

AUTOMATIC MAIN ROAD EXTRACTION FROM HIGH RESOLUTION SATELLITE IMAGERY

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ABSTRACT:

Road information is essential for automatic GIS (geographical information system) data acquisition, transportation and urban planning. Automatic road (network) detection from high resolution satellite imagery will hold great potential for significant reduction of database development/updating cost and turnaround time. From so called low level feature detection to high level context-supported grouping, so many algorithms and methodologies have been presented for this purpose. There is not any practical system that can fully automatically extract road network from space imagery for the purpose of automatic mapping. This paper presents the methodology of automatic main road detection from high resolution satellite IKONOS imagery. The strategies include multi-resolution or image pyramid method, Gaussian blurring and the line finder using 1-dimensional template correlation filter, line segment grouping and multi-layer result integration. Multi-layer or multi-resolution method for road extraction is a very effective strategy to save processing time and improve robustness. To realize the strategy, the original IKONOS image is compressed into different corresponding image resolution so that an image pyramid is generated; after that the line finder of 1-dimensional template correlation filter after Gaussian blurring filtering is applied to detect the road centreline. Extracted centreline segments belong to or do not belong to roads. There are two ways to identify the attributes of the segments, the one is using segment grouping to form longer line segments and assign a possibility to the segment depending on the length and other geometric and photometric attribute of the segment, for example the longer segment means bigger possibility of being road. Perceptual-grouping based method is used for road segment linking by a possibility model that takes multi-information into account; here the clues existing in the gaps are considered. Another way to identify the segments is feature detection back-to-higher resolution layer from the image pyramid. In section 1, the paper reviews the typical methods of road extraction from space imagery; in section 2, the strategy and each steps of our method are delineated. The experimental result is shown in section 3; it indicates the potential of the method. The conclusion and future works are given in section 4.

1. INTRODUCTION

Road information is very important for topographic mapping, transportation application, urban planning and other related application fields. Extracting road network from spatial imageries, such as aerial photos and satellite images, plays central role in road-net acquisition. Nowadays automated road information extraction from high-resolution satellite images holds great potential for reduction of database development/updating cost and turnaround time because the satellite images have large coverage, less unit cost and high temporal resolution (short orbital revisit period, e.g., 1-3 days).

In last twenty years many kinds of linear feature extraction algorithms and methods are developed. Some of them can be generally used for linear feature extraction, while others are particularly designed for the road extraction. We classify the methods to some types. (1) Linear feature detection. Generally roads are shown as ridges or valleys on an image intensity matrix, therefore road finding can also be considered as ridge finding, linking the ridge points that produces road segment. Image filtering for edge or ridge finding (Steger, 1996) are examples using ridge finding for road extraction. (2) Rule or knowledge based methods. This is so called 'high level' processing compared to pixel based processing and intermediate level processing. To deal with the linear feature alignment and fragmentation, some heuristic methods are developed.

(McKeown et al, 1985) built a road tracking system that depends on road texture correlation and parallel edge following alternatively. (3). Optimization. Treating the road extraction as optimization problem, Dynamic programming (DP) is frequently applied to formulate the road segments/candidate-points linking problem to a multi-step decision-making procedure, the optimal solution based on photometric and geometric information can be obtained by the DP technique (Gruen and Li 1995). Snakes (active contour) and Least Square Template Matching (Gruen and Li 1997) are also the 'optimization' methods; they are applied to semiautomatic road extraction from mono to stereo images (directly 3D linear feature information can be acquired from multi stereo images). (4).Content supported and map guided methods. Only by image feature can not extract road network completely (not missing) and correctly. Contextual information, such as buildings, trees, rivers, is helpful for road segments linking and road identification (Baumgartner et.al 1999). Map matching or map guiding methods are also developed. Existing map data can be used as the key clues for road finding. The algorithms focus on image-map matching to identify roads in image and map; others try to find new road based on the assumption that new roads are connected to old ones (Stilla U., 1995). In addition to above methods, hierarchical strategy and hypothesis-verification strategy (Heipke 1996) are often utilized to find and identify roads. More used methods are hybrid above methods (Trinder and Wang YD 1998, Laptev I et.al 2000). However, none of

those methods can extract road network from images 100% correctly or be a replacement of manual extraction to meet the demands of automatic mapping, because most of them face to the particular case (image resolution, complexity, road types etc.) and depend on some prior assumptions or parameters while the various complexity and image contents. But for some applications (for example in some transportation applications), one do not need to extract all road structures and just need to obtain the main road information with high reliability and accuracy.

In this paper, we briefly describe our method of main road extraction from high-resolution satellite image (IKONOS 1 m/pixel). It depends on a hybrid strategy of hierarchical analysis, perceptual grouping for salient linear feature extraction, and least square template matching based precise delineation. Some initial experimental results are also given.

2. STRATEGY OF MAIN ROADS DETECTION AND VERIFICATION

2.1 Strategy

We firstly define the main roads in particular resolution image. The definition depends on the geometric attributes. Geometric attributes include road width and road length limit. The road whose width and length is greater than a limit will be considered as 'main road'. For IKONOS 1m/pixel high resolution image, as a case study we set the width and length limit as 12m and 400m.

The main road extraction is based on hierarchical strategy. Firstly, image pyramid is generated according to image resolution and main road definition. Actually a 2-layers image pyramid in which the low resolution is re-sampled to 1/4 resolution so as to extract the main road in this layer is generated.

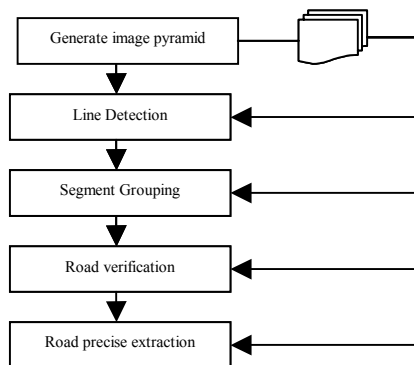


Figure 1. Workflow of automatic main road extraction

2.2 Line Detection

A 2-direction (horizontal and vertical) template matching is applied to detect road central point candidates in low resolution layer of the image pyramid. The procedure is shown in figure 2.

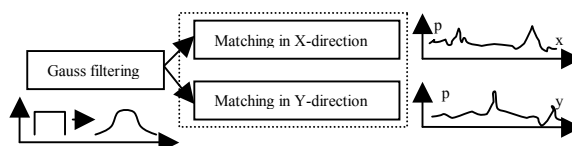
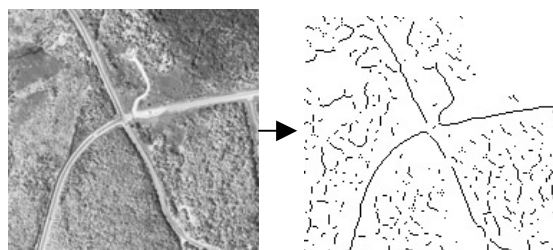


Figure 2. Line detection based on template matching



(a) 7600X6900 IKONOS image



(b) Line detection

Figure 3. Line detection from IKONOS image in 1/4 of 1m/pixel resolution.

This is a very simple and 'easy to use' detector. At first, Gaussian filtering smooths the image for reducing noise and then corresponding template is generated by road profile. Road profile template is used to matching image signal by correlating along x (horizontal) and y (vertical) direction, the local peak correlation coefficient indicates the existing of candidate of road centre point. Figure 3 is an example of the detection in a 1/4 resolution layer of the image pyramid. The detection from low resolution layer is much more effective, but it can not get so accurate geometric location of road point. However, finally the precise delineation will be applied to adjust the road central lines based on original resolution image.

After Line detection, candidate lines should be traced to vector form for next step of line segments grouping.

2.3 Lines Grouping

Grouping plays a very important role in road extraction. Due to the alignment and fragmentation of the candidate segments gotten from line detection step, grouping only by geometric attributes is often unreliable, so we should take more information into account. On the other hand, if one tries to group all detected candidate segments, it will be too complex and the computational cost is too high because of the great amount of segments. Now the question is: how to guarantee the ‘reliability’ of road grouping? In this paper, the grouping is based on a multi-level grouping according sorted segments by labelling ‘possibility of being road segment’ to each segment. Figure 4 shows the grouping strategy.

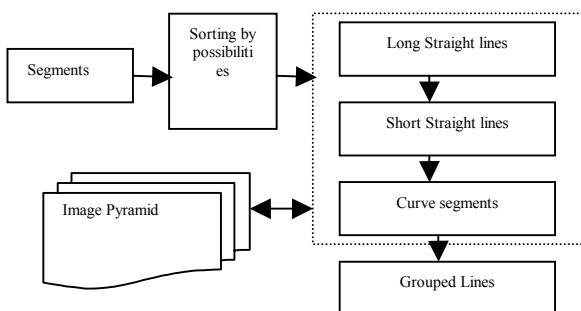


Figure 4. Grouping Procedure

Grouping starts from segments with higher possibility of being road segment. Long, straight, and bright line segment has the higher score while short, curve, and dark line has lower score. From the viewpoint of vision, one tries to find salient, bigger and more global structuralized features when one recognizes objects from image. This is the ability of so called ‘perceptual organization or grouping’ which can be defined as imposing

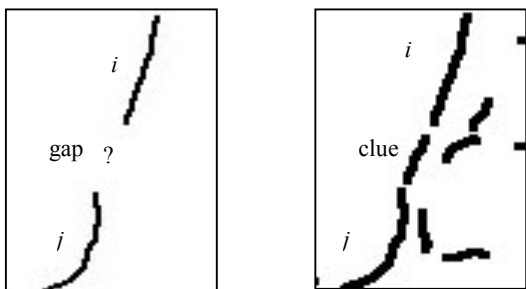


Figure 5. Link clue in the gap

structural regularity on sensory data. To evaluate the possibility of each candidate segment an evaluation function is built depend on geometric and photometric attributes, and then segments are sorted by the possibilities. Grouping starts from longer straight line segment, sequentially shorter, curve segments are grouped.

Grouping takes advantage of clues from detailed line detection result. The link clue between grouped longer segments mainly refers to short lines. See figure 5, shorter lines in the gap between segments strongly indicate the linkage. The strategy can not only reduce the computational complexity by starting grouping from segments having higher possibility of being road centreline, but also enhance the reliability of grouping via using the clues between segment gaps which are detected by line detector.

Grouping is based on the Gestalt principles of similarity, continuity and proximity. The salient linear feature on the image – the main road can be easily perceived by human vision system even the feature is locally occluded, perceptual grouping plays core role in segment linking.

The implementation of grouping is depended on a global link-matrix for extracting collinear segment (Daniel C 1999). The segment connectivity matrix A can be formed by considering the valid collinear junctions extracted in the previous steps. If n is the number of segments, A is of dimension $n * n$, with $a_{i,j}$ if segments i and j are collinear, and 0 otherwise. The candidate collinear chains are extracted from the matrix A by tracing the minimal-cost route (the sum of link possibilities is to be maximum). Figure 6 shows the collinear grouping work flow. It’s an iteration procedure that ends when there is no new link generated.

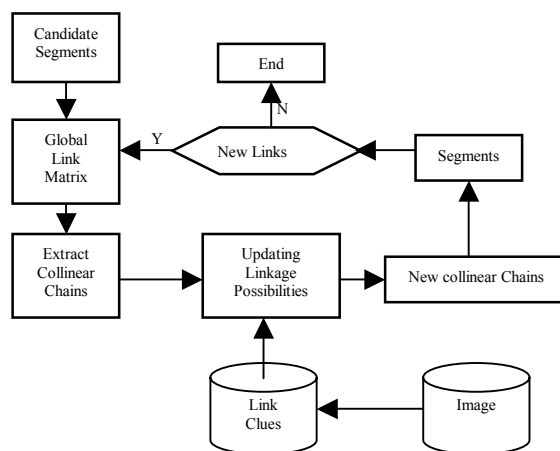


Figure 6. Collinear grouping work flow

2.4 Verification and Precise Delineation of Extracted Road Centerline

To verify the extracted centerlines, original resolution image is used to evaluate the ‘score’ of each line. Firstly, a length threshold is set to remove all short, isolated lines by applying a connection analyzer because the main road means that it has definitely length or is connected with other road parts; and then other longer lines are evaluated by peak value of profile-template matching. Correlation mean of each segment indicates the photometric possibility of being road, and the length and curvature of the centerline indicates the geometric attribute of being road. An evaluation function is set up to combine the geometric and photometric attribute together by weighted summing of the 2 items. So for each maintained centerline, there is an assessment value to indicate the reliability or possibility of road detection.

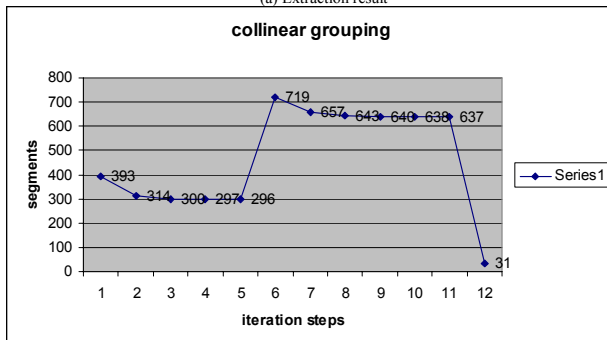
To get precise delineation of the road centerline, least square template matching is applied into the correction of centerline curve in original resolution image. The algorithm is similar to semiautomatic road extraction from initial seed points and image (Gruen, A.and H. Li, 1997).

3. IMPLMENTION

Figure 7 (a) is the extraction result from image shown in figure 3(a), the black lines are the identified road centrelines; Figure 7 (b) shows the collinear grouping procedure, it starts from the segments with higher possibilities and the link threshold is higher as mentioned in section 2.3, and then shorter and curve segments are grouped by setting lower link threshold and referencing link clues. In (b), it shows the starting segment number is 393, after grouping it becomes 296; in second stage, more segments with lower possibility are added into grouping procedure and the segment number is from 719 varying to 637, as final processing, simple topology analysis is used to remove the isolated and short segments, so the remaining main road centrelines number reduces to 31.



(a) Extraction result



(b) Collinear grouping

Figure 7. Implementation of main road extraction

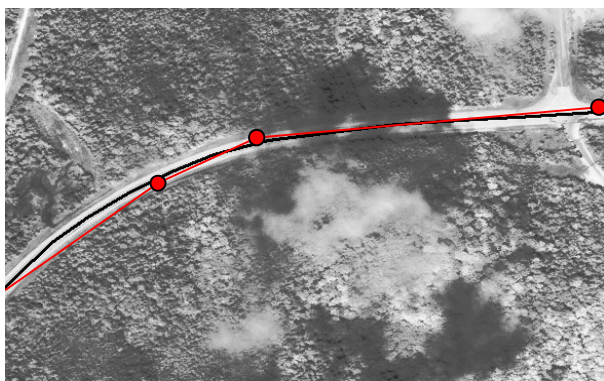


Figure 8. Road centreline line precise delineation

In figure 8, the result of precise delineation by least square template matching is shown in the original resolution, the red thin line is initial road centreline extracted in coarse resolution and the thick line is the adjusted centreline based on original resolution image by semiautomatic road extraction algorithm.

Checking the result, we find the extracted main road is quite correct in the open rural area, while it is not so correct and completed in the complex building site because in this case the extraction strategy and algorithm based on segment grouping is not so reliable because even by human vision system to identify the complicated structure of road or street network is still difficult due to the dependence of contextual and more information needed.

4. CONCLUSION AND FUTURE WORK

Main road (centreline) extraction from high resolution satellite image is very useful for GIS database revision, change detection, and some applications that transportation infrastructure information, such as disaster management, urban planning plays an important role. Presented method in this paper is trying to automatically extract the prior defined main road centreline. The hierarchical grouping strategy applied could reliably extract most of main road centrelines in the open rural areas even though there are some occlusions (caused by clouds, trees etc). The method attempts to simulate the perceptual capability of human vision system to find salient linear feature from image. The experimental result indicates the potential utility of the method. For complex scenes, more information should be integrated in order to obtain more robust result.

For acquiring more reliable result (no wrong extraction), we should take more road type (means more profile template) and more reliable verification algorithm into account, that can be done by combining kinds of template types and more segment attributes together for line detection and final assessment. Future work also includes extend the main road extraction to full road network extraction, because the main road network is very strong indication and contextual information for smaller road extraction and identification.

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REFERENCES

Baumgartner, A., C. Steger, H. Mayer, and W. Eckstein, 1999. *Automatic road extraction based on multi-scale, grouping and context*, Photogrammetric Engineering & Remote Sensing, Vol. 65 (7), pp. 777-785.

Daniel C, 1999. *A probabilistic method for extracting chains of collinear segments*. Computer Vision and Image Understanding, Vol 76(1), pp. 36-53.

Gruen, A., E. Baltsavias, and O. Henricsson (editors), 1997. *Automatic Extraction of Man-Made Objects from Aerial and Space Images II*, Birkhaeuser Verlag, Basel, Sweezerland.

Gruen, A. and H. Li, 1995. Road extraction from aerial and satellite images by dynamic programming, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol .50 (4), pp. 11-21.

Gruen, A. and H. Li, 1997. Semiautomatic linear feature extraction by dynamic programming and LSB-snakes, *Photogrammetric Engineering & Remote Sensing*, Vol .63 (8), pp. 985-995.

Heipke, C., C. Steger and R. Multhammer, 1996. A hierarchical approach to automatic road extraction from aerial imagery, In: *Integrating Photogrammetric Techniques with scene analysis and machine vision II*, Proceeding of SPIE (D.M. McKeown and I.J. Dowman, editors) (2486):222-231.

Laptev I, Mayer H, Lindeberg T, Eckstein W, Steger C, and Baumgartner A, 2000. Automatic extraction of roads from aerial images based on scale space and snakes, *Machine Vision and Applications*, Vol 12 (1), pp.23-31.

Mayer H. and C. Steger, 1998. Scale-space events and their link to abstraction, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol .53, pp. 62-75,

McKeown, D.M, Harvey, and J, McDermott, 1985. Rule-based interpretation of aerial imagery, *IEEE Tran On PAMI-7*, No 5, pp. 570-585.

Stilla, U., 1995. Map-aided structural analysis of aerial images, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 50 (4), pp.3-9.

Treash K, Amaratunga K, 2000. Automatic road detection in grayscale aerial images, *Journal of Computing in Civil Engineering*, Vol 14 (1), pp.60-69.

Trinder JC, Wang Y.D, 1998. Automatic road extraction from aerial images, *Digital Signal Processing*, Vol 8 (4), pp.215-224. OCT.

