The Individual Tree Crown (ITC) Approach to Forest Inventories: Satellite and Aerial Sensor Considerations

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Introduction

In Canada, forest management inventories are typically done by delineating forest stands and estimating their content via aerial photo interpretation (1:10K to 1:20K), with volume estimates being derived from plot samples and stratification. Recent improvements to this traditional methodology involve soft-copy interpretation systems and in some cases, digital acquisitions. The process is still very time-consuming, costly and subject to interpreters biases, but more importantly, it does not meet the full needs of modern forestry practices.

A modern forest inventory would require additional spatial detail, with increased precision, accuracy and timeliness. Semi-automatic computer analysis of multispectral high spatial resolution (better than 1 m/pixel) digital images from satellites or aerial sensors has the potential to fulfill this mandate.

Methodology

The individual tree crown (ITC) approach consists in a Suite of techniques for individual tree crown delineation (or simply detection, when crowns are too small), followed by species classification and regrouping into forest stands (Gougeon and Leckie, 2003). It can lead to the semi-automatic production of modern forest inventories.

The delineation of tree crowns is based on following the valleys of shade that exist between the much brighter crowns in medium to high density forests. Because crowns often touch each other or, are positioned in such a way as not to have shade between them (i.e, normal to sun's illumination), the valley following process is succeeded by a rule-base system that takes higher level decisions leading to additional crown separations. Under ideal circumstances, on an image at 31 cm/pixel, 81% of the resulting objects were found to correspond one for one with those delineated by an interpreter on the same image (Gougeon, 1995). Species classification (based on training by interpreters) is regularly found to be 60-70% accurate in separating 4-6 coniferous and 4-6 deciduous species in Canadian forests (Chubey *et al.*, 2009). Compared to transects on the ground, species composition has been found to have an average error of 10% for the leading species and 14%, for secondary species that are greater than 25% of the composition (Leckie *et al.*, 2003a).

Tree crowns that do not meet the minimum size requirement (of 2x2 pixels) for full crown delineation (e.g., regeneration, and sometimes mature trees such as lodge pole pine or black spruce, in certain circumstances) can be detected with the Tree Top (local maxima) technique (Gougeon and Moore, 1989). Although this does not lead to crown area information, species can be ascertained, and tree density and spacing established.

Similarly to the ITC valley following technique, the Tree Top technique relies on a shaded background between the tree crowns. When the forest is more open and specific shadows are visible, a technique that looks for local maxima associated with a shadow patch at a specific distance and direction can be used. The Locally Adaptive Tree Top (LATT) technique is capable of switching on-the-fly between these two modes of operation based on an *a priori* generated directionality mask (Gougeon, 1997).

Due to the size of Canadian forest management units and the desire to standardize on Geographic Information Systems (GIS) to store forestry information, the ITC-based information such as species, crown area, height, etc., is typically still summarized by forest stand polygons. Such polygons can be generated almost automatically using a methodology (Leckie et al., 2003a) that combines species composition, stem density, crown closure and, if available, stand height from a digital canopy model (DCM). They compare favorably with the photo-interpreted polygons. Of course, the ITCs can be regrouped following other criteria in order to be more useful for biodiversity assessments or wildlife management, for example.

Once the forest polygons have been generated, new fields (attributes) are attached to each polygon summarizing the ITC-based information: number of ITCs, stem density, crown closure, average ITC crown area, height (if a DCM is available), and the same information for each species, organized in order of prevalence (by crown closure or number of ITCs). Such information is readily transferred to a GIS (e.g., as a shape file), where it can be further explored and analysed. Of course eventually, with the trend towards precision forestry (e.g., just in time logging, very selective cuts), keeping all of the ITC information (i.e., tree position, species, size) will prevail.

In the production of forest inventories from ITC analyses, synergy with LiDAR (Light Detection and Ranging) returned pulse data and their derivatives (DTM, DSM, DCM) can occur at many levels. Firstly, a DCM, even one made from a low sampling rate (0.5-1 p/m^2) LiDAR acquisition, can provide the forest stand height for each forest polygon and may have already contributed in-part to the semi-automatic production of such forest stand polygon. Secondly, it can supply a mask, based on a simple height threshold, indicating low lying vegetation and/or bare ground. This will allow the ITC analysis to fare well even in more open canopy forest and is particularly useful to isolate individual tree crowns in wide open fields. Of course, this is also an easy way to remove roads and agriculture areas from the ITC analysis.

With a DCM from a high sampling rate acquisition (8-10 p/m^2), one can think in terms of individual tree heights (picking up the maximum return within each ITC) and thus, consider individual tree volume (biomass, carbon) assessments based on height and crown area. However, one can also use such precise DCM to delineate ITCs directly on the DCM image (Leckie *et al.*, 2003b). If geographic positions can be well reconciled, the crown delineations from both media could be combined to our advantage (two different view of the same tree). Conversely, one could decide to rely on the ITC delineation from the high resolution DCM and just use the imagery for species recognition. However, the acquisition of high sampling rate LiDAR is a bit prohibitive at this point in time.

BRDF Correction and Normalization of Aerial Data

Relative to satellite images (e.g., IKONOS, QuickBird, etc.), images from aerial sensors bring many additional challenges to an ITC analysis: a) their large view angles ($\pm 32^o$) show increasingly leaning trees as one gets away from the image centre (nadir), making crown delineation difficult and increasing the probability of trees being completely hidden, b) the effects of solar illumination are quite different from one side of the image to the other, as the trees on one side are generally seen as front lit, while on the other side, mostly backlit, c) there is a need to normalize between images and flight lines.

With scanned photos and digital frame cameras, these effects occur in a circular pattern. For "push-broom" sensors, that acquire their images line by line, this occurs in only one direction, across the image. To simplify the discussion, we will address the later case.

Good ITC analyses of aerial data can be obtained by concentrating on the more central regions of images and correcting for (and normalizing) intra- and inter-image variations of vegetation radiances. This can be accomplished via BRDF (Bidirectional Reflectance Distribution Function) correction curves. For multispectral images, different BRDF correction curves are collected and applied to each channel.

The first step consists in establishing a curve parameterizing the view angle and sun illumination effects across the image by accumulating a histogram of pixel averages in each column of an image. For this to work properly, one as to assume that the image is very long and/or that the ground features are random enough so that their spatial distribution does not overly affect the curve. This is rarely the case. Alternatively, a BRDF curve can be created from a single feature prevalent throughout the image, preferably the type of feature one is analysing (e.g., forest areas). With high resolution data, experience has shown that it may be better to acquire a separate curve for each specific feature, such as coniferous or deciduous tree crowns, as they respond differently to sun-view angle geometry because of their different shapes (i.e., conical trees vs rounded trees).

The second step consists in normalizing that BRDF curve relative to the grey-level value at nadir. Then, the curve represents typical additive or subtractive values found at off-nadir positions, relative to the average grey-level at nadir. The inversion of that curve becomes the correction curve. It describes the grey-level correction values to apply to each pixel based on its position off-nadir.

BRDF correction curves can also be used to normalize radiances between images and/or flight lines. Because these curves are relative to the average grey-level at nadir, it suffice to decide on a single fixed grey-level value (per channel) to be assigned to the nadir position of all images to normalize the radiances between them.

A recent test of BRDF corrections and normalization was carried out between two adjacent flight lines acquired with a Leica ADS-40/52 “push-broom” sensor. It showed that for two sample areas (one of softwoods, one of hardwoods) found on both images, the intensity differences between images could be brought down from 28% and 20%, respectively, to 3.2% and 3.4%, respectively (Chubey *et al*., 2009). Although these results illustrate the strength of the BRDF approach, such residual differences may still be too big to ensure consistent spectral-based species classification throughout an area covered by multiple flight lines. However, one should take into consideration that these two sample areas were at 20^o and 25^o off-nadir, respectively. If we stay to closer to nadir, these differences may become more manageable.

For this reason, and others having to do with the quality of crown delineation, a sidelap of 50% is recommended between flight lines such that the areas being analysed on each image are within $\pm 15^o$ of nadir. This should allow the ITC analysis to concentrate on only the central portions of each image or flight line, while producing decent results throughout the full area of interest. It should also be noted that additional care is needed when contracting-out aerial acquisitions for digital analysis, as their acquisition, manipulation and storage criteria are not quite the same as for visual interpretation of forests (Chubey *et al*., 2009).

Conclusion

The ITC methodology outlined above has been successful at delineating tree crowns, assigning them species and regrouping them into forest stand polygons with data from numerous satellite and airborne sensors at a variety of spatial resolution around 50 cm/pixel. For each stand, the ITC-based information can be summarized and used to populate new attribute fields of the polygon, leading to information judged superior to that the conventional process. Volume, biomass, and carbon assessments, growth and yield models, etc., can all remain substantially the same. They will benefit from the additional precision. However, on the long run, they shall be replaced by models doing assessments starting from individual tree crowns.

Due to their large view angle and their less instantaneous acquisition (compare to satellite images), series of aerial images covering large areas require additional correction and normalization steps before their ITC analysis. Increased sidelap (overlap) areas and feature-based BRDF corrections and normalizations appear to offer a viable solution to these issues. However, additional care should also be taken while contracting-out for the acquisition of aerial images aimed for digital analysis.

As the bulk of the ITC analysis process can be made automatic (except the training of the species classifier), it should free-up interpreters to concentrate on the precision and the quality of the analysis: the number of species and situations that can be considered. Forest inventories with additional spatial details, increased precision, accuracy and timeliness may be within our reach.

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