one that is more adapted to prediction: LARS (Least Angle Regression) stepwise.

The developed automated forest variable retrieval scheme was assessed on stands of maritime pine (*Pinus pinaster* Ait.) of the forest of “Landes de Gascogne” in south-western France. An accurate estimation of the forest variables is aimed. Indeed, covering about one million hectares (75% of the total area of the region), these maritime pine stands are economically important at regional and national levels and thus an accurate inventory of wood resource is required. Two sites covering a large part of the structure diversity of this forest were considered, using VHR Quickbird and Pléiades images.

2. Material

2.1. Study sites

Both study sites are located in south-western France within the largest European maritime pine (*Pinus pinaster* Ait.) forest (Fig. 1), so-called *the forest of Landes de Gascogne*, which covers approximately one million hectares in a nearly flat area except for the coastal dunes. This forest consists of maritime pine even-aged stands which are intensively managed. The pine trees are planted in rows usually 4 m apart. The regeneration techniques have changed in recent years. Now the trees are generally regularly planted along the rows with a low density (~1000 trees/ha, i.e. within-row spacing ~2.5 m). Previously, the trees were always sowed with a higher density in the row (~5000 trees/ha, i.e. within-row spacing ~0.5 m). The trees are periodically thinned after clearing the understory vegetation. The clear-cutting occurs mostly when the pine trees are 50 years old.

The Nezer site, whose area is around 60 km², is managed quite uniformly since it covers only two large tree farms. The stand size is large, the mean area is approximately 12 ha with a maximum of 50 ha. The stands are mostly rectangular and often circled by fire

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