Individual Tree Recognition from Multiple High Spatial Resolution Image Sources

M. Wulder[1], T. Nelson[2], K. O. Niemann[2], D. Seemann[1], D. G. Goodenough[1], A. Dyk[1] and A. S. (Pal) Bhogal[1]

[1] Canadian Forest Service (Pacific Forestry Centre), Natural Resources Canada, Victoria, 506 West Burnside Road, British Columbia, V8Z 1M5, Canada
[2] Department of Geography, University of Victoria, Victoria, British Columbia, Canada

***Abstract* - The availability of high resolution (1 m or better) imagery from space opens up the possibility of automatic detection of coniferous trees. Our test site is located within the Greater Victoria Watershed (GVWD) on Vancouver Island, British Columbia, Canada. In previous research we have examined various filters for detecting trees over an area with mature and immature Douglas fir trees.**

We have obtained a 1-m spatial resolution digital orthophoto generated from aerial photography, MEIS 1-m multispectral imagery, and IKONOS panchromatic 1-m imagery over our test site. Within the test site, there are ground plots in which the location of each tree has been determined. These detailed plots are used to assess the accuracy of the methods used for tree detection for each of the high resolution image types. The characteristics of each tree are documented allowing for an assessment of the conditions leading to the identification, or lack of identification, of each tree.

The comparison of three differing data sources, each with 1-m spatial resolution, indicates favorable results for the IKONOS satellite data. The highest proportion of the trees from the field stem plot data were identified with the IKONOS satellite panchromatic imagery. While the IKONOS results have a higher rate of false positives than the airborne multispectral data, a preference for the satellite data is due to characteristics such as ease of collection, large image extent, repeatability, and radiometric consistency over a larger area.

I. INTRODUCTION

Local maximum (LM) filtering is an image processing technique adapted to the detection of individual trees where the magnitude of the digital numbers within a kernel are compared to determine if the central pixel is greater than all neighbours. The assumption is that when processing high spatial resolution data with an LM filter, high digital numbers occur and correspond to the apex of conifer crowns. The efficacy in locating individual trees with high spatial resolution airborne data is often limited by the relationship between image spatial resolution and the size of the trees located in the imagery [1]. While smaller trees may not be correctly identified with the same frequency as larger trees, the importance of this limitation is a function of the intended application of the LM identified trees. As larger trees contain a greater proportion of the stand volume finding them is often sufficient for forestry applications. Missed trees, or omission error, is a consequence of an image spatial resolution that is too coarse relative to the crown size. False positives, or commission error, occur when random LM occur, not due to the presence of a tree.

Air photos are a common data source used for forest management. Combining multiple photos with a DEM in specialized software allows for the production of a digital orthophoto mosaic. A digital orthophoto mosaic, hereafter call an Ortho, capitalizes on readily understood and available data and provides a landscape level view with high spatial resolution data.

Airborne remotely sensed data, with a wide array of possible spectral and spatial configurations possible, has acted as a test-bed for remote sensing research and development. While airborne remotely sensed data has flexible spatial and spectral configurations, a key limitation is often the image extent. Images are often limited in size only by storage constraints along-track, but are limited by the sensor instrumentation across-track. As a result, mosaicking is often required when using airborne data in a mapping context with issues such as aircraft attitude, BRDF, changing sun angles, and topography impacting the image products generated.

Commercial satellite remote sensing instruments, with a spatial resolution similar to those collected by airborne remote sensing instruments, are now orbiting Earth. Airborne remote sensing techniques and algorithms may now be transferred for experimentation upon satellite data. Satellite remote sensing instruments collect data with a larger image extent than airborne systems and have consistent radiometry on a per scene basis. For mapping larger areas with the satellite data, edge matching issues and differing radiometry (i.e. related to the directable sensor), may need to be addressed in a manner similar to current airborne remotely sensed data preprocessing requirements.

Our objective is to compare the application of the same LM methodology to three differing data sources with the same spatial resolution. This comparison will allow for the determination of appropriate data types and conditions for the extraction of LM in a forestry context.

II. METHODS

A. Study Location and Field Data

The study site is located near Victoria on Vancouver Island, British Columbia, Canada, at 48°23' latitude and 123°41' longitude. A 0.72-ha stem map was created, with trees located to the nearest 10-cm, over an area with little topographic variability. In total 209 trees are mapped; 159 trees in a plantation stand, ranging in height from 8.6 to 25-m, and composed of a mixture of Douglas-fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*); 50 trees in the mature stand (with trees aged 140 to 250 years), ranging in height from 20 to 70-m, and dominated by Douglas-fir. Field data for the initial MEIS study were collected in 1993. A resurvey of the study site in 1999 found that some trees were blown down. These individuals were removed from the stem map resulting in 199 trees overall (150 plantation, 49 mature) and is applicable to the Ortho and the IKONOS data.

B. Digital Data

The second generation MEIS-II [2] was flown at an altitude of 1428-m over the study site at 11:30 hr PST on September 2, 1993. The resulting ground pixel size is 1-m, resampled to 720 pixels across track, for an image extent of roughly 700-m by 2000-m. Solar altitude and azimuth angles at the time of the flight were 52° and 133° respectively. To enable comparison with the IKONOS image and Ortho we simulated a panchromatic channel from the MEIS-II data by convolving the data ranging from 432.85 to 847.65-nm.

The IKONOS image was captured at 11:05 hr PST June 3, 2000. The solar altitude and azimuth angles at the time of the satellite overpass were 60° and 146° respectively. The extent of the IKONOS image is 9000 x 9000-m and has a spectral range of 450 to 900-nm.

The Ortho is created from 21 photos with an original scale of 1:15,000 collected on July 25, 1998, at an unknown time of day. The original photos were scanned at 400 dpi and orthorectified using a DEM made from ground control points. The resultant orthophoto mosaic has a spatial extent of roughly 8750 by 7950-m.

III. RESULTS AND DISCUSSION

The level of omission (related to missed trees) is largely due to image spatial resolution. The level of commission is in part a function of the radiometric sensitivity of the sensor. A low dynamic range will result in an image composed of digital numbers that vary slowly, providing little opportunity for local maximum indication. Imagery that has high radiometric sensitivity can be expected to have a high commission rate. This expectation is evident in TABLE 1where the IKONOS satellite data has the lowest omission levels and the digitized air photo with the highest proportion of missed trees. The omission trend indicates that the set of all possible trees which may be identified varies by data source. The commission trend also captures the differences in radiometric sensitivity of the sensors utilized.

When considering the efficacy of LM filtering of individual trees the results must be considered in reference to commission error, or false positives. As the omission level is largely a function of image spatial resolution, commission error indicates how well the LM filter is operating. Overall the IKONOS is performing the most favorable with high accuracy and moderate commission (TABLE 1). The MEIS imagery follows with accuracy less than the IKONOS but with a lower commission rate. The Ortho has the lowest level of accuracy and the highest level of commission. While the IKONOS has the highest accuracy rate, the commission level is higher than the MEIS which indicates a higher error level for the satellite source. While the MEIS commission error level is less than for the IKONOS, a preference for the satellite source may be justified by factors such as image spatial extent, ease of acquisition, and radiometric consistency across the image.

TABLE 1.
Comparison of LM filtering results for IKONOS and MEIS-II imagery (favourable proportions underlined).

	IKONOS	MEIS	Ortho
All	*n=199*	*n=209*	*n=199*
Correct	0.85	0.67	0.23
False positive	0.51	0.22	0.77
Missed	0.15	0.33	0.77
Plantation	*n=150*	*n=159*	*n=150*
Correct	0.81	0.62	0.19
False positive	0.11	0.05	0.70
Missed	0.19	0.38	0.81
Mature	*n=49*	*n=50*	*n=49*
Correct	1.00	0.80	0.22
False positive	1.76	0.78	0.60
Missed	0.00	0.20	0.78

Tree diameter and crown size ranges may be assessed to observe what trends exist of tree characteristics are related to LM stem identification. The level of commission from TABLE 1 should also be considered when assessing the relationship between accuracy and tree diameter (TABLE 2) and crown radius (TABLE 3). LM filtering of the satellite data produces favorable identification of stems across all size ranges. The rates for the MEIS are second to the IKONOS. The proportion of trees identified by DBH and crown size are poor across the entire range of characteristics for the Ortho.

IV. CONCLUSIONS

The IKONOS satellite data processed with a LM filter has correctly identified stems more often than identical filtering of airborne remotely sensed and scanned digital air photos of the same spatial resolution. The results are encouraging for forestry applications as the IKONOS high spatial resolution satellite has data with favorable acquisition and sensor characteristics.

ACKNOWLEDGEMENT

Paul Boudewyn and David Hill of the Canadian Forest Service (Pacific Forestry Centre) are thanked for collecting quality field data.

REFERENCES

[1] M. Wulder, K. O. Niemann, and D. Goodenough, "Local maximum filtering for the extraction of tree locations and basal area from high spatial resolution imagery," *Rem. Sens. Env.*, Vol. 73, pp. 103-114, 2000.

[2] S. Till, W. McColl, and R. Neville, "Development, field performance and evaluation of the MEIS-II multi-detector electro-optical scanner," Presented at the *Seventeenth Int. Symp. Rem. Sens. Env.*, Ann Arbor, Michigan, May 9-13, pp. 1137-1146, 1983.

TABLE 2.
Comparison of DBH estimates for IKONOS and MEIS-II data

Stand	*All*			*Plantation*			*Mature*		
DBH range (cm)	<35	35-70	>70	<35	35-70	>70	<35	35-70	>70
IKONOS n	*149*	*14*	*36*	*148*	*2*	*0*	*1*	*12*	*36*
IKONOS proportion correct	0.81	1.00	1.00	0.80	1.00	0.00	1.00	1.00	1.00
MEIS n	*158*	*14*	*37*	*157*	*2*	*0*	*1*	*12*	*37*
MEIS proportion correct	0.61	0.79	0.84	0.62	1.00	0.00	0.00	0.75	0.84
Ortho n	*149*	*14*	*36*	*148*	*2*	*0*	*1*	*12*	*36*
Ortho proportion correct	0.21	0.23	0.26	0.22	0.5	0.00	1.00	0.17	0.23

TABLE 3.
Comparison of LM filtering based on crown radius

Crown Radius (m)	*0 to 0.9*	*1 to 1.4*	*1.5 to 1.9*	*2 to 2.9*	*3 to 3.9*	*>4*
IKONOS n	*5*	*73*	*67*	*26*	*24*	*4*
IKONOS proportion correct	0.80	0.74	0.90	0.92	1.00	1.00
MEIS n	*6*	*76*	*71*	*27*	*25*	*4*
MEIS proportion correct	0.33	0.51	0.73	0.89	0.76	0.75
Ortho n	*5*	*73*	*67*	*26*	*24*	*4*
Ortho proportion correct	0.25	0.19	0.25	0.21	0.23	1.00

0-7803-7031-7/01/$17.00 (C) 2001 IEEE