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Single tree species classification with a hypothetical multi-spectral satellite

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Abstract

The requirements for high resolution multi-spectral satellite images to be used in single tree species classification for forest inventories are investigated, especially with respect to spatial resolution, sensor noise and geo-registration. In the hypothetical setup, a 3D tree crown map is first obtained from very high resolution panchromatic aerial imagery and subsequently each crown is classified into one of a set of known tree species such that the difference between a model multi-spectral image generated from the 3D crown map and an acquired multi-spectral satellite image of the forested area is minimized. The investigation is conducted partly by generating synthetic data from a 3D crown map from a real mixed forest stand and partly on hypothetical high resolution multi-spectral satellite images obtained from very high resolution colour infrared aerial photographs, allowing different hypothetical spatial resolutions. Conclusions are that until a new generation of even higher resolution satellites becomes available, the most feasible source of remote sensing data for single tree classification will be aerial platforms.

Keywords: Single trees; Species classification; High resolution satellites

1. Introduction

Individual tree crowns in aerial photographs may be found by delineation based on light/shadow contrasts as in Gougeon (1995) or Brandtberg and Walter (1998) or by fitting three dimensional optical tree crown models rendered in accordance with the geometry and lighting at image acquisition as in Larsen and Rudemo (1998). With the latter approach one may obtain a 3D tree crown map (i.e. a 3D model of the tree crowns in the canopy) from multiple images by fitting the crown shape parameters to maximize the correspondence of the rendered crowns within all images. Larsen and Rudemo (2004) describe a methodology for reconstructing 3D tree top positions using a Bayesian model as a first step towards obtaining a 3D crown map from multiple images. One could also use laser scanning data to obtain the 3D tree crown map as in Brandtberg et al. (2003) or Persson et al. (2004), alone or in conjunction with aerial photography such as in Suárez et al. (2005). The spatial resolution of images or laser data needs to be fairly high for successful individual tree crown detection and delineation. In Pouliot et al. (2002) a 5–15 cm pixel spacing produces good result while in Leckie et al. (2003) a resolution of 60 cm does not allow good isolation of individual trees.

Species classification from multi-spectral images can be achieved at the stand composition level as found by Leckie et al. (2003), but for individual trees complications such as shaded crowns and variability of spectral signatures between trees of the same species combined with poor isolation of individual trees reduce classification performance. This is typically less that 50% correct classifications as reported by Leckie et al. (2005a), and even with manual crown delineation classification performance may not necessarily be dramatically improved, cf. Leckie et al. (2005b). In Bunting et al. (2006) classification into five species classes of successfully delineated individual trees in 1 m CASI data is achieved with an overall accuracy of 77%. Even better results, although from leave-one-out cross-validation rather than validation against independent test data, are reported in Persson et al. (2004, 2006) where classification of individual tree crowns into three species classes is achieved with 83%–91% overall accuracy using both very high spatial resolution laser data and high spatial resolution three band near-infrared data.

The high resolution data sources enabling the generation of a 3D tree crown map do not necessarily carry the spectral

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information needed for species classification, and on the other hand multi-spectral data is rarely of sufficient resolution to accurately delineate individual trees. Therefore it seems a fusion of the two data types would be the way forward for operational tree species classification.

Specifically for Denmark, aerial photography used for survey purposes is panchromatic and earlier Danish research into high resolution remote sensing for forest inventory has been based on digitized large scale panchromatic images as reported e.g. in Dralle and Rudemo (1997), Larsen and Rudemo (1998), and Tarp-Johansen (2002). The advent of commercially available high resolution multi-spectral satellite imagery (i.e. IKONOS in September 1999) motivated experiments with a framework for single tree forest inventories where 3D crown mapping would be done from very high resolution panchromatic aerial photography followed by species classification from multi-spectral high resolution satellite imagery. Since then, airborne high resolution multi-spectral systems have become more an economically viable source for forest inventory data (at least in Denmark). An airborne sensor system is more flexible in terms of deployment than a satellite system and this is an advantage when images have to be acquired within a narrow time frame, e.g. as dictated by the desire to capture data when the trees are in a certain stage of their annual cycles. Furthermore, there is great promise in combining optical with laser scanning data when mapping the 3D canopy structure as reported in Næsset and Bjerknes (2001), Persson et al. (2004) and Suárez et al. (2005). Thus technological and commercial developments in aerial imaging mean that today the combination of aerial photography and satellite imaging is not economically sound for forest inventories. However, future development of space imaging platforms could make the multi-resolution approach with fine scale panchromatic and coarser scale multi-spectral data attractive again. Therefore it is of some value to know how the spatial resolution of a hypothetical future satellite providing multi-spectral data affects the performance of the tree species classification.

2. The proposed method

A method for tree species classification from a multi-spectral high resolution satellite image is proposed as follows.

It is assumed that a very accurate 3D tree crown map is available for the area of interest and that there is a limited set of candidate tree species (classes) for which spectral signatures are known, both for crown segments illuminated directly by the sun and for segments that are shaded. If the ground is visible through the canopy from above, spectral signatures for sunlit and shaded ground must also be known.

A high resolution multi-spectral satellite image of the area is acquired. The crowns of the 3D crown map are classified by minimizing the difference between this image and a model image.

2.1. The model image

The model image I is generated from the 3D tree crown map T containing the 3D position and extent of all tree crowns, with the spectral properties of each tree crown $t \in T$ determined by its proposed species $\phi(t)$, where the function ϕ assigns a species label to each tree. Each species s in the set of possible species' S has associated sunlit spectral vector α_s and shaded spectral vector β_s. The ground has associated sunlit and shaded spectral vectors α_{G} and β_{G}. Let T_i be the trees in T which are visible in image pixel $i \in I$. The spectral vector γ_i of pixel i is then:

$$\gamma_i = \sum_{t \in T_i} \left(\alpha_{\phi(t)} A_{\alpha_{t,i}} + \beta_{\phi(t)} A_{\beta_{t,i}} \right) + \alpha_G G_{\alpha_i} + \beta_G G_{\beta_i}, \tag{1}$$

where $A_{\alpha_{t,i}}$ is the fraction of the area of pixel i covered by the sunlit portion of the crown of tree t, and similarly $A_{\beta_{t,i}}$ is the fraction covered by the shaded portion of the crown of t, G_{α_i} is the fraction showing sunlit ground and G_{β_i} is the fraction showing shaded ground.

Fig. 1 (upper right) shows an example of a generated model image at 1 m resolution.

2.1.1. The lighting map

In order that γ_i can be computed efficiently, the $A_{\cdot t,i}$ and $G_{\cdot i}$ must be precomputed. This is however difficult to do exactly for any non-trivial 3D tree crown map and optical crown model. The difficulty lies in the partially self-shading nature of the tree crowns, i.e. that sunlight penetrates to and illuminates some parts of the “back” of the crown while other parts are shaded: see Larsen and Rudemo (1998) for an optical model. With trees close together and crowns often interlaced and partially shading each other, the situation is even more complex. Therefore, an approximating approach is adopted in which the 3D crown map, the image formation geometry and the sun position are used to ray-trace a lighting map image at very high resolution (5 cm pixel size in the experiments reported here). Each pixel of the lighting map image is classified as showing either sunlit tree crown, shaded tree crown, sunlit ground or shaded ground. To determine values for $A_{\cdot t,i}$ and $G_{\cdot i}$ the lighting map image is superimposed on the model image and each lighting map pixel contribute to one of the $A_{\cdot t,i}$ or $G_{\cdot i}$ according to its lighting class and position in the 3D crown map. Within model pixel i, a lighting map image pixel classified as sunlit or shaded ground contributed to G_{α_i} or G_{β_i} respectively, while for a lighting map image pixel classified as the tree crown the corresponding tree t was found from the 3D crown map and the contribution would go to $A_{\alpha_{t,i}}$ if sunlit or $A_{\beta_{t,i}}$ if shaded. The tree crown corresponding to a lighting map pixel was determined as the one which would be imaged at the centre of that pixel given the image formation geometry and the 3D crown map (where multiple crown surfaces intersect the ray through the pixel centre, the one closest to the sensor is taken). Depending on the resolution of the lighting map image and the sizes and spacing of the tree crowns, some very small tree crowns or tree crowns mostly hidden under larger tree crowns may not contribute to the weights $A_{\cdot t,i}$ at all. Such crowns will not be classified as their species labels have no influence on the model image.