Forest stand characterisation using very high resolutions satellite remote sensing

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Avril 2006

Thèse présentée en vue de l'obtention
du grade de docteur en sciences agronomiques
et ingénierie biologique

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A quoi bon soulever des montagnes
quand il est si simple de passer par dessus
(Boris Vian)

Avant-propos

Cette thèse a été réalisée en marge de différents projets de recherche menés à l'unité des Eaux et Forêts et à l'unité d'Environnemétrie et Géomatique de l'Université catholique de Louvain.

Les travaux présentés aux trois premiers chapitres ont été réalisés dans le cadre du projet ICRAFOL (Information Cartographique Relative aux Forêts OnLine) mené au sein de l'unité des Eaux et Forêts grâce à un financement de trois ans du Ministère de la Région wallonne, Direction Générale des Technologies, de la Recherche et de l'Energie. Ce projet avait pour objectif de proposer une méthodologie de cartographie complète des forêts de la Région wallonne (aussi bien les propriétés privées que les forêts publiques), et ensuite, de mettre en place une solution de distribution par internet des données forestières ainsi produites.

Les travaux présentés au quatrième chapitre ont été accomplis grâce au financement du programme PRODEX de l'Agence spatiale européenne dans le cadre de l'accompagnement scientifique de la mission CHRIS/PROBA, notamment l'exploitation des données issues de la mission pour les applications forestières. Le projet a duré dix-huit mois.

La poursuite des recherches au sein de l'unité ENGE a été possible grâce aussi au financement de la Politique scientifique fédérale à travers le projet SUGRES (sept mois) sur l'optimisation de la gestion des espaces verts en milieu urbain par l'usage d'images satellitales à très haute résolution spatiale. Les résultats de ce projet ne font cependant pas partie de cette thèse.

Un financement de six mois accordé par les Fonds spéciaux de recherche (FSR) de l'Université catholique de Louvain a permis de finaliser les articles et la mise ensemble des résultats obtenus au travers des autres projets.

Abstract

Effective management of forest resources requires reliable and timely information on their status. In this regard, remote sensing techniques have played an important role, as they allow collection of data on extensive, remote and inaccessible areas. Historically, aerial photographs were the primary remote sensing data source in forest inventory and mapping, and they are still extensively for visual photo-interpretation. In this thesis, we show that their use can be improved thanks to automatic processing and an application using digitised orthophotos is provided.

Satellite-based remote sensing has been regarded as an alternative, low-cost and rapid, data source to aerial photography and ground survey. Indeed, it has proved to be effective at the continental and global scales, but applications for local forest management purposes are still rare. The main reason for this is that the spatial resolution of satellite remote sensing data that was available until recently (mainly from Landsat TM/ETM and SPOT HRV) was too coarse for stand level information. Satellite images with enhanced spatial resolution (such as IKONOS) should overcome this limitation. This thesis investigates their actual capabilities for forest stand mapping and characterisation. We show that they are well suited for forest stand type classification and for retrieval of several dendrometric variables in coniferous stands with an accuracy similar to that of field sampling.

For the sake of solutions to provide more precise and detailed information on forest stand, we assessed also the contribution of hyperspectral and multiple-view angle data acquired by CHRIS/PROBA. Although the winter season scene did not fully permit utilisation of the hyperspectral dimension of this dataset, the study provides insights into directional effects.

This work makes, hopefully, a step towards automated processing and effective integration of satellite-based remote sensing data into the forest management information system and, by upscaling, into the national forest inventories.

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Introduction

With increasing concerns about sustainability of forest management practices and the role that forests may play in the climatic change, the request for data on forest status is becoming more and more demanding, either at the national or international level. For instance, the Global Forest Resources Assessment (GFRA) that is carried out by the Food and Agriculture Organization of the United Nations (FAO) every 10 years, focused mainly on forest area estimation in the 1980s. The last assessment finalised in 2000 had been designed to collect data on more variables defined at the stand level, as the basal area, the top height, the stand density and the standing volume. Future inventories should include more parameters and the precision and accuracy of currently measured variables should be improved (Holmgren and Persson, 2002).

The GFRA is based, on the one hand, on statistics reported by the States, that are usually collected in the framework of the national inventories, and on the other hand, on satellite image derived data. The remote sensing has been generally used to estimate the forest area and its change, but rarely to retrieve information specific to forest stands*.

National forest services base their forest policy on data acquired by measuring an extensive network of permanent field plots. Most of them do not have forest maps covering their entire territory. For instance, in the Walloon Region, where our study sites are located, it does not exist any comprehensive regional forest map. Such a map is however required to establish landscape and biodiversity

*A *forest stand* can be defined as a community of trees possessing sufficient uniformity in composition, age, arrangement, or condition to be distinguishable from the forest or other growth on adjoining areas, thus forming a silvicultural or management entity (Haddon, 1988).

indicators that are now fully integrated in the forest management planning process. The only data source that may be useful for this, is the CORINE Land Cover database; that is a European land cover/land use map derived from Landsat TM/ETM images. Its scale is 1:100 000 whereas a scale of at least 1:20 000 is required because the forest stands in the Walloon Region are often very small.

At the local level, a detailed forest stand map is a key component of the forest management planning. It provides information on the current status of the forest (area, species composition, stocking, etc.) so that the forest manager can draw a clear plan of operations needed to achieve the objectives of his management planning.

A large scale forest map should therefore meet a twofold need of forest information: local management planning and synoptic view of the forest resources at the national and global levels.

New opportunities for forest remote sensing

Forest remote sensing has traditionnaly considered separately spaceborne sensor images and aerial photographs because both data types had properties that made them incompatible in operational processing chain. While automated digital image processing methods have been always applied to satellite images, the aerial photographs have been mainly used through visual photo-interpretation. The spatial resolution of the output images was probably the most important factor that influenced the approach to remote sensing data processing.

The advent of satellite images with a spatial resolution of about 1 m opened new opportunities in forest applications because they provide a data source that is quite similar to high altitude aerial photographs that have been extensively used in forest mapping for several decades. Furthermore they are usually more convenient than aerial photographs for automatic processing and may be compliant with traditional requirements in spatial precision of forest planning maps.

Very high spatial resolution (VHSR)[†] satellite images raised great interest so that, since the launch of IKONOS-2, first civil satellite with a VHSR sensor, eight other satellites have been deployed and are operational or in commissioning phase. About ten others are planned within five years (Table 1). New opportunities are therefore offered to forest managers interested in the use of remote sensing data. These opportunities should be fully exploited provided that automatic methods of VHSR image interpretation address the mass processing challenges that are related to their very high resolution.

The great expectations of the forest community were hardly matched by the multispectral sensors (band width greater than 50 nm) because they did not succeed in discriminating the main forest species (Barnsley and Kay, 1990; Gougeon et al., 1999; Goodenough et al., 2003). Studies based on hand-held spectrometers data or airborne sensors showed that hyperspectral sensor data (strictly saying, more than 50 spectral bands with width inferior to 10 nm) could overcome this limitation thanks to their high spectral resolution (Gong et al., 1997; Martin et al., 1998; van Aardt and Wynne, 2001; Goodenough et al., 2004; Berge and Solberg, 2004; Goodwin et al., 2005). The conclusions of these studies can not however be directly extrapolated to images that are acquired by spaceborne sensors because the effects of specific factors acting in this context (atmosphere, observation geometry, spatial resolution, sensor calibration) are not well documented.

Hyperspectral remote sensing using high spatial resolution spaceborne sensors has been rarely tested (Goodenough et al., 2003). There are currently only two spaceborne sensors that can acquire images with a spectral resolution of about 10 nm and a spatial resolution better than 50 m. They are Hyperion on-board NASA EO-1 (Earth Observing–1) satellite and CHRIS (Compact High Resolution Imaging Spectrometer) on-board PROBA (Project for On-Board Autonomy) launched by ESA. The main research question is to figure out if these hyperspectral capabilities allow discriminating the main forest species.

Structure characteristics of a forest stand can also be obtained

[†]Very high spatial resolution images are typically those with a ground pixel size of less than 5 m

Table 1: Very high spatial resolution satellites (situation on 15/03/2006). Scheduled launch dates of missions in development are in italics.

Satellite/Sensor	Operator (Country)	Launch date	Spatial res.(m)
IKONOS	Space Imaging – Orbimage (USA)	1999	1.0
EROS A	ImageSat international (Israel)	2000	1.9
EROS B	ImageSat international (Israel)	*2006*	0.7
QuickBird	Digitalglobe (USA)	2001	0.7
WorldView-1	Digitalglobe (USA)	*2006*	0.5
WorldView-2	Digitalglobe (USA)	*2008*	0.5
SPOT-5	Spot Image (France)	2002	2.5
Pleiades	Spot Image (France)	*2008*	0.7
OrbView-3	Orbimage (USA)	2003	1.0
OrbView-5	Orbimage (USA)	*2007*	0.4
FORMOSAT-2	National Space Organization (Taiwan)	2004	2.0
CartoSat-1	Indian Space Research Organization (India)	2005	2.5
CartoSat-2	Indian Space Research Organization (India)	*2006*	1.0
BEIJING-1	Beijing Landview Mapping Information Technology (China)	2005	4.0
TopSat	British National Space Centre (United Kingdom)	2005	2.5
ALOS	Japan Aerospace Exploration Agency (Japan)	2005	2.5
KOMPSAT-2	Korean Aerospace Research Institute (North Korea)	*2006*	1.0
RazakSAT	Astronautic Technology (Malaysia/South Korea)	*2006*	2.5
THEOS	Geo-Informatics and Space Technology Development Agency (Thailand)	*2007*	2.0

by analysis of its bidirectional reflectance behaviour. Indeed the reflectance of the target at a given wavelength varies as a function of the relative position of the light source (the Sun in the case of passive remote sensing sensors) and the observer (the sensor). This directional effect is usually modelled by the means of the bidirectional reflectance distribution function (BRDF). The parameters of this function depend on the physical characteristics of the target (geometry, absorbance, transmittance and reflectance). Thus, variations in the reflectance of forest stands measured from different viewing angles denote to some extent the variations in the structure of the forest stands that are sensed. Inverting the BRDF model may allow estimating forest structure parameters. Fitting a BRDF model requires however a large number of images acquired in different configurations to ensure a sufficient sampling rate of the angular domain. This is usually achieved in experimental setup, namely laboratory controlled experiments or in simulation studies. In operational situations and particularly in satellite remote sensing, the angular sampling is hardly well designed. In studies using real satellite images an inferential approach to test the effect of the viewing angle, rather than explicitly modelling the BRDF, is often preferred. In this study, we will especially emphasize the interaction effect between the viewing angle and the forest stand structure on the reflectance recorded by the CHRIS sensors. The CHRIS-PROBA system is in fact capable of acquiring five images of the same target in a single overpass, with different viewing angles.

Objective and document organisation

The main objective of this thesis is to develop new approaches to retrieve forest stand characteristics from VHSR images and hyperspectral multiple-view images in order to improve the accuracy and precision of forest stand information retrieval. The VHSR images considered in this research are acquired either by airborne or spaceborne sensors whereas the hyperspectral multiple view-angle images are acquired by a high spatial resolution spaceborne sensor. The analysis is carried out at the stand level. This allows deriving detailed information for forest management planning as well as for large scale landscape analysis.

Chapter 1 is dedicated to forest stand discrimination on the basis of digital aerial photographs. We introduce a parcel-based classification approach and discuss the potential and limitations of this data source for operational forest mapping.

In Chapter 2 we extend the parcel-based classification approach to VHSR satellite images in order to improve the discrimination of forest types. The geometric accuracy of such images is also considered to evaluate their suitability for large scale forest mapping.

Chapter 3 focuses on forest stand characterisation through the retrieval of dendrometric variables. The approach relies on VHSR image texture analysis taking into account the geometry of observation. The sensitivity of the texture features to the parameters that control their computation is analysed in order to support an appropriate parameters selection.

Chapter 4 is devoted to the contribution of hyperspectral data for forest species discrimination on the one hand, and, on the other hand, the contribution of multiple viewing angle images to characterise the forest stand structure. This study has been possible thanks to the unique capabilities of the CHRIS-PROBA system that allow the acquisition of hyperspectral images with different viewing angles during a single pass.

Finally, the main results are summarised and some conclusions and suggestions on directions for future works are proposed.

The four chapters have been written each as a full journal article. Thus, they may be read independently, but the entire reading is suggested in order to have an overall view of the current observation systems performances for a better forest stand characterisation. The figure 1 shows the organisation of the different chapters, their main topics, their links and their contribution to the overall objective which is to improve the forest information system.

As the experiments have been carried out on different sites, we present shortly their description in the following section. A detailed description is provided in the concerned chapter.

Study sites

In this thesis we studied four sites located in the Walloon Region (southern Belgium). They have been selected in the most forested

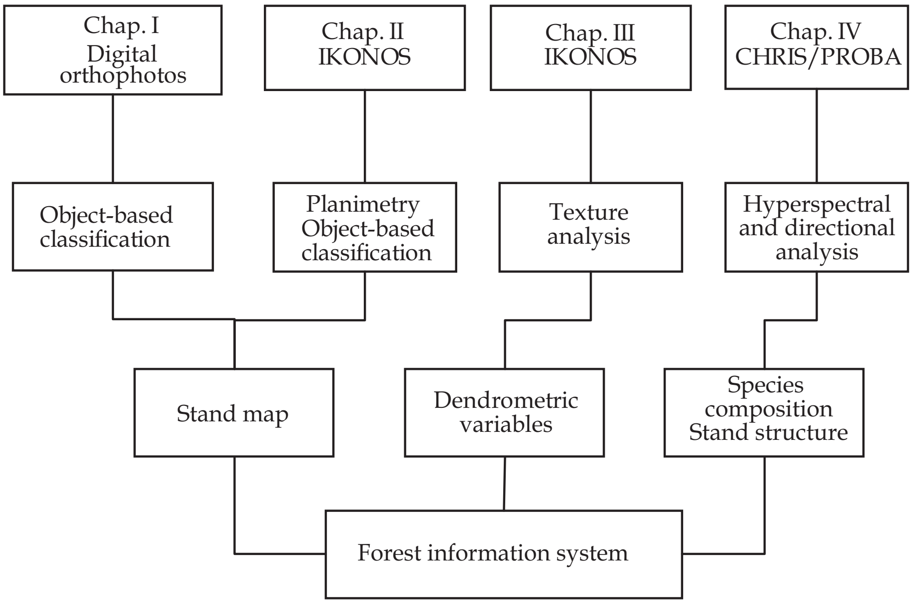

Figure 1: Outline of the document.

areas, namely in the Ardenne natural region. The map of the figure 2 shows their exact location.

The Attert site is located in the southern limit of the Anlier forest, between the Ardenne and Gaume natural regions. The main forest species in this site were the Norway spruce (*Picea abies* (L.) Karst), the beech (*Fagus sylvatica* L.) and the oak (*Quercus robur* L. or *Quercus petraea* (Mattuschka) Lieblien). The terrain in the western part of the site is slightly hilly, whereas the eastern part includes a narrow valley whose sides are steeply inclined. The altitude varies between 350 and 410 m. This site has been used for the study presented in Chapter 1. The remote sensing data consisted in aerial colour orthophotographs with a spatial resolution of 0.80 m.

The Saint-Hubert site is located in the centre of the Ardenne natural region on an almost flat plateau, excepted for a valley running in the northern part of the site where the minimum altitude is noted at 290 m. The altitude of the major part of the site varies between 450 and 580 m. The forest is made up mainly by mixed stands of oak and beech forming a large block, and a number of pure stands of Norway spruce and of Scots pine (*Pinus sylvestris*

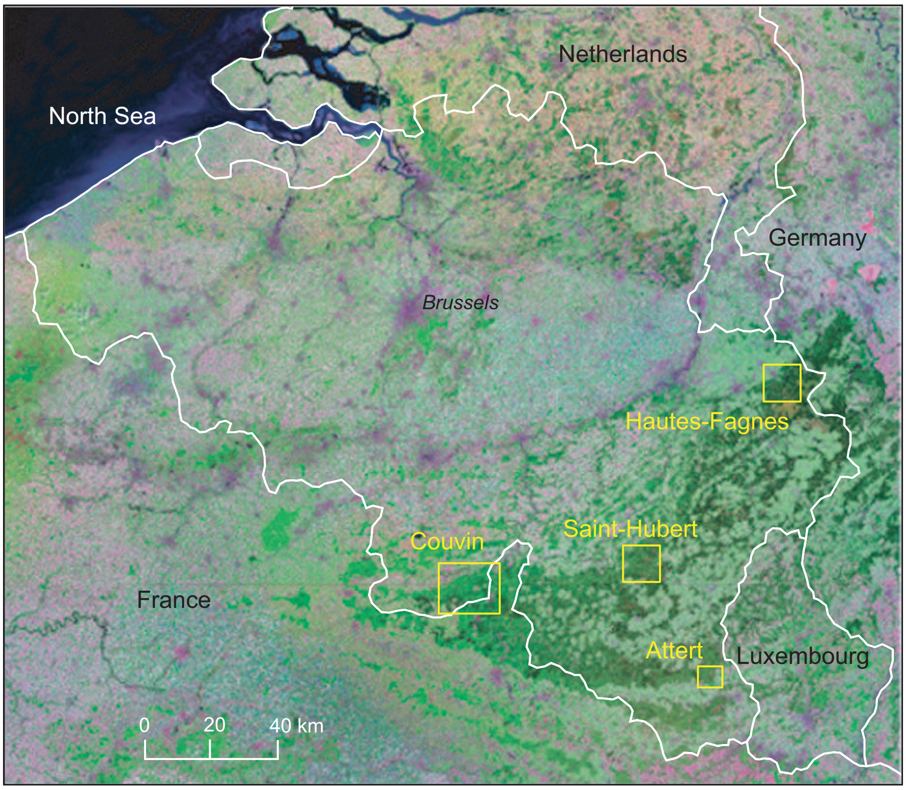

Figure 2: The rectangles show the study site locations in Belgium. The bakcground image is a Landsat ETM composite (spectral bands 2215 nm-825 nm-560 nm as the red-green-blue channels). Forests appear in green on this image composite.

L.). This site has been used for the experiments reported in Chapter 2. The main data source for forest type discrimination consisted in two IKONOS images, a 1-m resolution panchromatic image and a 4-m resolution multispectral image.

The works reported in Chapter 3 have been carried out over the Hautes-Fagnes site. This site is adjacent to the protected area of the *Plateau des Hautes-Fagnes*. The altitude ranges from 390 m to 610 m, but the most part of the studied forest were on almost flat plateau at about 500 m. The main species are the Norway spruce, which covers more than 50% of the forest stand, beech and oak. The remote sensing data consisted in two IKONOS images, a 1-m resolution panchromatic image and a 4-m resolution multispectral image.

Finally, the study reported in Chapter 4 has involved a site located near Couvin, in the western part of the Ardenne natural region. The altitude of the zone covered by the CHRIS-PROBA images over this site ranges from 200 to 350 m. This site is more hilly than the three others though its altitude is lower. The forest is largely dominated by two species, oak and Norway spruce.

The four sites have actually many similarities, like topography, species composition and management practices. Though, the results that we obtained on the different sites make an ensemble, and can be compared between them with regard to the methodological aspects.