UPDATING URBAN STREET NETWORK FILES WITH HIGH RESOLUTION SATELLITE IMAGERY

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ABSTRACT

Digital street network files, such as Statistics Canada's Area Master File (AMF), are of increasing importance in mapping and GIS applications for the Census, municipal operations and in vehicle navigation. Rapid urban growth makes it a challenge to keep the files up-to-date in a cost effective manner. The heightened interest in digital network files has also raised questions about the geometric and positional accuracy of existing files.

Statistics Canada in cooperation with Environment Canada is conducting research to assess the feasibility of using high resolution satellite imagery with visual interpretation techniques to update urban street network files and identify newly urbanized areas. Excellent results have been achieved in the delineation of arterial roads and subdivsional collectors. Approximately 86% of subdivisional streets were successfully delineated in newer residential areas within the study sites. Older subdivisions with well treed streets and industrial-commercial developments were problematic. Positional accuracy of 16 metres was attained with off-nadir SPOT-PLA imagery.

INTRODUCTION

The recent availability of high resolution imagery from the SPOT satellite have led to increased interest in the use of satellite data for large scale mapping applications, (Thirwall et al, 1988; Begin et al, 1988), and detailed land use assessments, (Buchan and Hubbard, 1986; Milazzo and DeAngelis, 1984; Hernadez et al, 1984). Mapping of land use change and rural to urban land conversions are topics of interest to both Environment Canada and Statistics Canada. Environment Canada has been monitoring land use changes in the rural urban fringe of major urban centred regions across Canada for the last twenty years. Statistics Canada requires an up-to-date geographic base to support the Census and other surveys. These complementary interests led to cooperative evaluation of the potential of high resolution satellite imagery, SPOT and TM, to support these applications.

This paper reports on the technical issues, methodology and results from the cooperative study. Specifically, it evaluates the utility of SPOT and TM transparencies, with visual based interpretation, for updating digital street network files, such as Statistics Canada's Area Master File (AMF). The following issues are addressed:

1) comparative merits of Landsat-TM, SPOT-PLA and SPOT-MLA for the

task,

2) feature resolution - what features can be identified and delineated. How often are they correctly identified, and what are the magnitude for errors of omission and errors of commission,

3) factors which complicate interpretation,

4) geometric and positional accuracy of results, and

5) compatibility with existing AMF.

Study Sites

The problem of keeping street network files up to date is most acute in the urban fringe of major urban conurbations where development pressures are most concentrated. Two study sites covering a variety of land uses and development characteristics in the urban fringe of Ottawa and Toronto were chosen for studying the limitations of image data and the factors which affect interpretation accuracy.

The Town of Orleans, one of the fastest growing satellite communities in the national capital region surrounding Ottawa, is typical of many expanding suburban communities across Canada in terms of dwelling characteristics and land cover mix. The community is characterized by a small core of older residential neighbourhoods with houses of 25 years or more in age, aligned in a modified grid street pattern, in the mid-eastern part of the study site. A commercial strip exists along the two main thoroughfares. Surrounding the established core are more recent residential subdivisions, composed mainly of detached single family houses with some row houses. These were built within the last twenty years, and are typified by curvilinear streets. Large areas of new development are located in the southern portion of the town.

The second study site is a portion of the suburb of Rexdale, in the northwest section of Metropolitan Toronto. This area encompasses a diversity of land uses including warehousing, light industries, and residential neighbourhoods of varied ages, dwelling types and tree cover. The older residential neighbourhoods, in the middle eastern part of the study site, is predominantly detached bungalows, approximately 30 to 50 years old. Mature trees line the streets with the houses uniformly set back from the curbs. Progressing northwards, one encounters a mix of row houses, semi-detached and detached houses that are 10-20 years old. Mature trees are generally absent from these areas, except in some of the row house developments. At the northern edge of the site are large, irregularly shaped single family houses, 5-10 years in age. This site provides a complex land use and buildings mix to explore the limitations of the data set.

METHODOLOGY

Inputs

The following data were used in the study:

1) SPOT-PLA (10 metres spatial resolution) and MLA (20 metres spatial resolution) test scenes were acquired for the Town of Orleans. The

PLA and MLA scenes, dated August 5, 1987, were taken with look angles of 27.89 and 28.27 degrees, respectively. For Rexdale, a regular system geocoded PLA image, dated June 4, 1987 with a look angle of 2.60 degrees, was used to cover the site.

2) Landsat TM (30 metres spatial resolution) colour composites, Bands 2, 3 and 4, dated June 186 for Orleans and May 186 for Rexdale.

3) 1:10K topographic maps for Orleans and Rexdale to serve as reference bases for creation of 1:20K base maps for image interpretation and delineation of roads. The maps for Orleans and Rexdale are derived from 1979 and 1982 air photos, respectively.

4) 1:2K engineering maps to serve as benchmarks for positional verification. The engineering maps for Orleans were compiled from May 1983 photos, while the Rexdale coverage was compiled from 1982 photos.

5) 1:5K, 1988 orthophotos of the Rexdale study site to provide ground truth data.

6) Area Master File (AMF) for the City of Gloucester which covers a large part of Orleans study site. This AMF was last updated in 1987 using municipal maps.

Procedures

1) Selected main arterial roads from 1:10K topographic maps were digitized using ARC/INFO and replotted at 1:20K to serve as a reference base to guide image interpretation.

2) Image interpretation:

   a) Roads were identified and delineated in pencil onto individual 1:20K reference maps from the TM, SPOT-MLA and SPOT-PLA transparencies, in their respective sequence, for the Orleans study area. Visual interpretation was carried out using the PROCOM-2 Image Analysis System, an analogue projection device. Visible landmarks, such as schools, hospitals, parks, prominent buildings, etc. were also noted on the base map.

   b) The same procedure as (a), but using only PLA imagery was then carried out on the Rexdale study site.

3) Feature resolution assessment - the delineation results were digitized and plotted at 1:2K and 1:5K, and compared with up-to-date air photos, topographic maps, engineering maps and the AMF to determine the accuracy of the captured features and the causes of error. Field checks were conducted where uncertainty existed.

4) For Orleans, the delineation results were transformed from UTM to three degree Transverse Mercator projection, then plotted at 1:2K for overlay and comparison with the engineering maps to assess the positional accuracy of the results. Positional error was evaluated by measuring the offset between the position of road intersections on the delineation overlay and the position of the same intersection on the engineering map.

5) AMF-SPOT compatibility was analyzed by overlaying the AMF with the SPOT delineation results. The assessment focused on the geometry, position, completeness and presence of errors of omission and commission.

RESULTS

Imagery Comparison - PLA vs MLA vs TM

A comparison of SPOT-PLA, MLA and LANDSAT-TM images was conducted to determine the most suitable imagery for the task of updating urban street network files.

Visual examination of the TM scenes indicated that delineation of residential roads within subdivisions would not be possible for many urban neighbourhoods. The insufficient spatial resolution resulted in a mottled pattern where the roads were indistinguishable.

On both SPOT MLA and PLA scenes of the Orleans study site, roads and some landmarks were clearly visible on cursory examination. However, when actual delineation of the features was attempted, some difficulties were encountered in determining the existence of some street segments.

Figure 1 - Overlay of the Orleans SPOT-PLA and MLA Delineation Results

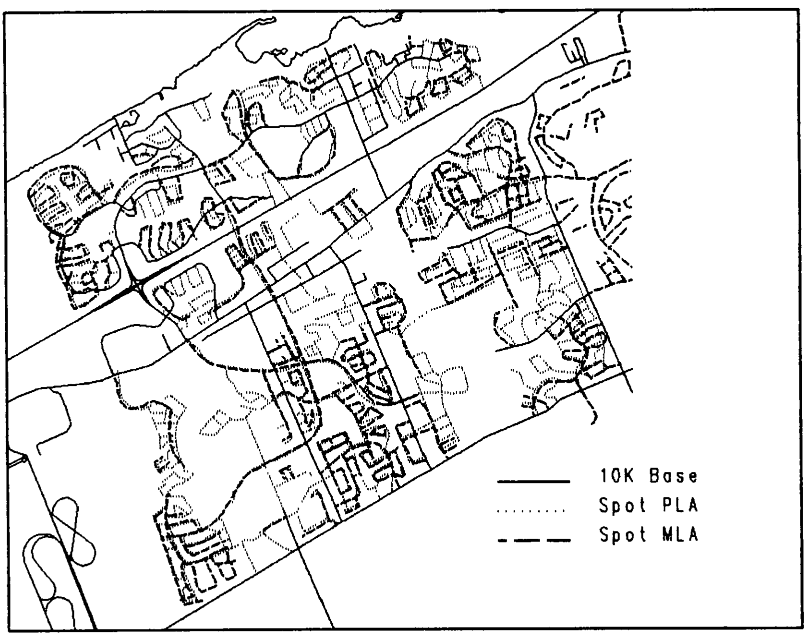


FIGURE 1 illustrates the achieved results. The superior resolution of the PLA imagery is evident in the high degree of completeness and better geometry of the captured road network. Quantitatively, the PLA imagery enabled correct delineation of approximately 86 % of the total of 93 kilometres of the roads within the Orleans study site. 54 road

segments were missed totaling 11.7 kilometres, and approximately 28 segments, totaling 2.9 kilometres were incorrectly added. For the MLA imagery, approximately 64 % of the roads were correctly delineated. 101 segments, totalling 32 km were missed, and approximately 13 segments, totalling 1.2 km were incorrectly added.

Large buildings and building sites, such as warehouses, offices and light industries, are visible where there is adequate contrast with the adjacent area. However, positive identification of the purpose of the building - hospital, warehouse, etc. is seldom possible. Oval sport tracks which are often associated with schools and community recreation centres, are identifiable in areas of sufficient contrast. Quantitative assessment of the comparative resolution of landmark features was not carried out.

<u>Resolution of Roads with SPOT-PLA</u>

The features of prime importance are roads for street network applications. The key issues are: 1) whether the features can be correctly delineated and classified and 2) how often features are incorrectly identified and delineated, either through improper classification, omission of features, or addition of features where none really exist.

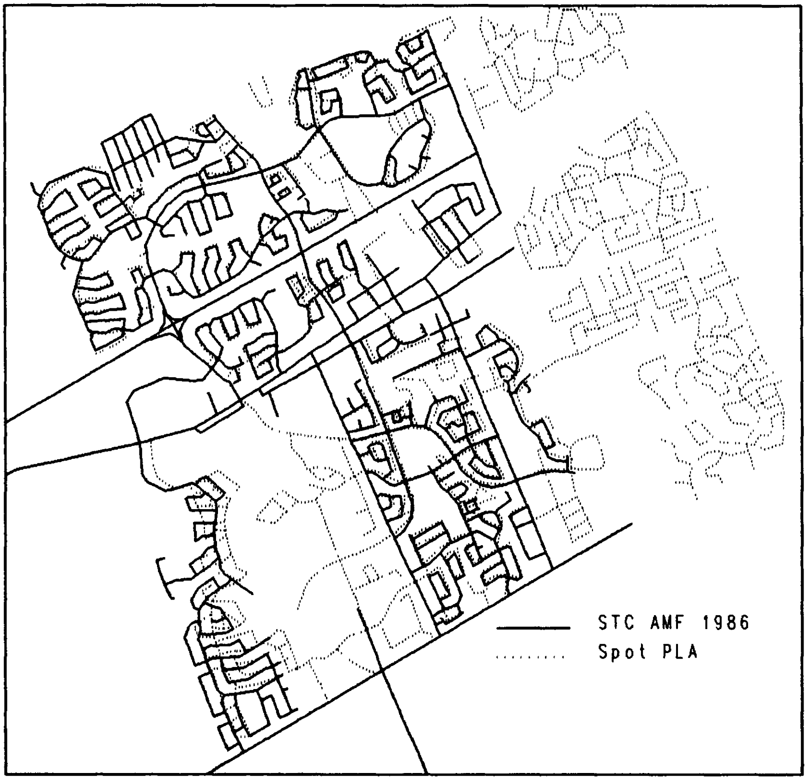
As evident in **Figures 2 and 3**, widely divergent results were obtained from the two study sites for the delineation of roads. The differences in the interpretation accuracy can be attributed to a number of factors including: the age of the neighbourhoods; dwelling types; amount and the maturity of the tree cover; alignment and shape of the houses; and presence of walkways in residential neighbourhoods. In industrial-commercial complexes, the landscaping and land cover significantly influence interpretation accuracy.

Comparison of the delineation results with the 1986 AMF for Orleans, **Figure 2**, indicates near complete capture of the road network. Approximately 86% of roads were correctly delineated with near perfect capture of all arterials and subdivisional collectors. Errors of omission and commission were evident in the mapping of subdivisional streets, with errors of omission being more prevalent due to the conservative interpretation approach used. Common errors included improper closure of crescents and incorrect joining of one crescent with another.

A higher incidence of error was found in the middle eastern portion of the study site where a mixture of older residential dwellings, detached houses from 5-20 years old and several apartment buildings are present. The errors include mistaking apartment parking lots and the long linear roofs of the apartment buildings as connecting road segments. The tree lined streets of the older residential area led to some misinterpretation of the ends of streets and incorrect connection of other streets. Use of imagery from early spring or late fall, rather than the June scene of the current study, would help to reduce this problem.

Figure 3, an overlay of the SPOT delineation results with the topographic base map, provides an indication of the lack of congruence between the delineated roads and the actual roads in for the Rexdale study site.

Figure 2 - Overlay of SPOT-PLA Delineation Results on the Orleans AMF



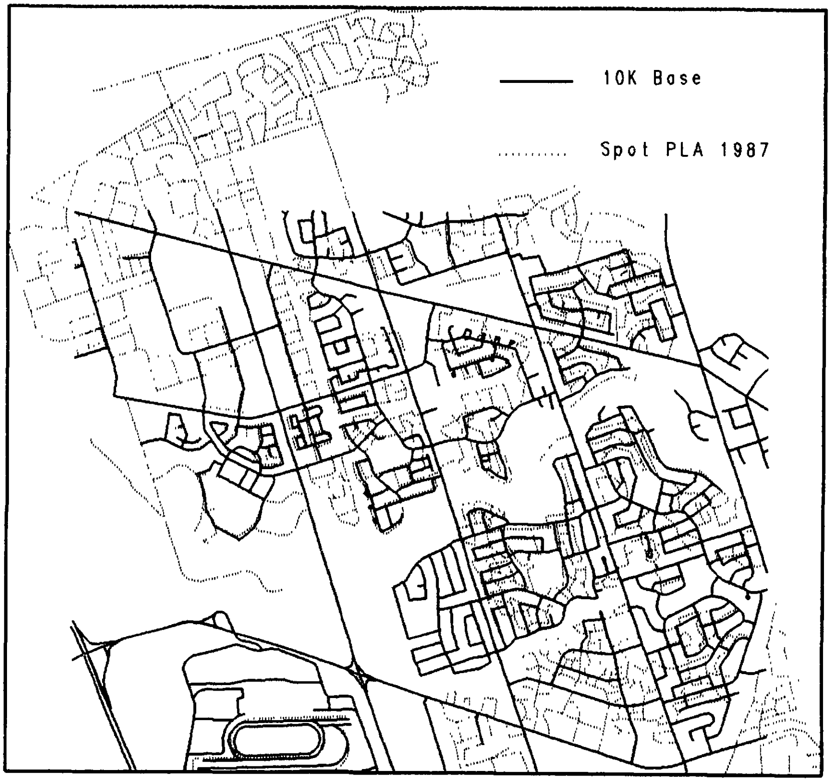
In the southeastern quadrant of the site, an older residential with area of 30-50 year old bungalows, the mature deciduous trees obscuring parts of the streets and linearly aligned houses of similar shapes and often with paved driveways in the space separating adjacent buildings led to mistaken identification of the rows of roofs as roads. The tree canopies also interrupted the expected pattern which made interpretation more difficult.

The central part of the study area is characterized by a mixture of semi-detached houses, detached houses and several row house developments, approximately 15-25 years old. In the row house complexes, success was extremely poor as the long roofs of the row houses, coupled with the network of walkways and mature evergreens resulted in the delineation of a confused pattern of streets where none existed.

The industrial area, in the southeast and northwest of the site, is characterized by expanses of pavement surrounding buildings. The difficulty in differentiating these pavement areas and the large roof of the commercial-industrial buildings from paved road surfaces resulted in numerous misplacement of roads and omission of existing streets.

At the northeastern fringe of the site are two 5-10 year old residential subdivisions. These subdivisions are similar to those found in Orleans with predominantly large detached single family houses, although their street patterns are somewhat unusual. The results achieved was similar to that of Orleans, where approximately 86% of the roads were correctly delineated. Again prevalent errors were omission of short street segments, mostly short dead-end streets, and incorrect connection of crescents, due mainly to misinterpretation of paved walkways or aligned light coloured roofs as streets.

Figure 3 - Overlay of SPOT-PLA Delineation Results on the 10K Rexdale Topographic Base



Resolution of Road-Related Features

Associated with roads are point and line features such as overpasses, underpasses, bridges, tunnels and ramps which are important for many street network applications, e.g., ambulance dispatch. A number of overpassess/underpasses, bridges and ramps are present in Orleans and Rexdale. Most ramps to major expressways are clearly visible by their cloverleaf pattern, however, where there are no grassed medians between the ramp and the roadways identification is more difficult. Overpasses/underpasses can be identified by determining which roadway is obscured at the intersection. However, only the places where major expressways pass over arterial roads and vice versa were identifiable. Likewise, only major bridge crossings of significant watercourses, such as the Humber River in the study area, can be interpreted. Minor watercourses which may be bridged or spanned with a culvert are not discernible.

Resolution of Landmarks

Landmarks are useful in street network files to assist users in spatial orientation. A variety of point, line and area features are captured in the AMF to provide census enumerators with landmarks to orient themselves. These include prominent buildings, like hospitals, school, churches, golf courses, cemeteries, hydro lines and railways. From the Rexdale image, some large buildings or building sites, three of five sports tracks, and horse racing ovals can be identified. However, correct classification of buildings as schools, colleges, hospitals or other institutions is not possible from the imagery, although assumption of relationships, such as the association of sport tracks with schools may make preliminary classification possible. High tension hydro transmission corridors and multi-track rail corridors are distinguishable.

Positional Accuracy

The positional accuracy of high resolution imagery for mapping has been a topic of much interest, especially within the topographic mapping community. Recent research indicates that X Y accuracies in the order of 5-15 metres can be expected depending on the scale of mapping (Thirwall et al, 1988; Begin et al, 1988(2)). The studies have generally relied on topographic maps at the same or slightly larger scale as the benchmark for comparison. As well, the focus have been on nadir looking scenes.

In this study, both a near nadir looking scene for Rexdale and a scene with an extreme look angle, Orleans, were assessed. Engineering maps with positional accuracies of better than one metre, were used as the measurement benchmarks.

From the Rexdale site, some promising measurements were recorded, however, the above-noted inability to accurately delineate roads within older residential subdivisions and industrial-commercial areas precluded fair assessment of positional accuracy.

The Orleans results, from a sample of 96 points, yielded a mean positional error of 16 metres, with a maximum error of 46 metres and a standard deviation of 0.443. Breakdown of the spatial distribution of error by neighbourhood characteristics showed no significant variation.

CONCLUSIONS

The results to-date indicate that for updating urban street network files, SPOT-PLA images can be useful, with approximately 86% accuracy in road identification in newer residential areas. SPOT-PLA appears to be most suitable for the task, as opposed to SPOT-MLA or LANDSAT-TM, although the combination of SPOT-PLA and MLA may be helpful to improve discrimination of vegetated areas from road surfaces in some areas.

With SPOT-PLA, primary highways, arterial roads and subdivisional collector streets can be confidently mapped. For subdivisional streets, excellent results can be attained for new single family detached housing developments. Correct results are less certain for row house developments without interior streets and in areas adjacent to large buildings and large paved surfaces. Older neighbourhoods with a mature tree cover and narrowly spaced, linearly aligned houses are problematic, especially when summer scenes are used for analysis. Areas having extensive paved surfaces and roof areas, such as large industrial-commercial complexes are confusing, since there is little difference between these hard surfaces and paved streets.

Identification of road related features, such as overpasses and bridges, and landmarks, such as schools, hospitals and golf courses, etc. are possible on occasion. Development of contextual rules to assist interpreters would be of benefit, not only for visual interpreters but also for automated digital processing.

In terms of positional accuracy, the results indicate that with careful referencing, off-nadir imagery can yield acceptable results with only minor degradation of accuracy.

Overall the results are encouraging and confirms the utility of high resolution satellite imagery for updating urban street network files and monitoring changes in the urban-rural fringe. Research is continuing to address some of the issues which still remain to be resolved before this application can be brought to fruition. Notably, the adequacy and reliability of image coverage must be assessed. Appropriate dates/seasons of the image to optimize feature identification would benefit from further study. Applicability of the techniques in higher relief urban centres and the effect of street pattern complexity must be further evaluated. Finally, once feasibility is better established, a detailed cost benefit analysis must be carried out to determine the end viability of this application.

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