AUTOMATIC ROAD CHANGE DETECTION AND GIS UPDATING FROM HIGH SPATIAL REMOTELY-SENSED IMAGERY

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ABSTRACT

This paper presents a framework for road network change detection in order to update the Canadian National Topographic DataBase (NTDB). The methodology has been developed based on road extraction from IRS-pan images (with a 5.8 m spatial resolution) using a wavelet approach. The feature matching and conflation techniques are used to road change detection and updating. Elementary experiments have shown that the proposed framework could be used for developing an operational road database updating system.

KEY WORDS: Road Extraction, Change Detection, Updating, Feature Matching, Conflation

1. INTRODUCTION

The updating of road network databases is crucial to many Geographic Information System (GIS) applications like navigation, urban planning, etc. The development of mature methodologies for automatic road extraction and change detection based on imagery may provide a hopeful solution to this problem. However, there are still a lot of issues required further investigations before an image-based road network updating system becomes operational.

An operational road database updating system should include the following three main functions:

1) The generation of a new version of road network by road extraction from imagery.
2) The detection of road changes using an image-based (e.g. snakes model) or vector-based (e.g. map conflation) method to identify the roads that remain unchanged, have disappeared, or emerged recently.
3) The updating of the road database. This includes updating the geometric data of the road network; transferring attributes from the old version database to the new version one; and organizing both versions of road databases in such a way that facilitate efficient spatio-temporal query and analysis.

It is clear that each of the three parts is related to at least one difficult issue in the GIS research area. For example, the first part, feature extraction from remotely-sensed imagery, is among one of the hottest topics in the Geomatics community. The second and third parts are in the general research area of map conflation and spatio-temporal modeling. We have noticed that there is a lot of works that has been done in each of these three areas separately, but very few researchers have treated the three parts in a united way. This paper presents a generic framework for an operational road database updating system and some of our research achievements along this line.

The paper is organized into five parts. Firstly, a framework for an operational road database updating system is presented in Section 2. Then road extraction from high spatial images, road change detection and updating based on map conflation will be studied in Section 3 and 4. Finally, some concluding remarks will be given in Section 5.

2. FRAMEWORK FOR A ROAD DATABASE UPDATING SYSTEM

This paper provides a new strategy to image-based road database updating, in which a wavelet-based road junction and centerline extraction processing was firstly performed, and then we deploy some map conflation techniques to road change detection and updating. Finally, the temporal information of the road network is kept in an efficient way to facilitate spatio-temporal queries and spatio-temporal analysis. The framework for an operational road database updating system is illustrated in Figure 1. The first two steps are detailed in the following sections.

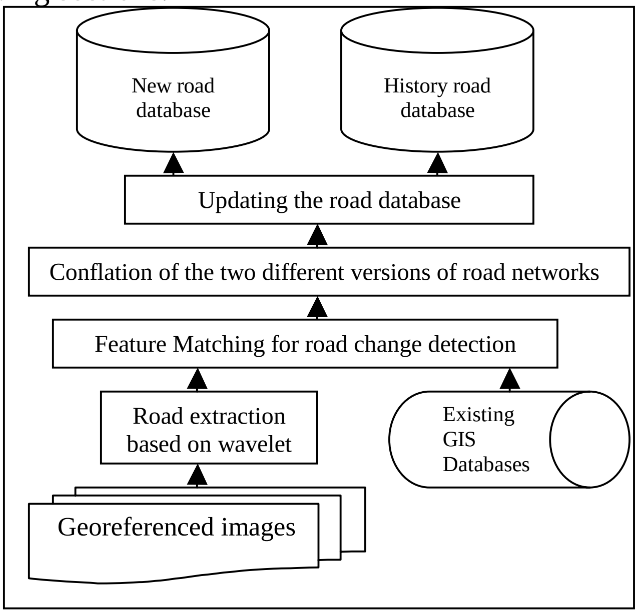


Figure 1 The framework for an operational road database updating system

3. WAVELET-BASED APPROACH FOR ROAD EXTRACTION FROM IMAGERY

Substantial work has been devoted to road extraction from imagery in the photogrammetric and computer vision communities during the last two decades. Among these, we could cite the gradient direction profile analysis (GDPA) method [Wang and Zhang, 2000], adaptive template matching [Hu, 2001], snakes model [Gruen and Li, 1997; Klang, 1998; Laptev *et al*, 2000; Fortier *et al*, 2001], perceptual grouping [Hu and Tao, 2002], hyper-spectral approach [Roberts *et al*, 2001], multi-scale or multi-resolution approach [Laptev *et al*, 2000; Couloigner and Ranchin, 2000], GIS data guided [Klang, 1998; Fortier *et al*, 2001]. The concept for road network extraction is relatively simple, but reliable processes remain a difficult challenge. There exists no algorithm sufficiently reliable for practical use [Xiong, 2001]. Road extraction remains largely, at least in typical production environments, costly manual process [Doucette *et al*, 2001].

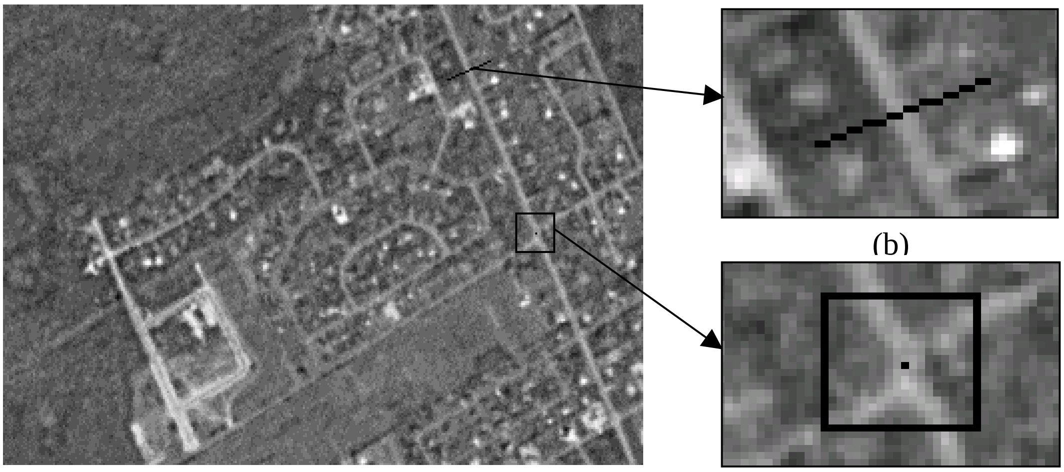
3.1 The roles of wavelet transform in road extraction

Wavelet-based representations of images enjoy the nice property of energy compaction in both the space and the frequency domain, which greatly facilitates the task of feature extraction. Wavelet transform can be involved in the process of road extraction in two ways. The first is to be used as a tool to obtain the multi-scale representations of the original image, and then use a method similar to [Laptev *et al*, 2000]. The main idea in their method is to take advantage of the scale-space behavior of roads in combination with geometrically constrained edge extraction by means of snakes. From the scale-space behavior of roads, they inferred to start by extracting lines at a coarse scale. Such lines are less precise but also less disturbed by cars, shadows, etc., than features at fine scales. The lines initialize ribbon snakes at fine scales, where roads often appear as bright, more or less homogeneous elongated areas. Optimized ribbons of constant width are accepted as salient roads. The connections between adjacent ends of salient roads are checked if they correspond to non-salient roads.

The second way to combine wavelet transform with road extraction is to detect edge pixels in the wavelet domain, *i.e.* to analyze the wavelet coefficients to find road centerline or roadsides pixels. [Mallat, 1998] presents a multi-scale version of the Canny Edge Detector, which uses the wavelet maxima modular for images. The research of [Couloigner and Ranchin, 2000] also shows the possibility to determine the accurate position of the road sides and central reservation through the analysis of multi-level wavelet coefficients. The algorithm they used is the "*à trous*" algorithm, a detailed discussion of which can be found in [Starck *et al*., 1998]. The approach we are going to use in this paper is similar to [Couloigner and Ranchin, 2000]: extract road sides or road centerlines based on an analysis in the wavelet domain. However, we aim at an automatic method while a semiautomatic approach was used in [Couloigner and Ranchin, 2000].

3.2 Road characteristics in wavelet domain

[Couloigner and Ranchin, 2000] has shown that we can determine the position of road sides through an analysis in either the approximate parts or the wavelet parts of a wavelet transform. Our experiments with both simulated images and natural images also indicated that in the wavelet domain we could easily determine the road centerline pixels. Figure 2 is a part of our test image, which is a subset of the 5.8 m IRS panchromatic image covering the urban area of Ottawa (ON, Canada). Figure 3 shows the cross profiles in the approximate parts and the wavelet parts after a three level wavelet decomposition of the image shown in Figure 2(b). The road pixels start from the 10th pixel and end at about the 13th pixel along the gradient direction shown as a black line in Figure 2(b). It is clear that, in IRS panchromatic images, a road centerline pixel will have a local maximum in the wavelet coefficients and the two sides of the road will have corresponding two zeros along the road gradient direction. Figure 4(a) illustrates the magnitude of the numerical values of the second level wavelet coefficients of the square part of the image shown in Figure 2(c) (only showing the center 21 by 21 region, the center pixel was tagged as black in Figure 2(c)). It indicates precisely a four-way road junction in the original image. The above observation leads us to a robust approach to road junction pixels and road centerline pixels detection.



(a) (c)

(b)

Figure 2 Part of the IRS panchromatic image

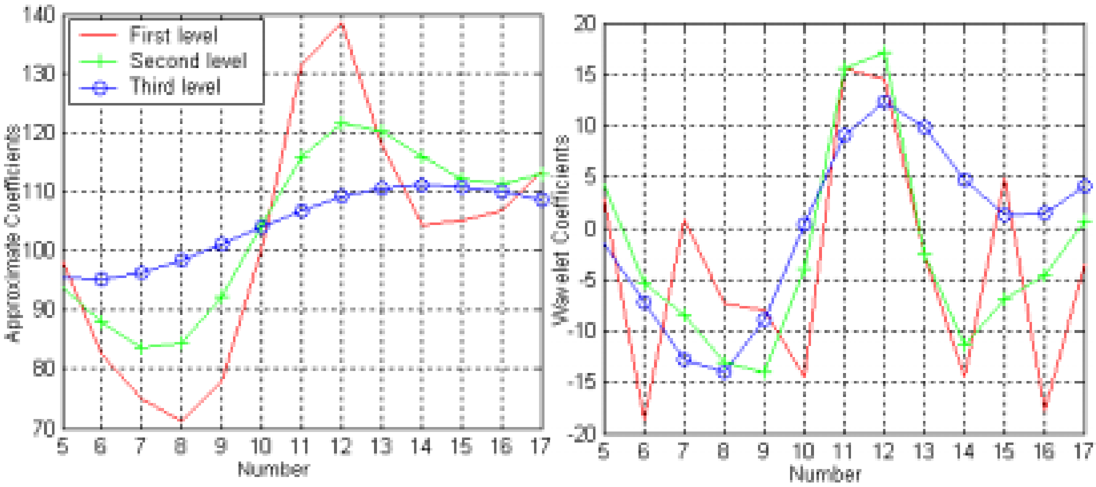
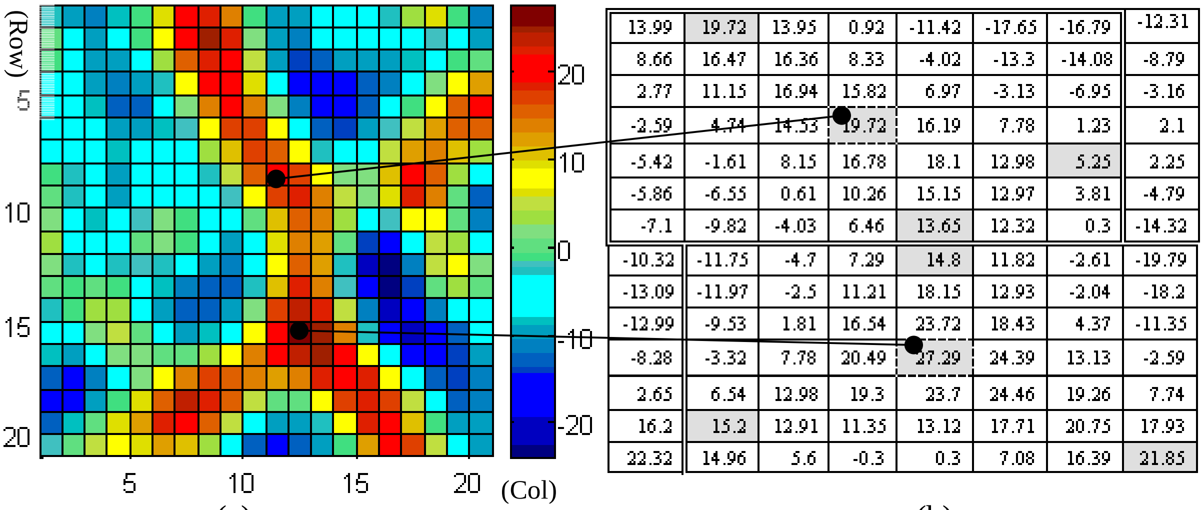


Figure 3 The cross profile of the multi-level approximate (left) and wavelet coefficients (right) of the image shown in Figure 2(b)



13.99	19.72	13.95	0.92	-11.42	-17.65	-16.79	-12.31
8.66	16.47	16.36	8.33	-4.02	-13.3	-14.08	-8.79
2.77	11.15	16.94	15.82	6.97	-3.13	-6.95	-3.16
-2.59	4.74	14.53	19.72	16.19	7.78	1.23	2.1
-5.42	-1.61	8.15	16.78	18.1	12.98	5.25	2.25
-5.86	-6.55	0.61	10.26	15.15	12.97	3.81	-4.79
-7.1	-9.82	-4.03	6.46	13.65	12.32	0.3	-14.32
-10.32	-11.75	-4.7	7.29	14.8	11.82	-2.61	-19.79
-13.09	-11.97	-2.5	11.21	18.15	12.93	-2.04	-18.2
-12.99	-9.53	1.81	16.54	23.72	18.43	4.37	-11.35
-8.28	-3.32	7.78	20.49	27.29	24.39	13.13	-2.59
2.65	6.54	12.98	19.3	23.7	24.46	19.26	7.74
16.2	15.2	12.91	11.35	13.12	17.71	20.75	17.93
22.32	14.96	5.6	-0.3	0.3	7.08	16.39	21.85

(a) (b)

Figure 4 (a): The corresponding second level wavelet coefficients of the 21x21 pixels square part of the image shown in Figure 2, the center pixel was tagged as a black pixel in Figure 2(c). (b): The detection of road junctions.

3.3 The detection of road junctions

The intersection of several roads constitutes a road junction or road node. The endpoints of a road are commonly called road terminations. Junctions and terminations represent robust information. They are very useful features, particularly in solving matching problems, because they are generally reliable, stable elements [Fortier *et al*, 2001]. Moreover, effective and accurate road nodes detection will benefit many processing in the road network change detection and updating work. The successfully extracted road nodes can be also used as initial points for most of the semi-automatic road extraction approaches (e.g. the snakes model). Unfortunately, till now very few existing approaches for road extraction from remotely-sensed imagery have used these features. [Deschênes and Ziou, 2000] proposed a line junction detector based on a measure of curvature between the direction vectors of the line pixels within a given neighborhood. Based on their road junction detector, they have obtained better results in updating road maps from high-resolution aerial images [Fortier *et al*, 2001].

The basic idea in the approach we developed for road junction detection is based on a local analysis in the wavelet domain. We have observed that, a road intersection or junction will have a local maximum wavelet coefficient in a 7 by 7 neighborhood. Moreover, along the 24 boundary pixels, we could find more than three local maximum pixels corresponding to linked road branches, as shown in Figure 4(b). In Figure 4(b), the two black dashed cells correspond to the two road junctions in the original image. The other shadowed cells are their corresponding road branches, which have local maximum values along the 24 boundary pixels. It shows that our wavelet-based road node detector has good localization accuracy. Other tests also illustrated its efficiency in extracting reliable road nodes from remotely-sensed imagery (see Figure 5).

3.4 Application of wavelet-based approach for road extraction

The wavelet-based approach we developed to extract road network from remotely-sensed imagery consists of five steps:

1) Perform a wavelet transform using the "*à trous*" algorithm for example.
2) Detect road junction pixels based on a local analysis (e.g. 7 by 7 neighborhoods) in the wavelet domain. The first pixel of each road branches of each road junction will also be given in this step.
3) Extract the road centerline segments through a road centerline following algorithm based on detected road junctions. The road centerline pixels are determined by finding the pixels having a significant wavelet coefficient (e.g. greater than a certain threshold) in the approximate road direction, which was determined by previous detected road pixels.
4) Group the road centerline segments into a road network with their topological relationship information. The road junctions are reinvestigated in this step. The pseudo-nodes which only have two linked road arcs are discarded and the corresponding road arcs are connected into one. Some new road nodes may be created in the case that two road arcs meet at the same pixel other than detected road node.
5) Perform line simplification to reduce the vertices number while preserving necessary positional accuracy. In the current implementation, the Douglas-Peucker algorithm is used and the threshold distance is 1.5 times the cell size.

Figure 5 Road junction detection based on a local analysis of the 2nd wavelet coefficients (Square markers: detected road junctions from IRS pan image)

The proposed approach has been applied to various remotely-sensed images. Figure 6 and 7 illustrates the roads extracted from the IRS panchromatic. We can see that most of the roads are extracted with good accuracy and completeness. For the accuracy evaluation purpose, we have obtained both the NTDB 1:50,000 data and the Updated Road Network (URN) data covering the same area from the Centre for Topographic Information, Natural Resources of Canada. The NTDB data has a positional accuracy of 10 meters and the URN data was captured by GPS and has a better positional accuracy, about 4 meters. The extracted road centerlines shown in Figure 7 are compared with corresponding URN road features. The average distance between them is about 3m, while the average distance between NTDB road features and corresponding URN lines is about 4m. This result indicates that, based on feature extraction technologies, the IRS panchromatic image can be used as main spatial data source for change detection and updating of 1:50,000 NTDB databases.

Figure 6 Road centerlines extracted from IRS pan image shown in Figure 2(a)

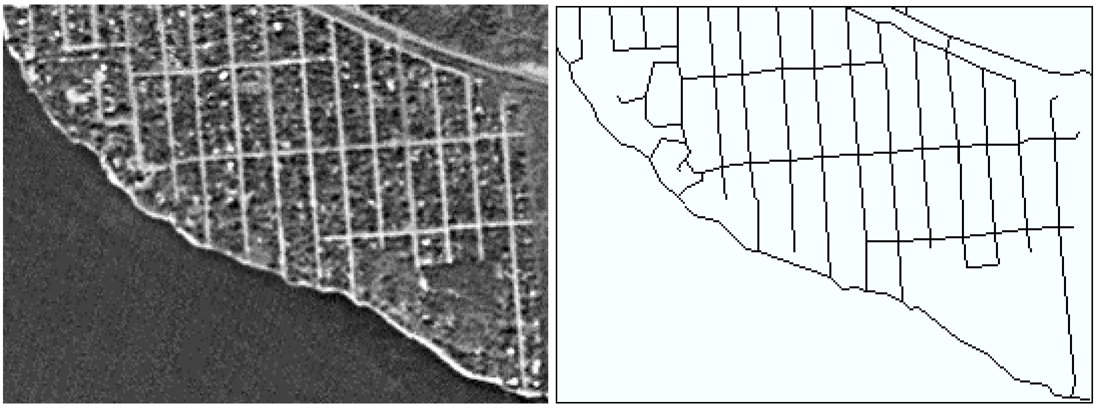


Figure 7 Road centerlines extracted from IRS pan image of urban area

4. ROAD CHANGE DETECTION AND UPDATING USING MAP CONFLATION

4.1 The problem of road change detection and updating

Research on image-based geospatial change detection is rather limited, at least compared to the body of work on object extraction [Agouris *et al.*, 2001]. Among the methods developed, we can mention particularly the work of Klang (1998). He developed a method for detecting changes between an existing road database and a satellite image. First he used the road database to initialize an optimization process, using a snake approach to correct road location. Then, he ran a line following process using a statistical approach to detect new roads, starting from the existing network. In Fortier *et al.* (2001), the authors extend the above approach by using road intersections. Road intersections improve matching between the road database and the lines on the image, and hypotheses for new road segments are generated from these line junctions. To avoid the pitfall in GIS updates that results in storing multiple slightly different representations of an object that has actually remained unchanged, Agouris *et al.* (2001) extend the model of deformable contour models (snakes) to function in a differential mode, and introduce a new framework to differentiate change detection from the recording of numerous slightly different versions of objects that may remain unchanged.

Our studies show that a snake model based approach to road change detection has the following problems: 1) It requires the initial position of every snake which makes it of little use in finding new roads; 2) It is very sensitive to initial position (an undesirable initial snake will lead to an inaccurate result); 3) In a typical road change detection scenario, there is existing road database which provides initial version of the snake, but very often, the end points of the existing road lines will not be in a position that will lead to the desired position after snake deformation; and 4) It is also sensitive to the noise in the digital number along the road lines, which is often the case due to the complex radiometric background.

Usually a road updating processing will involve several issues, such as 1) the improvement of the weak positional accuracy of the existing road location that remain unchanged; 2) the updating of the changed road; 3) the detection of the new roads; and 4) the transfer of attributes data from the previous version of road database. These issues are actually among the typical concerns in map conflation research area. Map conflation is the process of creation of a new database based on two or more different databases covering the same area [Cobb *et al*., 1998]. The new database is superior to any single one in the whole, with high accuracy, rich attribute information, up-to-date, etc.

4.2 Road change detection and updating based on map conflation

The map conflation techniques are used in the change detection and updating stage in this research because of the following reasons. 1) Feature matching is a well-known map conflation technology to determine the conjugate features between two different versions of geographic databases. Both node feature matching and linear feature matching technologies could be used in road change detection processing. 2) Through feature matching we can not only identify the conjugate features so that we could determine the relative accuracy of the two versions of databases, but also determine which parts of the road network have changed and which parts remain unchanged. In addition, we can perform conflation operation to transfer attributes to new database and update the spatial position of related roads. 3) Map conflation is also useful in the case that we need to or want to improve the positional accuracy of the original version of road database. Both node-based conflation (e.g. TIN approach in [Saalfeld, 1993]) and polyline-based conflation (e.g. polyline mapping method in [Filin and Doysther, 1999]) could be served the purpose of correction the old version of road database. 4) Map conflation is originally an editing operation in GIS to reconcile the position of related features. So the results from map conflation will have a good consistency between the changed road features and the unchanged road features.

After a successful extraction of road feature from imagery, a feature matching is performed to identify the conjugate road nodes and road centerlines from the two versions of road datasets. And then, a conflation procedure is followed to obtain a new, more accurate road database. The steps of the general procedure are listed below.

1) Perform node matching to identify the conjugate road nodes in the two versions of road databases.
2) Perform point based conflation (e.g. TIN method) to the original road database to reduce the positional discrepancy between the two versions of road databases. The typical point based conflation procedure is based on a piecewise local transformation determined by two TINs constructed from the conjugate nodes. A detailed description of this can be found in [Cobb *et al* 1998].
3) Perform polyline matching to identify the conjugate road arcs. In this stage, a road will be categorized into one of the following cases:
    a. Unchanged, the road arcs that are successful in finding conjugate features;
    b. Disappeared, the road arcs in the original version of database that are failed in finding conjugate features;
    c. Created, the road arcs in the new version of database that are failed in finding conjugate features;
    d. Changed, the road arcs that are successful in finding conjugate features but the positional discrepancy is significant;
    e. Partially changed, the road arcs that are partially successful in finding conjugate features.
4) If necessary, perform polyline-based geometric conflation to improve the accuracy of the original GIS data.
5) Transfer attributes from the old version database into new one. This is easy for unchanged road features, but may have problem for that only partially changed.

6) Organizing the newly-updated road database and historic database using a spatio-temporal model for road network. A reasonable spatio-temporal model for road network is still under development.

At node matching stage, both distance similarity and topological similarity between nodes are used. The topological similarity is based on the “Spider code” of a road node which was originally presented by Saalfeld (1988, 1993). It is a measure of the structure information of a node based on the number of linked arcs and corresponding directions. The distance similarity between polylines is determined by the distance calculated using a modified intermediate area approach, which is capable of identify the case of partially matching between the road polylines. Figure 8 illustrates one of the preliminary experiment results of above procedure.

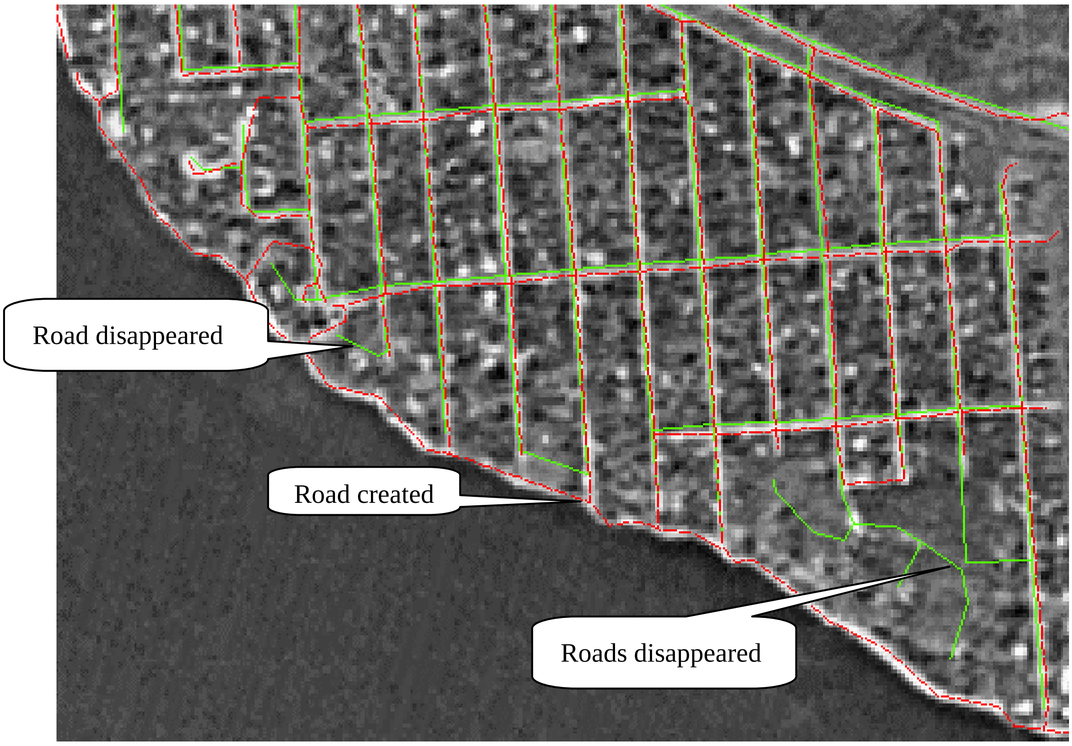


Figure 8 Road centerlines extracted from IRS pan image of urban area (red dashed line) superimposed with NTDB roads (green solid line)

5. CONCLUSIONS

Road change detection and database updating based on remotely sensed imagery has been the purpose of many works in the geomatics field, and because of its complexity, is still a challenging topic. We have presented an efficient approach to this problem based on wavelet and map conflation techniques in the proposed framework for an operational image-based road database updating system.

Future work includes the application of wavelet-based road extraction approach to even higher resolution remotely-sensed imagery, such as IKONOS panchromatic or Quickbird panchromatic. Another work is to develop a comprehensive spatio-temporal model for road network. Our long term goal is to develop a series of approaches for automatic change detection and updating of geographic databases in urban area with multi-scale, multi-source spatial data.

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REFERENCES

Agouris, P., Stefanidis, A., and Gyftakis, S. (2001). Differential Snakes for Change Detection in Road Segments. *Photogrammetric Engineering and Remote Sensing*, 67(12), pp.1391-1399.

Cobb M.,Chung M.,Foley H. (1998). A Rule-based Approach for the Conflation of Attributed Vector Data, *GeoInformatica*, V 2,No1,7-35.

Couloigner, I., and Ranchin, T. (2000). Mapping of Urban Areas: A Multiresolution Modeling Approach for Semi-Automatic Extraction of Streets. *Photogrammetric Engineering and Remote Sensing*, 66(7), pp.867-874.

Deschênes, F. and Ziou, D. (2000). Detection of Line Junctions and Line Terminations Using Curvilinear Features, *Pattern Recognition Letters*, 21(6-7), pp.637-649.

Doucette, P., Agouris, P., Stefanidis, A., Musavi, M.,2001.Self-Organised Clustering for Road Extraction in Classified Imagery. ISPRS Journal of Photogrammetry & Remote Sensing, 55(2001),pp.347-358.

Filin S. and Doytsher Y. (1999). A Linear Mapping Approach to Map Conflation: Matching of Polylines. *Surveying and Land Information Systems*, 59(2), pp.107-114.

Filin S. and Doytsher Y. (2000). A Liner Conflation Approach for the Integration of Photogrammetric Information and GIS Data. *International Archives of Photogrammetry and Remote Sensing*, 33(B3/1): 282-288.

Fortier, M.F.A., Ziou, D., Armenakis, C., and Wang, S. (1999). Survey of Work on Road Extraction in Aerial and Satellite Images. *Http://www-l2ti.univ-paris13.fr/~aucl air/ Publi/Auclair-TR247.pdf*, accessed on June 20, 2003.

Fortier, M.F.A., Ziou, D., Armenakis, C., and Wang, S. (2001).Automated Correction and Updating of Road Databases from High-Resolution Imagery. *Canadian Journal of Remote Sensing*, 27(1), pp.76-89.

Gruen, A., and Li, H. (1997). Semi-automatic linear feature extraction by dynamic programming and LSB-Snakes. *Photogrammetric Engineering and Remote Sensing*, 63(8), August 1997, pp. 985-995

Hu, X. (2001). Automatic Extraction of Linear Objects and Houses from Aerial and Remote sensing Imagery. *Phd Dissertation* (in Chinese): Wuhan University, China.

Hu, X.,Tao, C.V. (2002). Automatic Extraction of Main-Road from High Resolution Satellite Imagery. *IAPRS, VOLUME XXXIV, PART 2, COMMISSION II*, Xi’an, Aug.20-23,2002.

Klang, D. (1998). Automatic Detection of Changes in Road Databases Using Satellite Imagery. *IAPRS, Vol. 32, Part 4 "GIS-Between Visions and Applications"*, Stuttgart, 1998,pp.293-298.

Laptev, I., Mayer, H., Lindeberg, T., Eckstein, W., Steger, C., Baumgartner, A. (2000). Automatic Extraction of Roads from Aerial Images Based on Scale Space and Snakes. *Machine Vision and Application*, 2000(12),pp.23-31.

Li, X. (2000). Spatially Adaptive Statistical Modeling and Its Application to Image Processing, *Phd thesis*, Princeton University, March 2000.

Mallat, S. (1998). *A Wavelet Tour of Signal Processing*. Academic Press.

Roberts, D., Gardner, M., Funk, C., Noonha, V. (2001). Road Extraction Using Spectral Mixture and Q-Tree Filter Techniques. *In NCRST technical reports:3nd Quarter Progress*, Feb.,2001.

Saalfeld, A. (1988). Conflation: Automated map compilation *International Journal of Geographical Information Systems,* 2(3),pp.217-228

Saalfeld A. (1993). Automated Map Conflation, Ph.D. Dissertation, Dept. Of Computer Sci.,The Unversity of Maryland, Washington D.C.,USA

Starck, J.L., Murtagh, F., Bijaoui, A. (1998). *Image Processing and Data Analysis: the Multiscale Approach*. Cambridge University Press, Cambridge.

Wang, J.,Zhang, Q. (2000). Applicability of a Gradient Profile Algorithm for Road Network Extraction-Sensor,Resolution and Background Considerations. *Canadian Journal of Remote Sensing*, 26(5),pp.428-439.

Wang,Y., Trinder, J.C. (1998). Extraction. *Http://www.gmat.unsw.edu.au/photolab /extraction.html*, accessed on May 20,2003.

Xiong, D. (2001). Automated Road Network Extraction from High Resolution Images. *National Consortia on Remote Sensing in Transportation, Technical Notes,* Issue 3, May 2001.