Automatic Extraction of Road Network using GDPA (Gradient Direction Profile Algorithm) for Transportation Geographic Analysis

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Abstract: Currently, high-resolution satellite imagery such as KOMPSAT and IKONOS has been tentatively utilized to various types of urban engineering problems such as transportation planning, site planning, and utility management. This approach aims at software development and followed applications of remotely sensed imagery to transportation geographic analysis. At first, GDPA (Gradient Direction Profile Algorithm) and main modules in it are overviewed, and newly implemented results under MS visual programming environment are presented with main user interface, input imagery processing, and internal processing steps. Using this software, road network are automatically generated. Furthermore, this road network is used to transportation geographic analysis such as gamma index and road pattern estimation. While, this result, being produced to de-facto format of ESRI-shapefile, is used to several types of road layers to urban/transportation planning problems. In this study, road network using KOMPSAT EOC imagery and IKONOS imagery are directly compared to multiple road layers with NGI digital map with geo-coordinates, as ground truth; furthermore, accuracy evaluation is also carried out through method of computation of commission and omission error at some target area. Conclusively, the results processed in this study is thought to be one of useful cases for further researches and local government application regarding transportation geographic analysis using remotely sensed data sets.

I. INTRODUCTION

In the advent of commercial high-resolution remotely sensed imagery such as KOMPSAT, ORBVIEW and IKONOS, applications of remote sensing has been extended to various engineering, geography or spatial sciences. Among them, this study focuses on transportation geographic approaches; especially, US DOT/NASA supports this application named RS-T (Remote Sensing in Transportation), comparatively GIS-T(GIS for Transportation) by vector-based network topology data model (Lee, 2001). Whereas, RS-T is initiated by NCRST (National Consortium for RS-T) in US with four on-demand research programs: Traffic Flow, Infrastructure, Environ-mental Assessment, and Hazards/Disaster (US DOT/NASA, 2002). Furthermore, new applications of high-resolution imagery have been tentatively attempted to various types of urban engineering problems such as transportation planning, site planning, and utility management (Khuen, 1997).

This approach aims at software development and followed applications of remotely sensed imagery to transportation geographic analysis. At first, GDPA (Gradient Direction Profile Algorithm) and main modules in it are overviewed, and newly implemented results under MS visual programming environment are presented with main user interface, input imagery processing, and internal processing steps. Conclusively, the results processed in this study is thought to be one of useful cases for further researches and local government application regarding transportation geographic analysis using remotely sensed data sets.

II. EXTRACTION OF TRANSPORTATRION PLANNING INDICES

As the previous work (Lee et al. 2002), some extension-wares, TFI/TFL, URI (Foresman, 1999), and AI (Ma and Lilian, 1999) , running on ESRI-ArcView™ environment for transportation planning indices were implemented for demonstrate uses of remotely sensed imagery to transportation problems; in these extensions, geo-rectified imagery and layers of digital map in GIS-type, at the local government of interests, were used (Lee, 2002) .

III. GDPA FOR ROAD NETWORK EXTRACTION

GDPA algorithm, initially proposed by Wang and Zhang(2000), is classified as profile analysis one of methods for automated linear feature tracking, unlike Hough transform method and optimal search method (Gruen and Li, 1997; Karathanassi, et al, 1999).

The algorithm of GDPA implemented in this study can be summarized as follows.

① *Perform edge enhancement by image filtering*

② *Calculate the maximum 'Gradient Direction' for each pixel, shown Fig. 1.*

③ *Define 'Gradient Direction Profile' as a list of pixels along GD*

④ *Fit 'Gradient Direction Profile' using polynomial function, and determine the parameter in the fitting function*

$$f(x)=b_0+b_1+b_2x^2 \quad x\in [k_1, k_2]$$

⑤ *Compute the derivatives of fitting function, and find extreme value (x_0) in the pre-defined boundary*

⑥ *Compute curvature function of fitting function, and estimate extreme value condition with respect to first derivative, second derivative, and curvature function*

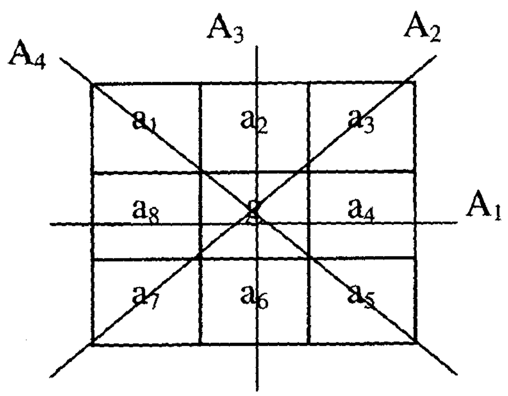
$$K(x)=|f'(x)|/(1+f''(x)^2)^{1.5}$$

⑦ *Determine thinning variable with respect to curvature function*

$$K(x_0) > \text{A given constant } T$$

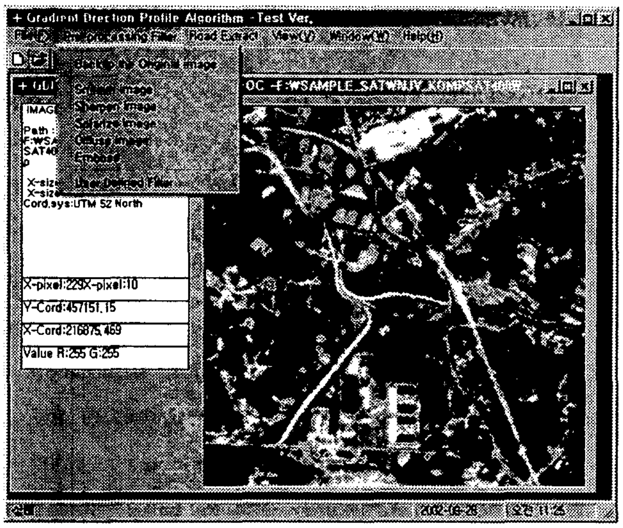
⑧ *Convert to binary-type image showing road element pixel based on acceptance of extreme value satisfied conditions after steps above were applied at original image*

$$x_0\in [k_1, k_2]$$
$$f'(x_0)=0$$
$$f''(x_0)<0$$

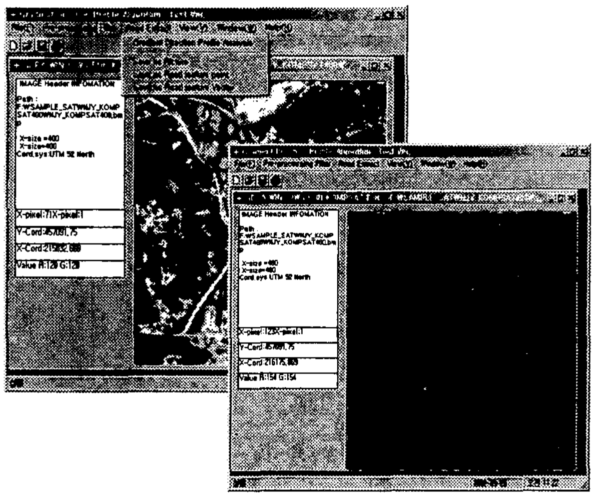


[Fig. 1] Computation of gradient direction, which means direction of maximum slope among four defined directions near a centered pixel.

In this study, these algorithms are implemented under MS visual programming environment. At Fig. 2, main GUI for GDPA is represented with importing remotely sensed image format and pre-processing modules as first step by using spatial filtering. While, it is assumed that input imagery is geo-rectified and ortho-rectified.

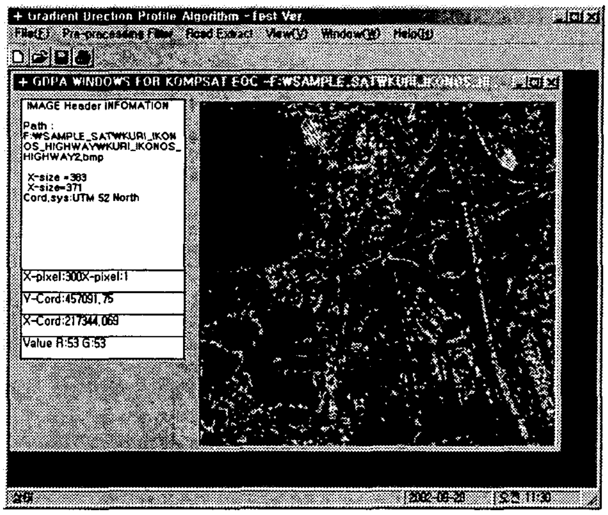


[Fig. 2] Main GUI for GDPA processing with KOMPSAT image loading and pre-processing modules, step 1.



[Fig. 3] GDPA processing with GUI, as core modules of step 2-6, and 8, with KOMPSAT EOC imagery. But this resultant image in bitmap is not final road network extracted, due to not calibrated thinning variable, yet.

At Figs. 3 and 4, actual GDPA processing in this software is shown; however, this resultant image in bitmap is not final road network extracted, because calibrated thinning variable at step 7 in curvature function, yet. After done by step 7 and 8, this bitmap image is converted into vector-based data structure of CAD-typed DXF or GIS-typed Shapefile, such as Fig. 5, showing example result with respect to part of high-resolution IKONOS imagery.



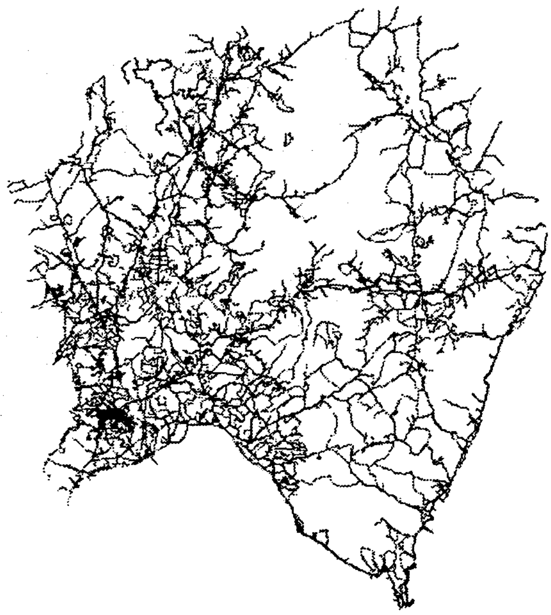
[Fig. 4] GDPA processing, as core modules of step 2-6 and 8, with IKONOS PAN-Sharpen imagery.

[Fig. 5] Road network centerline problems in high-resolution imagery: single, multiple line, or foot-print: (A) input imagery, (B) road center line, and (C) road layers.

As the practical aspect, linear-typed or curve-typed road features are well extracted, if KOMPSAT EOC imagery is applied. However, multiple road-related elements are extracted in GDPA processing such as Fig 5(C), in the case of uses of high-resolution imagery.

IV. ERROR EVALUATION

While, this result needs error-assessment, and the following method can be utilized with road layers within NGI digital map such as Fig. 6.



[Fig. 6] Examples of multiple road layers from digital map.

As the first simple method, after conversion road layer into bitmapped image format, GDPA result and this image is compared using difference operation. Therefore, three values are shown as -1, 0, and +1. Of course, 0 means completely matched. Whereas other unit values represent newly constructed road for digital map updating or true error for road, extracted by GDPA.

As second method to evaluate error rate, pixel counting method can be also applied.

Overall accuracy=Nce / Ntr

Commission error=(Nte-Nce) / Ntr

Omission error=1 – Nce / Ntr

Error Ranking

where Number of pixel, extracted as road element: *Nce*, Number of pixel, classified road on digital map: *Ntr*, and Total number of pixel in area of interests: *Nte*.

It is noted that both methods are used road layers of digital map data as ground truths.

V. CONCLUDING REMARKS

(1) Using this algorithm of GDPA, road network can be automatically generated, if user-defined variables such as k_1 , k_2 or T shown at step 7 are determined. There are some advantages in GDPA over other algorithms. First, edge detection and road tracking are done simultaneously, and second, it can describe local conditions of features (Saleh, 2001),. And it can be implemented as relatively simple procedure using only gradient value. However, it provides bad result, if similar radiometric contrast between roads and surroundings occurred in processing imagery, just like other algorithms.

(2) In KOMPSAT-EOC imagery, main features by GDPA are road center-line and road boundary with road facilities, and then these are converted into road network. While, in IKONOS imagery of high-resolution resolution and narrow coverage, main features using this algorithm is somewhat different. Therefore, GDPA using IKONOS imagery need more detailed processing or semi-automated processing.

(3) Road features extracted by GDPA can be used to GIS database for road information. If road database is already built in a local government, this method can be applied to road feature updating purpose. While, If not built such as inaccessible region, this method is for road database building in GIS-typed data structure.

(4) As for transportation geography, Taaffe and Gauthier (1973) dichotomized the measures of spatial pattern regarding road network is: numerical description of geometric element with primitives of line segments and nodes and vector description of each road network. In road network, connectivity of linear features with multiple nodes is first determined; for this purpose, it is

known to some quantitative index such as α index, β index, or γ index. Therefore, road network by GDPA using multi-temporal KOMPSAT EOC is re-built to node-arc structure, GIS-typed shapefile from bitmapped image, in GIS-T, and then these indices are computed in this software. The result provides quantitative temporal change of road network development. Also this result can be utilized to urbanization rate during several period in a certain local government.

(5) This road network information can be linked with transportation planning extensions such as TFL/TFB, URI, and AI, mentioned before. Thus, these implementations is composed of RS-T components.

VI. REFERENCES

A. Gruen and H. Li, 1997, Semi-automatic Linear Feature Extraction by Dynamic Programming and LSB-Snakes, PE&RS, 63: 985-995.

B. Khuen, 1997, Commercial Application for High Resolution Geo-spatial Imagery, PE&RS, 63: 933-941.

E. J. Taaffe and H. L. Gauthier, 1973, *Geography of Transportation*, Prentice-Hall, NJ.

R. A Saleh, 2001, Comprehensive Survey of Extraction Techniques of Linear Features from Remote Sensing Imagery for Updating Road Spatial Databases, CLEM Specialist Meeting 2001.

J. Wang, and Q. Zhang, 2000, Applicability of a Gradient Profile Algorithm for Road Network Extraction-Sensor, Resolution and Background Considerations, Canadian Jour. of Remote Sensing, 26: 428-439

K. Lee, Remote Sensing in Transportation: An Overview, 2001, ISRS Proceedings.

K. Lee, K. Y. C. Yu, and H. S. Sagong, 2002, Application of KOMPSAT EOC Imagery in Transportation Reference Planning, with Korean National Land-Use Thematic Data: A Case Study, IGARSS 2002 Proceedings.

K. Lee, 2002, Prototyping of Some Indexes Extraction for Transportation Reference Planning using Remotely Sensed Imageries, Korean Jour. of Remote Sensing, 18, to be submitted.

M. L. Ma and S. P-C. Lilian, 1999, The Study of Accessibility Indices in Transportation Planning by using GIS, URISA Conference Proceedings.

T. W. Foresman, 1999, An Index for the Quantified Definition of Urban and Rural Areas, Presentation on the Association of American Geographers, 95th Annual Meeting, Honolulu, Hawaii.

U. S. DOT/NASA, 2002. Achievements of the DOT-NASA Joint Program on Remote Sensing and Spatial Information Technologies: Application to Multimodal Transportation: 1-79.

V. Karathanassi, C. Lossifidis and D. Rokos, 1999, A Thinning-based Method for Recognizing and Extracting Peri-Urban Road Networks from SPOT Panchromatic Images, Int. Jour. of Remote Sensing, 20: 153-168.