A Study on the Road Extraction Using Wavelet Transformation

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Abstract

Topographic maps can be made and updated with satellite images, but it requires many human interactions that are inefficient and costly. Therefore, the automatizing of the road extraction procedures could increase efficiency in terms of time and cost.
Although methods of extracting roads, railroads and rivers from satellite images have been developed in many studies, studies on the road extraction from satellite images of urbanized area are still not relevant, because many artificial components in the city makes the delineation of the roads difficult.
So, to extract roads from high resolution satellite images of urbanized area, this study has proposed the combined use of wavelet transform and multi-resolution analysis. In consequence, this study verifies that it is possible to automatize the road extraction from satellite images of urbanized area. And to realize the automatization more completely, various algorithms need to be developed.

I. Introduction

With the emergence of high resolution satellite images topographic maps can be revised by satellite remote sensing. However, the extraction of geospatial informations from satellite images requires many skillful human interventions. This is inefficient, unproductive, and costly. Therefore, many researches on automatization of extraction processes have been performed. One of the main research topics is automatic road extraction.
Cleynen-brengel et al.(1990) have tried to extract roads using auxiliary informations, such as land cover, DTM and existing road maps. Solberg (1992) has updated the existing road maps by visual comparison of newly extracted roads with existing ones. Couloigner et al.(1998) have extracted road networks using road intersection points which are extracted from multi-resolution images.
In urbanized areas, the mixture of spectral signatures of different land features makes road extraction difficult. So, fine spatial resolution makes good distinctions between neighboring features in urban areas, but automatic or semi-automatic road extraction with high resolution images become a complicated task, because of other features such as vehicles, buildings, trees and feeders.
In this study, for improving road extraction results in urbanized areas, following three methods are applied and their results are integrated. The first one is extracting the basic information from spectral characteristics of roads; the second is extracting the road lines with edge operators; and the third is classification of images, which are combined of panchromatic and multispectral images. Here, the "a trous" algorithm which integrates multiresolution analysis and wavelet transform is used for edge extraction, and wavelet transform is used as an image merger. Delineated road

edges are refined with geometric constraints, such as maximum width, minimum length, etc. to generate road networks.

II. Methodology

2.1 "a trous" Algorithm

A scale, which gives the best discrimination of a feature, differs among features. For example, in macro scale(e.g. the globe) the continents and oceans can be found easily and the details of topographic or man-made features are eliminated by coarse resolution of maps, but in micro scale the details like road networks in urban areas can be seen promptly and larger features can be omitted inadvertently. Therefore, for detecting edges in various scale, an appropriate scale should be used for each edge formation.
In multi-resolution analysis, wavelet is used as scaling basis. The expansion and the contraction of the basis wavelet determines an image scale. The basis wavelet, $\Psi(x)$, is scaled by $\Psi(x/a)$ ($a>1$ means smaller scale and $0<a<1$ means larger one).

1) Pyramid Algorithm

A N/2 x N/2 image can be obtained by deleting every second rows and columns of an N x N image. Where, $N=2^i$. The recursion of this process makes a smaller image (i.e. macro scale image), and eventually 1 x 1 image. If one wants to extract the edges, fine edges can be found in the original image, and coarser edges can be detected in smaller scale images.

2) Laplacian Pyramid Coding

A lowpass filtered image is obtained by applying Gauss impulse to the original image, and high frequency details are remained by subtracting the filtered image from the original image. Then, an image can be sub-sampled without any expense of details. This process decomposes an image into low frequency components with the half of the original resolution ($f_1(i,j)$) and high frequency components of the original image ($h_1(i,j)$).

$$f_1(i,j) = [f_0 * g](2i, 2j)$$
$$\text{and} \quad h_1(i,j) = f_0(i,j) - [f_0 * g](i,j)$$

2.2 MWD (multiresolution wavelet decomposition) Image Merger

Image merging integrates spectral and spatial information into a single data set. A merged image is useful for geometric and attributive measurement. If a merged image can retain much of the spectral signature of input images, it is very useful in spectral classification.
Recently, Yocky(1995) has proposed a new merge method using MWD(multi-resolution wavelet decomposition) algorithm which adopt two-dimensional discrete wavelet transform.
A multispectral image is up-sampled up to the resolution of panchromatic image to obtain approximation coefficients of the wavelet transform. This approximation coefficients substitute for coefficients of a panchromatic image, and the inverse transform is performed to make a merged image.

III. Road Extraction

In this study, IRS-1C panchromatic image of Dec., 1996 and SPOT XS image of Jan., 1997 are used. The study areas are Dae-chi·Il-won Dong area in Seoul city and Go-deung·Shi-heung·Sa-song Dong area in Sung-nam city. Each of the study areas have 512 x 512 pixels for IRS-1C and 128 x 128 pixels for SPOT XS. These areas are selected by their urbanization, one is fully urbanized and the other is half urbanized.

<Figure 1> IRS-1C Image of Study Area 1

<Figure 2> SPOT Image of Study Area 1

<Figure 3> IRS-1C Image of Study Area 2

<Figure 4> SPOT Image of Study Area 2

ER Mapper and Matlab have been used for image data processing in this study.

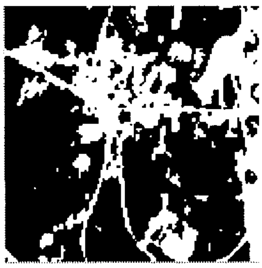
3.1 Spectral Signature

To extract the spectral signature of the road, NDVI is calculated for each image. NDVI of SPOT XS is given as follows.

$$NDVI_{HRV} = \frac{XS3 - XS2}{XS3 + XS2}$$

The urbanized area, including the roads, have high NDVI values in SPOT XS images. To detect edges, the threshold is applied to NDVI, so that the roads remain(Fig. 5, 6). As shown in Figures 5 and 6, the roads cannot be distinguished from other urban features.

<Figure 5> NDVI of Study Area 1 after Thresholding



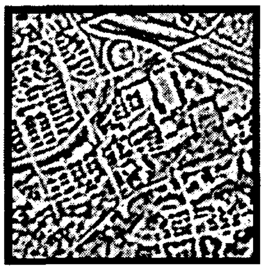
<Figure 6> NDVI of Study Area 2 after Thresholding

3.2 Edge Extraction by "a trous" algorithm

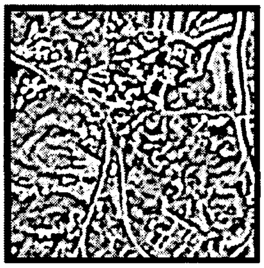
In this study, "a trous" algorithm is used for multi-resolution analysis. The threshold is applied to the final coefficient image among image pyramids, to substitute the meaningless coefficients by zeros, and meaningful coefficients by ones. The primitive edges are extracted from this result and high pass filter.

<Figure 7> Context Image of Study Area 1 at Phase 5

<Figure 8> Context Image of Study Area 2 at Phase 4



<Figure 9> Coefficient Image of Study Area 1 at Phase 5

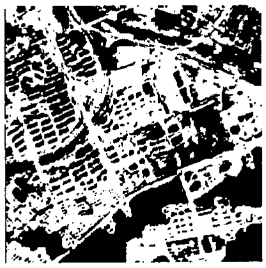


<Figure 10> Coefficient Image of Study Area 2 at Phase 4

3.3 Classification of merged images

A merged image is varied with wavelet basis in the merging process. In this study, Daubechies's basis is used in the merging process (Yocky, 1996). This process has modified the existing wavelet merging process to reduce the ringing effect which is formed by quantifying the spectral image by spatial distribution terms. The modified wavelet merging process takes the averaged detail coefficients of panchromatic and multi-spectral images as detail coefficients of merged image for horizontal, vertical, and diagonal elements, respectively. With this method, more spectral characteristics are reserved, compared with standard MWD as well as IHS merger(Yocky, 1996).

<Figure 11> Merged Image of Study Area 1



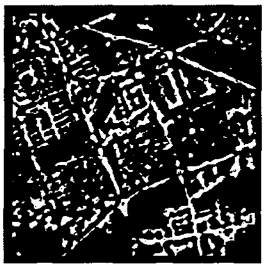
<Figure 12> Road Class of Study Area 1

<Figure 13> Merged Image of Study Area 2

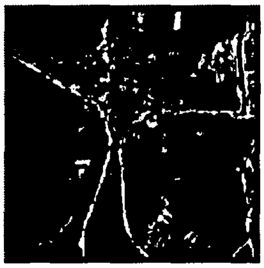
<Figure 14> Road Class of Study Area 2

3.4 An Integration of the results

The candidate edges of the roads are generated by integrating the results that are extracted above this section, and retrieving the common feature.



<Figure 15> Edge Extraction Result of Study Area 1



<Figure 16> Edge Extraction Result of Study Area 2

IV. Evaluation

4.1 Evaluation Method

The accuracy of the extracted road centerlines is evaluated using the existing road maps as a reference.

If the extracted roads within a buffered area of the existing roads, it is considered that the extraction has been done correctly. In accuracy measurement, TP(True Positive), FP(False Positive) and FN(False Negative) are defined by the matched length of the extracted roads, the unmatched length of the extracted roads, and the length of unmatched roads in the reference, respectively. The measurements of accuracy refer to the completeness and correctness.

① Completeness

$$completeness = \frac{matched\ length\ of\ extracted\ roads}{length\ of\ reference\ roads} \fallingdotseq \frac{TP}{TP+FN}$$

$$completeness \in [0,\ 1]$$

② Correctness

$$correctness = \frac{matched\ length\ of\ extracted\ roads}{length\ of\ extracted\ roads} \fallingdotseq \frac{TP}{TP+FP}$$

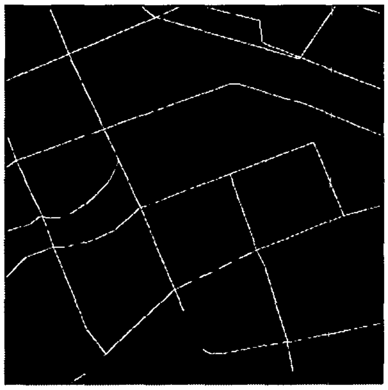
$$correctness \in [0,\ 1]$$

4.2 Evaluation

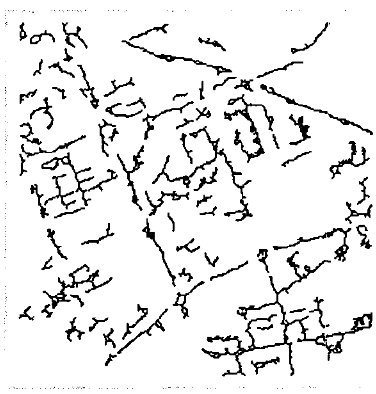
Pixedit software is used for vectorizing, and Matlab Image Processing Toolbox for buffering and matching.

Lines, which are wider than 11 pixels and shorter than 20 pixels, are eliminated in the vectorizing process.

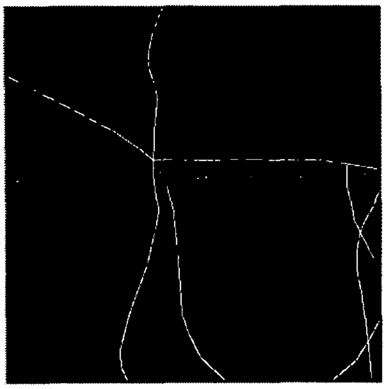
The reference is edited from the 1/25,000 digital maps.



<Figure 17> Reference Data of Study Area 1



<Figure 18> Vectorized Road of Study Area 1



<Figure 19> Reference Data of Study Area 2

<Figure 20> Vectorized Road of Study Area 2

Heipke et al.(1996) have recommended half of the road width as a buffer width, which greatly affects the evaluation result. In this study, 15m is used as the buffer width.

〈Table 1〉 TP(True Positive), FP(False Positive) and FN(False Negative) of Study Areas

unit : km

	TP	FP	FN
Study Area 1	10.759	19.690	8.931
Study Area 2	5.734	5.603	3.825

〈Table 2〉 Evaluation Statistics of Study Areas

	completeness	correctness
Study Area 1	0.5464	0.3589
Study Area 2	0.5998	0.5058

In study area 1, the correctness is much smaller than the completeness. As shown in <Fig. 17, 18>, the extracted roads are much more complicated than the reference and the net length of the extracted roads is much longer than that of the reference. The study area 1 is a fully urbanized area, so there are many driveways, feeders and service roads besides the arteries or main lines. In this study, the multi-resolution analysis and the MWD merger can extract these smaller roads that diminish the correctness of the result.

The threshold of the vectorinzing options can affect the road extraction result and the accuracy of the medium scale existing road maps can lower the accuracy of the road extraction result.

V. Conclusion

The results of this study are as follows;

Firstly, fully urbanized area(study area 1) has had similar accuracy value to half urbanized area(study area 2). Then, it is expected that the automatize the road extraction in fully urbanized area is possible with remotely sensed images.

Secondly, smaller roads as well as the main road networks can be extracted using multi-resolution analysis and MWD merger. So, if the proposed method is applied to high resolution images, it is expected that the road networks of various sizes can be extracted by scale.

And the lastly, merged result of IRS-1C and SPOT XS images has retained much of the spectral signals and spatial relations of original ones, therefore this merging process is useful at spectral classification and updating GIS database.

In this study, we have proposed the possibility of the automatic road network extraction in urbanized area, but to produce more complete results further researches are necessary; How to vectorize the candidate edges, considering topological structures and geometrical characteristics of the road networks; and how to use auxiliary information such as building information in the DEM for the edge extraction.

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