Comparison of Fixed-size and Variable-sized Windows for the Estimation of Tree Crown Position

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Abstract – Tree crown recognition with high spatial resolution remotely sensed imagery provides useful information relating the number and distribution of trees in a forest. A common technique used to identify tree locations uses a local maximum (LM) filter with a static-sized (user-specified) moving window. LM techniques operate on the assumption that high local radiance values represent the centroid of a tree crown. The static nature of this technique is inconsistent with both natural canopy structure and digital images. A variable window size (VWS) LM technique operates under the assumption that there are multiple tree shapes and sizes within an image and that the LM filter should be adjusted to an appropriate size, based on the spatial structure found within the imagery.

To compare the utility of the VWS LM technique versus that of static LM techniques, tree location accuracy was evaluated for static 3x3, 5x5, 7x7 filters, VWS, and VMS plus a false positive filter based on the Getis statistic. The study site incorporates two stands of Douglas fir (*Pseudostuga menziesii*); a 40 year old planted site and a >150 year naturally regenerating site. The imagery used was MEIS-II with 1 m ground resolution acquired in 1993 as part of the SEIDAM project [1].

The plantation site has a uniform distribution of tree size and spacing, while the naturally regenerating stand is composed of irregularly sized and spaced trees. The spatially sensitive VWS technique out-performs the static technique when both plantation and naturally regenerating stands are examined. False-positive filters are introduced to screen for local radiance maxima which may not be representative of tree centroids.

INTRODUCTION

Forest structure is the above ground organization of vegetation [2]. The ground instantaneous field of view (GIFOV) dictates the amount of the original landscape variance that is captured in a raster image. Low spatial resolution imagery reduces the natural scene variance due to the inclusion of a variety of surface cover types within each pixel. Airborne remote sensing with 1 m, and proposed high resolution satellite instruments [3] capture a greater amount of the original variance. For example, high resolution imagery of a forest is composed of contiguous pixel regions which represent individual trees or groups of trees. Tree objects may be understood as regions of marked spatial autocorrelation [4]. Individual trees may be discerned in high spatial resolution imagery as regions of high radiance values in the near infrared. The utility of tree crown recognition techniques is directly related to image scale: image spatial resolution needs to be high enough in relation to the tree size to allow for a sufficient number of pixels to represent the tree crown or the shadow region surrounding a crown [4]; [5]; [6]. One of the simplest tree crown recognition procedures identifies radiance maximums [7]; [8] in single channels. This local maximum (LM) technique is particularly well suited to identifying objects with a single, concentrated apex (i.e. conifers) versus those consisting of multiple, distributed pieces. The LM technique is based on the assumption that the brightest pixels correspond to the crowns of the dominant trees (the portion of the tree with the greatest amount of vertical foliage overlap). However, the stem location may be displaced from this radiance maximum due to leaning and bi-directional reflectance effects [9].

Successful recognition of the trees using LM techniques relies on careful selection of the filter window size. If the selected window is too small, errors of commission occur through identification of non-existent trees or of multiple radiance peaks for an individual tree crown. In the case of too large a window, errors of omission increase.

IMAGE SPATIAL STRUCTURE

Image spatial structure is a two-dimensional representation of the forest structure. The horizontal variability of forest canopy structure is captured in the spatial structure present in the image. In texture analysis, as in peak radiance filtering, a window size which captures the maximum amount of variance is desired. In [9], the authors demonstrated the use of semivariance to customize window sizes for use in texture analysis. A similar methodology is applied in this study to suggest windows appropriate for the filtering of local peak radiance values.

Semivariance

Digital image semivariance generates values relating pixel self-similarity over a transect of pixels. Semivariance is a well-understood and frequently applied image processing

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technique [10]. A variogram describes the magnitude, spatial scale, and general form of the variation in a given set of data [11]. Semivariograms are a graphical representation of spatial variability and provide a means of measuring the spatial dependency of continuously varying phenomenon. The semivariogram also displays the average change of a property with increasing lag, although the true variogram is continuous. Semivariance is the variance per site when sites are considered as profiles or areas of pixels, and is developed from the theory of regionalized variables [12]. The range is the point of the variogram where the spatial dependency between the original pixel and the pixels along the transect begins to diminish. The range of the semivariogram, as an indicator of a region of spatial dependence, may be applied to suggest appropriate window sizes for peak radiance filtering.

Getis Statistic

In contrast to semivariance, the Getis statistic (G_i^*), generates values which relate variations *within* patterns of spatial dependence. Thus, it has the potential to uncover discrete spatial regimes which might be overlooked by existing techniques. Semivariance and G_i^* values are complementary techniques with semivariance computing an indication of a region of pixel similarity and G_i^* providing the strength of pixel association within this region of spatial dependence.

Wulder and Boots [13], have adapted the Getis statistic for processing remotely sensed imagery. The Getis statistic, G_i^*, yields a standardized value which indicates both the degree of autocorrelation in the values of the digital numbers centered on a given pixel and the magnitude of these values in relation to those of the entire image. The G_i^* values measure the extent to which a pixel is surrounded by a cluster of high or low values of a particular variable (e.g. DN). Large positive G_i^* values denote a cluster of high DN values; large negative G_i^* values denote a cluster of low DN values. In a high spatial resolution forestry context, G_i^* values indicate the spatial dependence within a tree crown or between shadow elements. High positive values generated from infrared wavelength image data indicate the presence of a tree object whereas high negative values relate a non-tree feature.

DATA AND METHODS

Study Area

The Greater Victoria Watershed is located at 48° 23' latitude and 123° 41' longitude. Within this watershed, a study area was selected composed of a 40 year old plantation and a 150 year old naturally regenerating stand. The plantation stand (planted in 1965 and spaced in 1975), is composed of trees ranging in height from 11m to 25m., while the naturally regenerating stand contains trees from 140 to 250 years with heights from 20m to 70m. The dominant species are Douglas fir (*Pseudotsuga menziesii*) and Western Red Cedar (*Thuja plicata*). A dense layer of understory consists of Hemlock (*Tsuga heterophylla*), some Red Alder (*Alnus rubra*), salal (*Gaultheria shallon*), sword fern (*Polystichum munitum*), Oregon grape (*Mahonia nervosa*) and Oregon beaked moss (*Kindbergia oregana*).

MEIS-II Image Data

The MEIS-II sensor [14] was flown at an altitude of 1428m over the study site at 11:30 hr PST on September 2nd, 1993 as part of the SEIDAM (System of Experts for Intelligent Data Management) project [1]. The resulting ground pixel size is 1 m, with 720 pixels across track. The raw data were geometrically corrected using BC Ministry of Environment Terrain Resource Information Management (TRIM) planimetric data (horizontal accuracy of ± 20m). Solar altitude and azimuth angles for the flight line were 52° and 133°, respectively.

Radiance Peak Filtering

Tree crown locations were extracted with five filters on two different image spectral channels. Of the five different filters, 3 were fixed, square windows with sides of 3, 5, and 7 pixels. The two remaining filters were variable in size based upon the mean semivariance range at each pixel. In the variable window size (VWS) technique, prior to LM filtering, a window size appropriate to each location is calculated by averaging the semivariance range in 4 orthogonal directions. A mode filter was then passed over the resultant mean semivariance range image to remove any noise which may have been present. The semivariance range values were then mapped to window sizes ranging from 3 to 7 pixels square (Table 1). The second VWS filter uses the same semivariance to window size mapping, but uses Getis statistic generated spatial dependence values to screen for false positives.

Two channels were chosen for analysis; a red edge channel centered at approximately 675nm, and a near infrared channel centered at 875nm. The tree crown location results from the radiance peak filtering were compared for commission and omission errors using a detailed ground survey map. The survey map includes all trees greater than 25cm dbh within the study area.

RESULTS AND CONCLUSIONS

On a per stand basis (Table 2), the best static filter sizes would be 3x3 for the immature and 5x5 for the natural regeneration stand. However, when the image as a whole is processed, the mismatching of window-size to image structure results in high commission and omission errors (Table 3 & 4). Tables 3 and 4 show results from different semivariance and

Table 1. Semivariance range conversion to window size key

Semivariance Range (this study)	Window Size	Semivariance Range [9]	Window Size
1, 2, 3, 4	3	1, 2	3
5, 6	5	3	5
≥ 7	7	≥ 4	7

window size choices detailed in Table 1. Table 3 results reveal that the technique used in [9], which moves quickly to larger window sizes, results in an unacceptable omission rate. In this study, the conversion heuristic was set so that the window size was too slow in moving to the larger size (i.e. too loose). The result was that most of the image was filtered using a 3x3 window (and hence the similarity between the VWS results and the static 3x3 results: i.e. large numbers of commissions). The most appropriate method lies somewhere in between.

With a minimum of 25% of the plantation trees being missed with LM techniques in this study, it appears that 1 m imagery is too coarse for individual tree crown recognition in a 40 year old Douglas fir stand. In addition, 5 of the ten omitted trees in the naturally regenerating stand are known to be closely paired with neighboring trees and it is unreasonable to expect that a simple LM technique would be able to distinguish these as separate tree objects. This pairing situation requires an analysis of the shape or spectral qualities of the crown.

The Getis statistic filter reduces the commission error in the naturally regenerating stand, but performs poorly when it encounters immature trees in a shadowed area. This high omission rate may be acceptable if the goal of the tree location is signature extraction

This research has suggested a future change to the LM-technique in which one uses a two-phase system of conifer identification using high-resolution imagery. In the first stage, a broad VWS LM tree location technique is adopted wherein the goal is to preserve as many potential scene objects as possible. In the second phase, the tree candidates are sorted through a series of spatial filters based on the directional slope, shape, and semivariance range around the object's LM centroid. The authors are actively exploring the image spatial relationships which will underpin the rules for the second phase filters [16].

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Table 2. Results for each technique run on each stand separately

Channel	Stand	Algorithm	# Trees in Groundtruth	# Local Maximas	Trees - # Correct	Trees - % Correct	Commission Errors	Omission Errors
Chn 7 675 nm	Plantation 40y	3x3	94	74	70	74	4	24
		5x5	94	46	43	46	3	51
		7x7	94	27	25	27	2	69
		VWS	94	74	70	74	4	24
		VWS + Gi*	94	57	53	56	4	41
	Plantation 40y Shadow	3x3	34	28	24	71	4	10
		5x5	34	16	15	44	1	19
		7x7	34	6	6	18	0	28
		VWS	34	27	23	68	4	11
		VWS + Gi*	34	0	0	0	0	34
	Natural Regeneration >150y	3x3	48	83	38	79	45	10
		5x5	48	47	33	69	14	15
		7x7	48	38	29	60	9	19
		VWS	48	82	38	79	44	10
		VWS + Gi*	48	43	35	73	8	13

Table 3. Results from [9] for each algorithm run on the image as a whole (see Table 1 for mapping key)

Channel	Stand	Algorithm	# Trees in Groundtruth	# Local Maximas	Trees - # Correct	Trees - % Correct	Commission Errors	Omission Errors
Chn 7 675 nm	All 3 Stands	3x3	176	185	132	75	53	44
		5x5	176	109	91	52	18	85
		7x7	176	71	60	34	11	116
		VWS	176	138	112	64	26	64
		VWS + Gi*	176	81	75	43	6	101
Chn 3 875 nm	All 3 Stands	3x3	176	161	129	73	32	47
		5x5	176	105	97	55	8	79
		7x7	176	60	57	32	3	119
		VWS	176	105	86	49	19	97
		VWS + Gi*	176	73	71	40	2	112

Table 4. Results for each algorithm run on the image as a whole (see Table 1 for mapping key)

Channel	Stand	Algorithm	# Trees in Groundtruth	# Local Maximas	Trees - # Correct	Trees - % Correct	Commission Errors	Omission Errors
Chn 7 675 nm	All 3 Stands	3x3	176	185	132	75	53	44
		5x5	176	109	91	52	18	85
		7x7	176	71	60	34	11	116
		VWS	176	183	131	74	52	45
		VWS + Gi*	176	100	88	50	12	88
Chn 3 875 nm	All 3 Stands	3x3	176	161	129	73	32	47
		5x5	176	105	97	55	8	79
		7x7	176	60	57	32	3	119
		VWS	176	154	123	70	31	53
		VWS + Gi*	176	66	82	47	4	94