Application of Satellite and GIS Technologies for Land-Cover and Land-Use Mapping at the Rural-Urban Fringe: A Case Study

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ABSTRACT: SPOT HRV multispectral and panchromatic data were recorded and co-registered for a portion of the rural-urban fringe of Toronto, Canada. A two-stage digital analysis algorithm incorporating a spectral-class frequency-based contextual classification of eight land-cover and land-use classes resulted in an overall Kappa coefficient of 82.2 percent for training-area data and a Kappa coefficient of 70.3 percent for test-area data. A matrix-overlay analysis was then performed within the geographic information system (GIS) to combine the land-cover and land-use classes generated from the SPOT digital classification with zoning information for the area. The map that was produced has an estimated interpretation accuracy of 78 percent. Global Positioning System (GPS) data provided a positional reference for new road networks. These networks, in addition to the new land-cover and land-use map derived from the SPOT HRV data, provide an up-to-date synthesis of change conditions in the area.

INTRODUCTION

REGIONAL AND MUNICIPAL PLANNERS require up-to-date information to effectively manage land development and plan for change. In urban areas, particularly at the rural-urban fringe, this change is very rapid. As a result, it is difficult to maintain up-to-date information on new housing and industrial/commercial developments. This is particularly true for regional municipalities whose jurisdictions cover large areas.

The land-use map, as a source of thematic information, has been an important component of urban and regional planning for many years. In areas where change is marginal or very slow, land-use maps that are considered relatively old (i.e., 10 to 20 years) may continue to portray adequately current conditions, and thus provide useful information. However, this is not the case in areas of rapid change, such as the rural-urban fringe, where the entire landscape can change over a short period of time. Here, fields and open areas are converted to residential subdivisions and commercial/industrial plazas. In such areas, the most recent map may be of little value to the person requiring up-to-date information.

Even with the availability of satellite imagery and computer storage of information, the stage has not yet been reached where up-to-date information can be rapidly and easily provided. However, steps are being taken to achieve this. In Ontario, for example, data obtained as part of the Ontario Basic Mapping (OBM) program are being digitized and input to geographic information systems. This provides baseline information for an area, but the information is only as up-to-date as the aerial photographs from which it was mapped. In practical terms, there has been a great deal of improvement in recent years in data collection, storage, and presentation. However, much information on land cover and land use is still five to ten years out of date and for many areas is too old for operational use. For example, for the Town of Markham at the rural-urban fringe of Metropolitan Toronto, the latest OBM maps were published in 1984. Thus, the land use shown for many areas is now incorrect. For a variety of planning purposes, it would be beneficial to have up-to-date information. The question is, how can this be provided rapidly and economically?

Remote sensing has been recognized as a useful means of supplying up-to-date information on activities within the urban environment, including the rural-urban fringe (Ehlers *et al.*, 1990; Forster, 1985; Jensen and Toll, 1982). However, it is felt that the interfacing of GIS technology with remote sensing will provide the maximum information content and analysis capabilities and thus be of benefit to land-use planners (Nellis *et al.*, 1990). It has been recognized (e.g., Quarmby and Cushnie, 1989; Forster, 1985; Welch, 1985) that there are many advantages to combining remotely sensed data with existing spatial, image, and statistical data, thereby maximizing the information upon which responsible decisions for land-use planning can be made. Geographic information systems (GIS) technology provides the medium for this integration of spatial data, and at the same time provides a powerful tool for the quantitative analysis of land-use change and map revision (Welch *et al.*, 1988). However, while GIS technology has grown exponentially, implementation of this technology for management applications has only experienced linear growth (Johnston, 1987).

Research is ongoing into the potential for digital image processing of high resolution imagery for mapping areas of rapid change (Gong and Howarth, 1991; 1990a; 1990b; Swann *et al.*, 1988). However, it remains difficult to map some point and linear features, particularly digitally, due to the fact that they are not always recognizable at the spatial resolution of the data, nor are they represented at their "true" location due to sensor and panoramic distortions inherent in satellite data collection. It has also proven difficult to digitally separate linear features such as road networks from surrounding land cover and land use (Schanzer *et al.*, 1990; O'Brien, 1988; Nevatia and Babu, 1980). This is largely due to the complexity of pattern recognition procedures required for tracing specific cultural edge features. Global Positioning System (GPS) data, on the other hand, are static and provide positional information for newly developed, presently unmapped features such as new roads.

Earlier work has examined visual and digital techniques for classifying SPOT HRV data for integration into a geographic information system with various types of digital data (Treitz *et al.*, 1990a; 1990b). The aim of this paper is to present a procedure whereby SPOT HRV imagery, GPS data, and land-use zoning information can be used in conjunction with existing OBM data to provide updated, intermediate map products that the planner can use between official survey-grade updates to the database. Accuracies of the procedure are evaluated.

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PLATE 1. A 10 m resolution color composite of the Markham study area. The area shown is approximately 4 km by 4 km.

STUDY SITE

The Town of Markham, located at the northeastern fringe of Metropolitan Toronto, Canada, has been the location of research concerned with mapping the changing conditions at the rural-urban fringe (e.g., Treitz *et al.*, 1990a; 1990b; Gong and Howarth, 1990a; 1990b; Martin *et al.*, 1988). The study location is centered on latitude 43° 53′ N, longitude 79° 18′ W and covers an area of approximately 200 sq km. The landscape is relatively flat and, with close proximity to Toronto, is subject to "urban sprawl." Typical of large North American cities, farmland and natural land are rapidly being converted to residential, industrial and commercial uses.

A study site measuring 16 sq km that contains a wide variety of land uses and land covers, as well as exhibiting significant change, was selected for detailed analysis and testing of the techniques (Plate 1). The area is representative of the environment within the region and has undergone significant change over the last ten years. Discussions with planners in the region revealed that it has been difficult to collect timely information on land-use change necessary to devise and implement land-development policies.

DATA DESCRIPTION

The SPOT HRV XS (multispectral mode) and P (panchromatic mode) data were recorded by the Canada Centre for Remote Sensing (CCRS) on 18 August 1989 at 1622 GMT for the Markham study area (Scene K615/J262). A summer scene was requested to optimize the spectral contrast between vegetated surfaces and cultural surfaces such as pavement, bare soil, construction areas, and buildings. The sun elevation and azimuth at the image center were 57° and 153°, respectively. The satellite sensor data were processed by CCRS using the MOSAICS system which corrects for Earth rotation, Earth curvature, off-nadir viewing, sensor alignment on the satellite, and satellite position, velocity, and attitude variations.

Global Positioning System (GPS) data were collected on 24 October 1989 using a Trimble Advanced Navigation Sensor (TANS) incorporated into the Trimble Pathfinder System. TANS is a two-channel sequencing GPS Navigation Sensor; it receives the L Band in C/A code which is broadcast by the NAVSTAR GPS satellites. By means of an automobile driven around the roads of the study site, data were collected at one-second intervals for approximately two hours using a single receiver in autonomous position mode. In this mode, the absolute accuracy of the GPS data is approximately 12 m CEP[1] (Lange, 1990). The receiver

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[1] CEP stands for Circular Error Probability and equates horizontal, two-dimensional accuracy to a median: 50 percent of the collected points will be inside a circle with radius 12 m and 50 percent of the points will be outside that radius. CEP is the horizontal accuracy standard adopted by the U.S. Department of Defense for radionavigation systems (U.S. Department of Defense, 1984).

antenna was attached to the roof of the automobile with a magnetic mount, and driving speeds ranged from 0 to 60 km per hour in the area covered. Data collection was limited to a time window between 1200 and 1830 GMT. During this time interval, no less than three GPS satellites were "in view" above the horizon, a requirement for two-dimensional coordinate positioning by triangulation. It is estimated that by mid-1991 sufficient satellites will be in orbit to provide 24-hour-a-day global coverage in two dimensions, and by mid-1992, full coverage will be available in three dimensions (Lange, 1990).

Generalized zoning data for Lots 11 to 15 of Concession 4 were digitized into the GIS from a map sheet produced by the Town of Markham (Scale 1:4,000). It should be noted that, although the zoning by-law information on these maps is kept up-to-date, the positions of parcel boundaries are not based on survey data, but are estimated from lot and concession coordinates from the original basemap. The zoning information was generalized to a level compatible with the satellite data and the land-cover and land-use classification scheme. For example, individual residential lots were not digitized separately, but were incorporated into a residential-land-use zone.

Digital OBM data of the study site were not yet available from the Ontario Ministry of Natural Resources. Instead, the data were obtained by digitizing original OBM map transparencies (1:10,000 scale) to OBM specifications and then importing them into the ARC/INFO environment. OBM specifications dictate that 90 percent of all well-defined features, with the exception of those unavoidably displaced by symbolization, shall be located within 0.5 mm of their true planimetric locations; 5 m at 1:10,000 scale. These specifications are comparable to the circular map accuracy standard (CMAS) (Maling, 1989). The OBM map of the area was published in 1984 and was based on 1982 aerial photography.

Supplementary data, used as ground confirmation for accuracy assessment, included photomaps at 1:5,000 scale produced from aerial photographs (1:8,000 scale) acquired in April 1987. Field reconnaissance data were also collected in September 1989.

METHODOLOGY

The study involved the combination and analysis of XS and P data from the HRV sensor on the SPOT satellite, GPS data, land-use zoning maps, and OBM data. An outline of the procedures used in this study is presented in Figure 1.

PREPROCESSING

Preprocessing of the SPOT HRV data was performed using a Dipix ARIES III Image Analysis System, as well as software developed at the University of Waterloo on a VAX 11/785 computer in FORTRAN 77. SPOT HRV XS and P data were combined to preserve the spatial and spectral information of the two data sets (Holder, 1990). First, SPOT HRV P data were resampled to 20 m and co-registered with SPOT HRV XS data using a first-order polynomial transform and nearest-neighbor resampling algorithm. The residual errors were 4.6 m in both the x and y direction (0.23 pixels, 0.23 lines, ten ground control points (GCPs)) and are well within the spatial resolution of the image data sets.

Second, the corrected SPOT HRV XS data were resampled to 10-m spatial resolution using a nearest-neighbor resampling routine. As a result, the SPOT HRV XS data possess similar spatial and geometric characteristics to the original SPOT HRV P data. The nearest-neighbor resampling algorithm was used to preserve the statistical properties of the data.

Third, the SPOT HRV data were geometrically corrected to the Universal Transverse Mercator (UTM) coordinate system. GCPs were identified on OBM 1:10,000-scale map sheets and on the SPOT HRV image data (line and pixel coordinates). A first-order polynomial transform was calculated to model the geometric distortions in the SPOT HRV data. Finally, a nearest-neighbor resampling algorithm was applied to the SPOT HRV data to produce the geometrically corrected image. The residual errors were 2.5 and 2.1 m in the x and y directions, respectively (0.25 pixels, 0.21 lines, ten GCPs). The registration error for the rectified 10-m SPOT data can also be stated as 4.9 m based on the circular mapping accuracy standard (CMAS) (Maling, 1989). This estimate falls within the accuracy levels of the OBM data before digitization.

Correlation coefficients were calculated for the digital values of the SPOT HRV XS and P data. High values were observed between the panchromatic and the red band (0.950) and the panchromatic and the green band (0.954). A negative correlation coefficient (-0.183) was observed between the panchromatic and infrared bands. To avoid data duplication or redundancy, the SPOT HRV infrared band at 10-m spatial resolution was used with the SPOT HRV panchromatic band for subsequent classification. For visual interpretation, an edge enhancement in the form of a high-pass filter was applied to the data to enhance the boundaries between cover types, while at the same time smoothing some of the internal heterogeneities within cover types (Holder, 1990). A three-band color composite with a spatial resolution of 10 m was produced consisting of an infrared band, an edge-enhanced panchromatic band, and the panchromatic band (Plate 1).

GPS data were initially downloaded into ARC/INFO and a point-to-vector conversion was applied to the raw data. Many anomalous vectors occurred where the vehicle (receiver) became stationary (e.g., at intersections) or when a road was traveled more than once (Figure 2). The data were edited in order to produce a single-line road network map. GPS vector coverage was processed to build polygon topology, and an associated polygon attribute table was produced. The topology that resulted was necessary for the CLEAN command with its "poly" option to collapse the small elongate polygons which existed in the coverage (ESRI, 1989)(Figure 2).

The GPS data were cleaned using a fuzzy tolerance of 10.5 (m) to collapse small unwanted polygons (e.g., cul-de-sacs and double-line road networks) without changing the overall representation of the area. The fuzzy tolerance determines the resolution of the output coverage because no two coordinates in the output coverage resulting from the clean operation will be within this distance of one another (ESRI, 1989). The remaining unwanted arcs were visually identified and recoded to an identification value of 500 so that they could be distinguished from the wanted arcs. All arcs with a value less than 500 were extracted from the coverage and stored in another coverage using the RESELECT command in ARC. This was done through the use of a set of logical criteria which were applied to the feature attributes. Finally, additional editing was required to delete and connect a few remaining arcs/polygons (Figure 3). The final coverage that resulted was exported to TYDAC SPANS.

Land-use zoning information was digitized using TYDAC's TYDIG module, and was then imported into the SPANS environment. Zoning information classes of interest include floodplain, public/institutional, residential, industrial/commercial, local commercial, and utilities (Figure 4). OBM data (1:10,000 scale) were digitized and edited using ARC/INFO software, and exported to TYDAC SPANS.

CLASSIFICATION

Standard per-pixel classification algorithms are based on the assumption that the distribution of spectral values for the land-use classes of interest demonstrate a normal or Gaussian distribution and are separable. This assumption is rarely true in an urban environment where land-use classes possess a wide range of spectral reflectance values that overlap in spectral space, and thereby confound the probabilistic decision rules com-

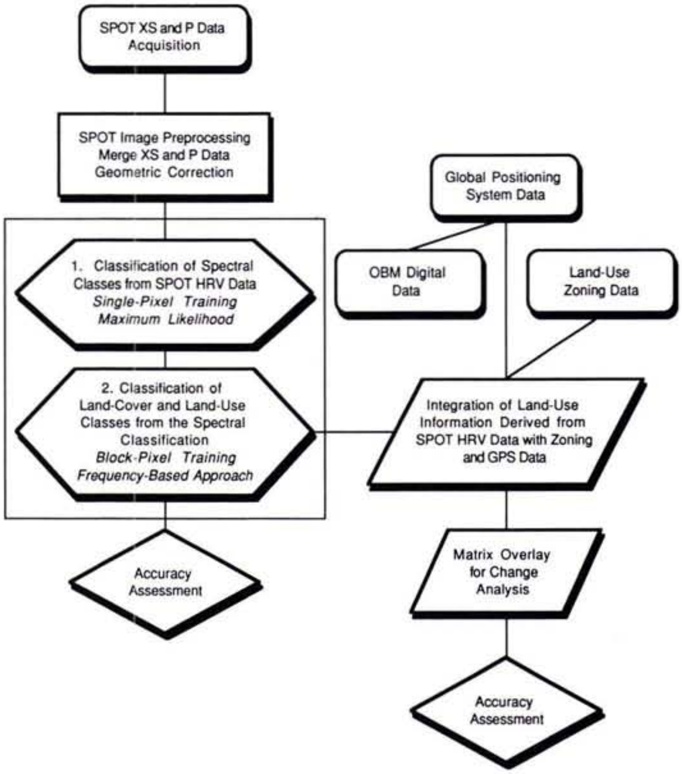

FIG. 1. Flow chart depicting the procedures followed in this study.

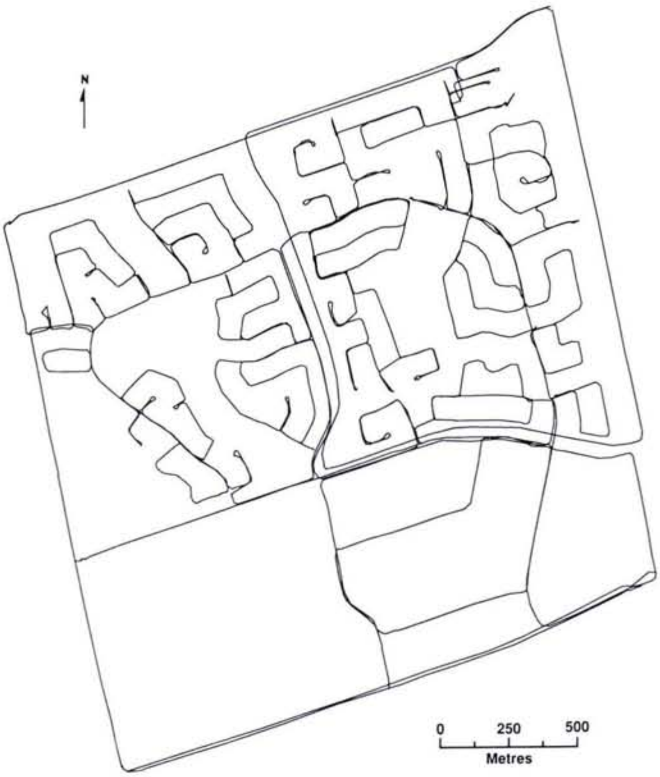

FIG. 2. Global Positioning System data after point-to-vector conversion.

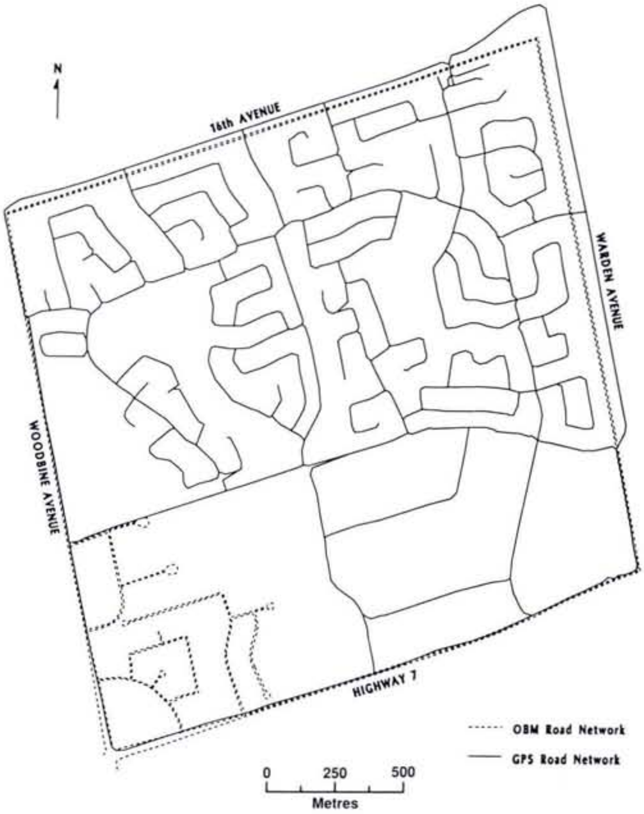

FIG. 3. Final edited version of the GPS road network overlain with OBM road data.

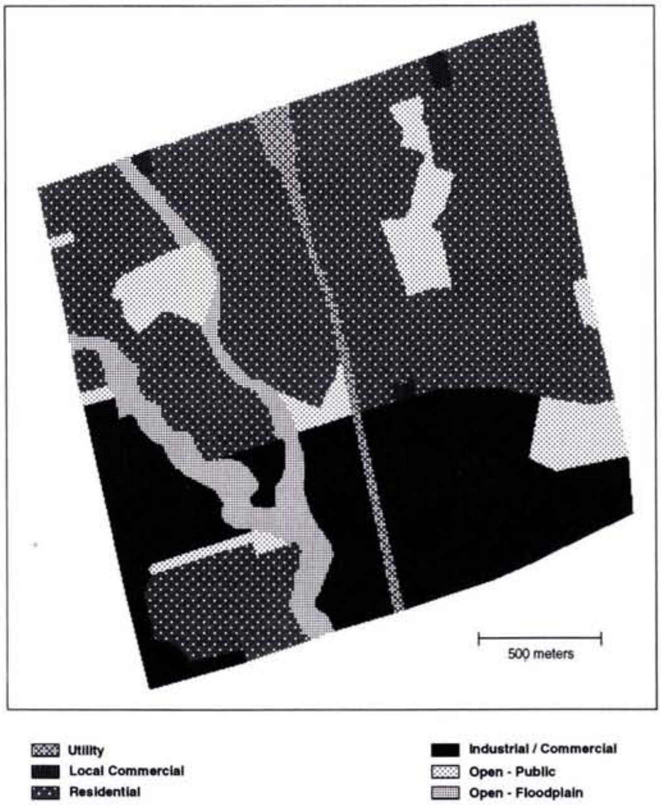

FIG. 4. Land-use zoning information.

monly used in per-pixel classifiers (Jensen and Hodgson, 1987; Khorram *et al.*, 1987; Haack *et al.*, 1987; Toll, 1985). In this study, an indirect classification approach was used for an area of approximately 16 sq km (Gong and Howarth, 1991).

The first stage in the classification procedure involved classifying the SPOT HRV XS and P data into eight spectral classes using the conventional supervised maximum-likelihood classification. The eight spectral classes used were bare and dry soil, forest and trees, grassland, crop land, pavement, fallow land, industrial roofs, and residential roofs. These spectral classes were selected on the assumption that they possess a minimal amount of intra-class variability. In defining the spectral classes, single-pixel training was used to ensure that the training data sampled this low intra-class variability. A minimum of 45 pixels was identified for each spectral class. This satisfies the requirement for a representative sample, as recommended by Swain and Davis (1978). During a second stage, a frequency-based method was used to classify the land-cover and land-use classes from the results of the spectral classification (Gong and Howarth, 1991; Zhang *et al.*, 1988; Wharton, 1982)(Figure 1).

The land-cover and land-use classes identified for the rural-urban fringe are outlined in Table 1 (Martin *et al.*, 1988). The main components of the industrial/commercial class are large industrial parks and shopping plazas with low-rise buildings and large associated parking areas. Smaller commercial areas (i.e., local commercial, as identified in the zoning data) are also incorporated into this class. Industrial and commercial land uses are grouped together due to their spectral, locational and functional similarities (Martin and Howarth, 1989). The open space class consists of cultivated farmland and parkland. Rough, pasture-like terrain is also a component of this class (Martin and Howarth, 1989). The purpose of this study was to identify the current land cover and land use for an area undergoing rapid urban growth. This includes the identification of land conversion activities. It should be noted that, as an area evolves from an existing land cover (e.g., natural vegetation) to a fully developed cultural class (e.g., residential), a variety of changes occur in the spectral reflectance. As a result, several stages in the land conversion were aggregated into two classes: "cleared land" (e.g., clearing, subdivision) and "under construction" (e.g., transportation, building, and landscaping) (Martin *et al.*, 1988; Jensen and Toll, 1982). Cleared land exhibits high uniform spectral reflectance, characteristic of bare soil, while sites under construction possess a more varied high reflectance resulting from building foundations and superstructures, construction materials, and partially installed roads and utilities (Martin *et al.*, 1988).

In the second stage, the eight land-cover and land-use classes listed in Table 1 were classified from the results of the spectral classification of the SPOT HRV data using a frequency-based approach (Gong and Howarth, 1991; Zhang *et al.*, 1988; Wharton, 1982). This procedure involved three steps. First, an 11- by 11-pixel window was moved over the classified image. The 11- by 11-pixel window was selected because it provided the optimum classification accuracy in tests of window sizes ranging from 3 by 3 to 21 by 21 (Gong and Howarth, 1991). Within each particular 11- by 11-pixel window, the frequencies of all eight spectral classes were counted and assigned to the center pixel of the window as spatial features for the final classification of this pixel. For example, the 121 pixels in an 11- by 11-pixel window in a residential area will consist of a certain proportion of each of the eight spectral classes. Second, mean frequencies for the eight spectral classes were extracted from the frequency features for each land-cover and land-use class using a block training (i.e., contiguous pixel) sampling strategy (Gong and Howarth, 1991). As a result, the average proportion of each spectral class contained within a specific land-cover/land-use class was calculated. Finally, the frequency features for each pixel were classified, according to the mean frequencies, using a minimum-distance classifier. The result is shown in Figure 5.

TABLE 1. LAND-USE AND LAND-COVER CLASSIFICATION SCHEME FOR DIGITAL CLASSIFICATION OF SPOT HRV DATA.

Class	Abbreviation
Low-Density Residential	LDR
Cleared Land	CL
Under Construction	CS
Industrial/Commercial	I/C
Open Space	OS
Woodland	W
Cropland	C
Fallow Land	FL

CLASSIFICATION ACCURACY ASSESSMENT

The accuracy of the SPOT HRV classified image was assessed first by examination of the training-area pixels, and second by independent test-area samples. Test areas (i.e., pixels independent of the maximum-likelihood decision rules) consisted of a series of 5- by 5-pixel blocks, and were selected randomly from a color composite of the study area. A minimum of 100 pixels was selected for all classes, regardless of abundance in the study area. "Classification accuracy" refers to the agreement between the training-area pixels and the ground-truth information, while "interpretation accuracy" refers to the agreement between the test-area pixels and the ground-truth information. Accuracy assessments, expressed in percent, are reported for each class along with a mean estimate for the study site. Kappa coefficients were calculated for each class, and for the digital classification as a whole (Cohen, 1960). Rosenfield and Fitzpatrick-Lins (1986) identified the Kappa coefficient as a suitable accu-

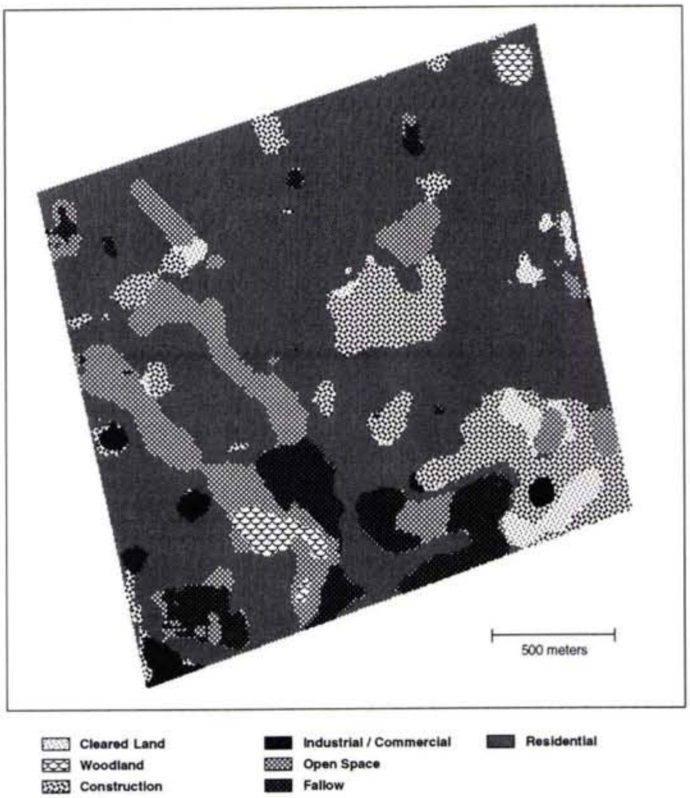

FIG. 5. SPOT HRV digital classification.

racy measure in thematic classification for representing class accuracy. Its strength lies in the fact that it takes all the elements of the confusion matrix into consideration, in contrast to the overall accuracy measures which only consider the diagonal elements of the matrix.

DATA INTEGRATION

The data sets (SPOT HRV digital classification, GPS road network data, zoning data, and OBM data) of various forms (raster and vector) were imported into a TYDAC SPANS geographic information system. A matrix-overlay analysis was performed to construct a map containing the significant information from the land-use zoning information and the land-cover and land-use classification derived from the SPOT HRV data (Table 2 and Plate 2). A matrix overlay allows the analyst to select only those class combinations, arising through the combination of the source data sets, that are relevant to the study. The objective here was to incorporate up-to-date land-cover information into the known zoning information. SPOT HRV data were able to show the changes that were occurring within the zones in terms of development stage (e.g., cleared, under construction). Additional overlay techniques were used to integrate GPS data with the matrix-overlay map. The GPS data provided a simple means of mapping the new road networks, with accuracy levels comparable to the resolution of the SPOT HRV data. Together, the three data sets provide a good information source for land use and land cover, as well as development activities, at the time of SPOT HRV data acquisition. A hardcopy map containing the most up-to-date information from the three data sets was then output on a color plotter. This map provides an intermediate information source between provincial updates of OBM data.

MAP OVERLAY ACCURACY

Currently, there is no reliable method for comparing map data when both maps may contain error. In this study, it was desirable to determine the accuracies for each of the 19 classes generated by the combination of data from the land-use zoning data and the digital classification through the matrix-overlay analysis. The first six classes listed in Table 2 represent the classes derived from the land-use zoning map produced by the Planning Department of the Town of Markham. Even though the zoning boundaries are not based on survey data, it was assumed that the identification or classification of the polygons is correct. Therefore, the generalized zoning classes were assumed to have an accuracy of 100 percent. It was difficult to assess boundary-location accuracy because no accuracy measure was attached to the zoning map.

TABLE 2. LAND-USE AND LAND-COVER CLASSIFICATION SCHEME FOR THE GIS MATRIX OVERLAY.

Floodplain
Public/Institutional (parkland, schools, church lands)
Residential (single-family dwelling)
Industrial/Commercial
Local Commercial
Utility (hydro corridor)
Floodplain/Open Space
Floodplain/Woodland
Public/Institutional/Cleared Land
Public/Institutional/Construction
Public/Institutional/Open Space
Public/Institutional/Woodland
Residential/Cleared Land
Residential/Construction
Industrial/Commercial/Cleared Land
Industrial/Commercial/Construction
Industrial/Commercial/Open Space
Local Commercial/Cleared Land
Local Commercial/Construction

However, when the zoning classes occurred in combination with classes derived from the SPOT HRV digital classification (i.e., the remaining 13 classes),,the interpretation accuracies of the SPOT HRV-derived classes were used as a measure of those class accuracies. In this sense, the SPOT HRV classification served as the ground truth or prime reference for the resulting class combinations. This method follows the assertion by Newcomer and Szajgin (1984) that the highest accuracy achievable for any GIS output product is restricted to the least accurate data plane in the source data. Therefore, the interpretation accuracy of each theme in the SPOT HRV classification represents the limiting factor for the resulting class accuracies. These accuracies were then averaged to provide an estimate for the overall interpretation accuracy of the map.

RESULTS

SPOT HRV DIGITAL CLASSIFICATION

The overall Kappa coefficients for the training- and test-area data were 82.2 percent and 70.3 percent, respectively (Tables 3 and 4). The highest Kappa values for training-area data were achieved for woodland (100 percent), low-density residential (93.1 percent), industrial/commercial (87.8 percent), cropland (80.9 percent), and fallow land (80.4 percent) (Table 3). High Kappa values for test-area data included cleared land (100 percent), cropland (100 percent), and low-density residential (83.3 percent) (Table 4). It should be noted that Kappa coefficients were higher for test area data than training area data for cleared land, construction sites, and cropland (Tables 3 and 4). This is probably a function of the block-sampling technique used for

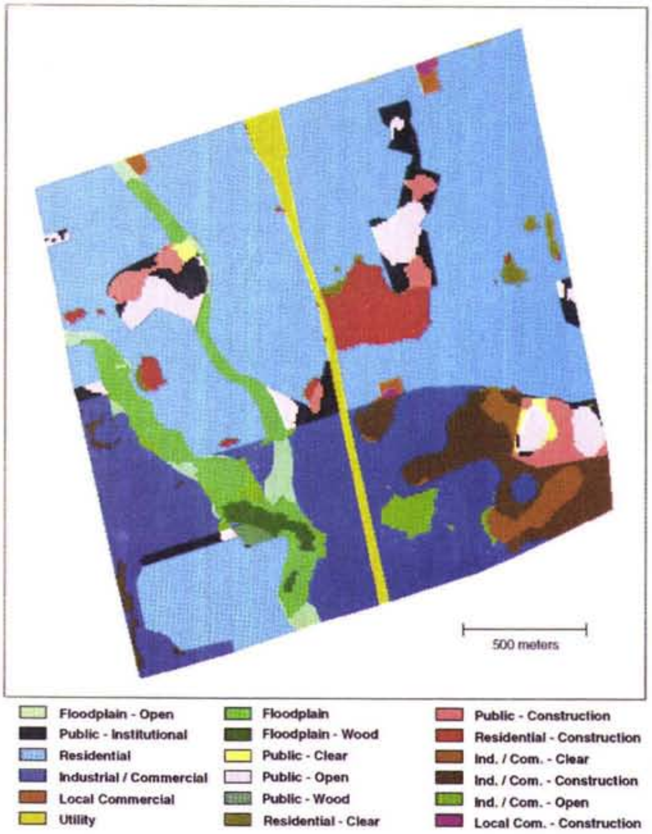

PLATE 2. A land-use and land-cover map generated by a matrix-overlay analysis combining zoning information with the digital classification.

TABLE 3. CONFUSION MATRIX AND SUMMARY STATISTICS FOR TRAINING-AREA DATA*

	Classified Results											
	LDR	CL	CS	I/C	OS	W	C	FL	Total	Omission errors(%)	Classification accuracy(%)	Kappa coefficient(%)
LDR	**2350**				33			57	2440	3.7	96.3	93.1
CL	7	**43**	25						75	42.7	57.3	55.3
CS		186	**378**						564	33.0	67.0	63.7
I/C			59	**472**					531	11.1	88.9	87.8
OS	9				**241**			101	351	31.3	68.7	65.6
W						**70**			70	0.0	100.0	100.0
C					129		**642**		771	16.7	83.3	80.9
FL	4				48			**235**	287	18.1	81.9	80.4
Total	2370	229	462	472	451	70	642	393	5089	12.9		
Commission errors (%)	0.8	81.2	18.2	0.0	46.6	0.0	0.0	40.2	12.9			

Mean classification accuracy = 80.5%
Overall classification accuracy = 87.1%
Overall Kappa coefficient = 82.2%
Percent unclassified pixels = 0.0%

*The abbreviated classes are listed in Table 2.
Mean classification accuracy refers to the average of all class accuracies.
Overall classification accuracy refers to the total correctly classified pixels.

TABLE 4. CONFUSION MATRIX AND SUMMARY STATISTICS FOR TEST-AREA DATA*

	Classified Results											
	LDR	CL	CS	I/C	OS	W	C	FL	Total	Omission errors(%)	Interpretation accuracy(%)	Kappa coefficient(%)
LDR	**175**							25	200	12.5	87.5	83.3
CL		**100**							100	0.0	100.0	100.0
CS		25	**75**						100	25.0	75.0	72.6
I/C	25		4	**71**					100	29.0	71.0	68.5
OS					**25**			75	100	25.0	25.0	18.2
W					50	**50**			100	50.0	50.0	47.1
C							**100**		100	0.0	100.0	100.0
FL	26							**74**	100	26.0	74.0	67.8
Total	226	125	79	71	75	50	100	174	900	25.6		
Commisssion errors (%)	22.6	20.0	5.1	0.0	66.7	0.0	0.0	57.5	25.6			

Mean interpretation accuracy = 72.8%
Overall interpretation accuracy = 74.4%
Overall Kappa coefficient = 70.3%
Percent unclassified pixels = 0.0%

*The abbreviated classes are listed in Table 2.
Mean interpretation accuracy refers to the average of all class accuracies.
Overall interpretation accuracy refers to the total correctly classified pixels.

the test-area definition, where test areas were collected as 25-pixel blocks.

Significant confusion occurred between cleared land and construction, as evidenced by high classification omission errors (42.7 percent and 33.0 percent, respectively) and commission errors (81.2 percent and 18.2 percent, respectively) (Table 3). This is not surprising because cleared areas occur within construction sites as part of the spectral make-up of that class. There was also confusion in class assignment for the vegetated classes: open space, cropland, and fallow land (Table 3). The spectral characteristics of these classes are similar because they contain the same cover type in the form of grasses. For test-area data, residential, open space, and fallow land exhibited some confusion, as did open space and fallow, and woodland and open space (Table 4).

SPOT HRV / ZONING DATA OVERLAY

The average interpretation accuracy for the land-cover and land-use map produced through the matrix overlay of the zoning information and the SPOT digital classification was 78 percent (Table 5). As explained below, this is indicative of the individual components from each of the two source maps, and should be considered only as an estimate of the map's accuracy.

DISCUSSION

Welch (1982) stated that medium- to large-scale aerial photographs with ground resolutions ranging from 0.5 to 3 m are required for urban land-use mapping for Levels II and III of the four-level classification hierarchy proposed by Anderson *et al.* (1976). This was supported by Konecny *et al.* (1982) who demonstrated that a resolution of 5 m or less is required for urban cartographic mapping. However, these types of resolutions may not be necessary for thematic mapping, where detection of themes is more important than identification (Forster, 1985). For example, Welch (1982) considered that a minimum of four pixels is necessary to identify basic land parcels reliably, and that a sensor with an instantaneous field of view of 30 m may be adequate for urban centers in North America. Although the results are inconclusive, SPOT HRV XS and P data may be more amenable to urban monitoring through the improved detection of high frequency targets resulting from the finer spatial resolution.

Satellite remote sensing is capable of providing information

TABLE 5. LAND-USE AND LAND-COVER CLASSIFICATION ACCURACY FOR THE GIS MATRIX OVERLAY.

Floodplain	100%
Public/Institutional (parkland, schools, etc.)	100%
Residential (single-family dwelling)	100%
Industrial/Commercial	100%
Local Commercial	100%
Utility (hydro corridor)	100%
Floodplain/Open Space	25%
Floodplain/Woodland	50%
Public/Institutional/Cleared Land	100%
Public/Institutional/Construction	75%
Public/Institutional/Open Space	25%
Public/Institutional/Woodland	50%
Residential/Cleared Land	100%
Residential/Construction	75%
Industrial/Commercial/Cleared Land	100%
Industrial/Commercial/Construction	75%
Industrial/Commercial/Open Space	25%
Local Commercial/Cleared Land	100%
Local Commercial/Construction	75%
Average Interpretation Accuracy	78%

on development activities in the rural-urban fringe (Forster, 1985; Jensen and Toll, 1982). For example, it has been found that a great deal of spatial detail can be extracted both visually and digitally from SPOT data (Treitz *et al.*, 1990a; 1990b; Ehlers *et al.*, 1990; Gong and Howarth, 1990b; Li *et al.*, 1989; Martin *et al.*, 1988). The spatial resolution of SPOT HRV XS and P data (20 m and 10 m, respectively) is able to sample high-frequency land-use parcels characteristic of a typical North American urban environment (Stromquist *et al.*, 1988; Welch, 1985). As a result, there are fewer mixed pixels resulting in sharper boundaries in a heterogeneous environment such as the rural-urban fringe.

The two-stage classification algorithm applied in this study was relatively successful in identifying residential and industrial/commercial land use from SPOT HRV XS and P data. This is due to the ability of the algorithm to model the spectral and spatial characteristics of these classes (Gong and Howarth, 1991). Of particular interest in land-change analysis is the detection of land being converted from an existing land cover to either residential or industrial/commercial land use. Here, the classifier had some difficulty separating cleared land from land under construction, as exhibited by Kappa coefficients of 55.3 percent and 63.7 percent, respectively, for training area data, and 100 percent and 72.6 percent for test area data. This is understandable because their spectral characteristics are very similar and large areas of cleared land will occur within a construction site. However, more detailed spectral class components may be needed to model these land-cover and land-use classes. The confusion between woodland and open space for the test-area data may be explained by the fact that areas of sparse tree cover were sampled in the test-area data.

The matrix-overlay analysis technique is a convenient method of combining land-cover and land-use classes from two separate data sets. In fact, combining data from a variety of sources can actually enhance the value of the information contained in the individual layers (Chrisman, 1987). Here, the important information from the digital classification of the SPOT HRV data and the zoning data were identified within the matrix to create new land-cover and land-use classes that portrayed the changing conditions at the rural-urban fringe. For example, cleared land and construction areas could be identified within residential and industrial/commercial areas to provide data on the extent of development within those land-use classes. However, it is difficult assigning an accuracy measure to the new data when one or more of the data sets cannot be assumed to be 100 percent correct.

GIS products must be examined with reference to the quality of the source data, as well as the decision criteria used in the analysis. A number of authors have examined the concepts of accuracy and error in geographic information systems (Foody, 1988; Walsh *et al.*, 1987; Drummond, 1987; Chrisman, 1987; Newcomer and Szajgin, 1984; Vitek *et al.*, 1984). Even though it is recognized that error statements or evaluation matrices are required for data input to a GIS or generated within a GIS (Dicks and Lo, 1990; Story and Congalton, 1986; Vitek *et al.*, 1984), there is no standard method by which to derive this assessment. As a result, GIS products rarely possess a quality indicator. This is particularly true for boundary maps of discontinuous themes (Drummond, 1987). Foody (1988) expressed a need to include more than a single accuracy measure for a classified remotely sensed image in order to account for the spatial variability of spectral response, and hence accuracy, as a function of viewing geometry. However, due to the narrow field of view experienced for the coverage in this study, it was felt that this precaution was unnecessary.

Hord and Brooner (1976) identified three components that determine the quality of a thematic map product. These are errors in boundary location, map geometry, and classification. These types of errors in source documents are compounded during overlay analysis. Two types of errors affect the accuracy of products generated by a geographic information system. These are inherent errors, or errors present in the source data, and operational errors that arise from data capture and manipulation within the GIS (Walsh *et al.*, 1987). Operational errors may further be categorized as positional and identification errors, and in combination are a component of every thematic overlay (Newcomer and Szajgin, 1984). The authors add that the accuracy of products generated through GIS manipulation is a function of the number of layers involved in the analysis, the accuracy of the individual layers, and the frequency of coincident errors at similar locations within several map layers.

To date, there is no clear consensus on how to assess the accuracy of a map that has been created by combining selected classes from two maps using a matrix-overlay technique. The primary question that comes to mind is "what is to be used as the reference or ground truth for the new map product?" One method of obtaining an accuracy measure would be the acquisition of in-depth ground information obtained for the area that corresponds to the SPOT HRV data acquisition and land-use zoning information. For a proper accuracy assessment, a knowledge of the class combinations derived from the matrix overlay must be anticipated in advance. This is difficult, if not impossible. However, it may be proven over time that certain land-cover and land-use classes are useful and these will become the reference for ground truth data collection. At any rate, accuracy assessment for this type of map product, where data components are selected from a variety of sources and then integrated, needs to be addressed in future studies.

Other features of importance for rural-urban fringe monitoring include road networks because these provide the framework for land-use change and development (Forster, 1985). Although algorithms are being developed to extract these types of linear features from SPOT HRV data, GPS data provide an attractive method by which linear features can be mapped quickly and accurately. GPS data can potentially provide the positional information required for the location of new road networks within the spatial context of the SPOT HRV data, while the SPOT HRV XS and P data provide the spatial information for the thematic data. Because GPS data are collected as digital point data, they are suited to data integration within a GIS environment. To achieve positional accuracies comparable to OBM accuracy specifications, however, it is recommended that GPS data be collected in differential mode in which two GPS receiver/recorders are used.

An integrated approach is optimal in providing the land-use planner with the maximum information content and benefit. This integrated approach maximizes the spatial information content and positional accuracy of land-use change detection. While SPOT HRV data provide a means of monitoring the rate of change with respect to land-cover conversion and construction activities, other forms of digital data provide the positional reference for new and existing land covers and land uses. Through the integration of varied data sets, the land-use planner is able to make responsible decisions based on existing information within the digital database, as well as create new information through various spatial analysis techniques. In this study, the SPOT HRV, GPS, and land-use zoning data complement the existing OBM data and provide a means for land-use planners to monitor development in the rural-urban fringe.

GIS technology provides a suitable environment for the integration and analysis of image, spatial, and statistical data. However, certain editing and analysis procedures are more suited to particular GIS platforms. This is particularly due to the fact that certain systems handle vector or raster data more efficiently. For this reason, ARC/INFO was selected for handling a majority of the vector processing, whereas TYDAC SPANS was selected for the overlay analysis. ARC/INFO currently provides extensive vector editing functions, whereas SPANS, a raster/quadtree based system, provides effective overlay analysis capabilities.

CONCLUSIONS

This study provides a natural extension of current research in rural-urban fringe monitoring using SPOT HRV data. The ability to extract land-use information from spectral data has long been a problem faced by remote sensing scientists. The classification results described here for land-cover extraction from SPOT HRV data are encouraging. A two-stage digital analysis algorithm incorporating a spectral-class frequency-based contextual classification of eight land-cover and land-use classes achieved an overall Kappa coefficient of 82.2 percent for training-area data and a Kappa coefficient of 70.3 percent for test-area data. This type of approach, where contextual information is incorporated into the digital decision rules, is necessary for classification of high-resolution data such as from the SPOT HRV system. It is evident that SPOT HRV XS and P data provide sufficient detail to routinely update map information at scales as large as 1:10,000. This can be attributed to the incorporation of spectral classes within the image, as well as structural information within the land-use classes.

In this study, it was demonstrated that classified digital image data can enhance the information portrayed on a land-use zoning map. Because SPOT HRV data records timely land-cover information, the stages of development that are occurring on the ground can be monitored. Through the integration of zoning information, and land-cover and land-use information obtained through the digital classification of SPOT HRV data, an intermediary map product for monitoring the changing landscape within large areas (e.g., regional municipalities) can be produced. This is particularly true for areas of rapid change such as the rural-urban fringe. As digital classification techniques for the identification of land-use classes improve, and GIS and image analysis systems (IAS) become more fully integrated, this technique will provide a valuable method by which planners can monitor the activities within their jurisdictions.

Significant research is still required in the area of accuracy assessment where a variety of data sources are integrated to create new information. This is of particular importance when information extraction from the source documents is selective, rather than complete. Accuracy measures must be made available for source data, as well as for new information created through spatial analysis techniques within a geographic information system environment.

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