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Urban Road Extraction from Aerial Photo by Linking Method

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Abstract

We have seen rapid changes in road systems and networks in urban areas due to fast urbanization and increased traffic demands. As a result, many researchers have put greater importance on extraction, correction and updating of information about road systems. Also, by using the various data on road systems and its condition, we can manage our road more efficiently and economically. Furthermore, such information can be used as input for digital map and GIS analysis. In this research, we used a high resolution aerial photo of the roads in Seongnam area. First, we applied the top-hat filter to the area of interest so that the road markings could be extracted in an efficient manner. The lane separation lines were selected, considering the shape similarity between the selected lane separation line and reference data. Next, we extracted the roads in the urban area using the aforementioned road marking. Using this technique, we could easily extract roads in urban area in semi-automatic way.

Keywords : Road Extraction, Aerial photo, Road Markings, Top-hat filter, Thresholding, Linking

1. Introduction

Recently, there have been rapid changes in road systems due to the fast urbanization and increased traffic demands. Many researchers have put greater importance to the correction and updating of road systems. Ground surveying intended for updating road system information is considered to be the most inefficient methods. However, the use of satellite image fails to describe detail road network, e.g., center line and zebra crossing, etc. Thus, if we use high-resolution aerial photo, not only can we extract the road layout, but also the various road details allowing us to construct excellent geo-spatial database.

Generally, we perform road extraction from images using various line detection algorithms. We can classify the previous works that were done on line detection into three categories: The first approach detects lines by considering the gray values of an image only and uses purely local criteria, e.g., local gray value differences. The second approach regards lines as objects having parallel edges. First, the local line direction is determined for each pixel. Then, two specially tuned edge detection filters are applied perpendicularly to the line, where each filter detects either the left or right edge of the line. The final approach is to regard the image as a function z(x, y) and extract lines from it by using differential geometric properties. The basic idea behind these algorithms is to locate the positions of ridges and ravines in the image function. They are then further divided according to the property they use (Steger, 1998). The region of interest of approach that is used for automatic road extraction from aerial photo can be divided into rural and urban areas. In rural areas, the method uses an explicit model for lines and their surroundings has been proposed (Steger, 1998). Another approach based on Marr's theory of vision is proposed. This approach consists of low-level image processing for edge detection and linking, mid-level processing to form road structure, and high-level processing for the recognition of roads (Trinder, 1998). In urban areas, road extraction is based on a semantic

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model for roads. The images are divided into categories so called "global context": rural, forest, and urban. Different parts of the road model and different strategies are used in each global context. In rural areas, a multi- scale approach is employed to find initial hypotheses for roadsides, which are then grouped into road segments using local context knowledge. In urban areas, road markings and DEM information are used to extract road segments (Hinz, 1999). In order to deal with the high complexities of the aeria, a multi-scale approach is employed to find initial hypotheses for roadsides, which are then grouped into road segments using local context knowledge. In urban areas, road markings and DEM information are used to extract road segments (Hinz, 1999). In order to deal with the high complexities of the aerial photo, they integrated the detailed knowledge about roads and its context (Hinz, 2003).

2. Our Approach

Fig. 1 illustrates schematic diagram of road extraction we performed. Our system attempts to apply the top-hat filter to aerial photos to discriminate between road markings and background. Then, we change the gray-level image into binary image by thresholding, selecting the appropriate road markings, and extracting the roads by linking the selected road markings. Accuracy is assessed by calculating the spatial difference between the actual road and the extracted road.

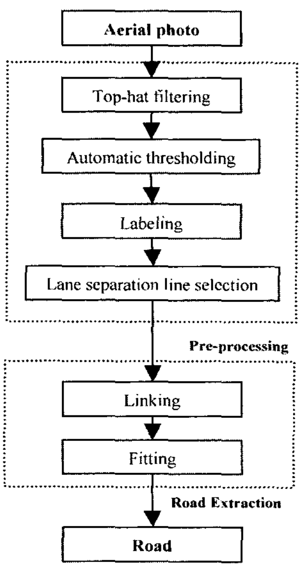


Fig. 1. Schematic diagram of road extraction.

3. Pre-processing

3.1 Top-hat filter

The main goal of road extraction is to clearly discriminate between road markings and its background. To achieve this objective, many approaches are presented, e.g., edge detection, line detection, and thresholding (Jain, 1989). But, natural and artificial features prevent road markings from being extracted accurately. In order to process the algorithms based on shape, we used morphological operation. A matrix is used to define a structuring element shape and size for morphological operations. By choosing the size and shape of the structuring element, we can construct a morphological operation that is sensitive to the region of interest. This size is large enough to detect most of the interesting objects (Eckstein, 1999). Structuring elements used for the circle, square, and diamond shapes are merely approximations (Parker, 1997).

In order to deal with the high complexities of ground features, we used circular structural element. Specifically, we applied the top-hat filter using circular structural element to the region of interest. The top-hat filter is given by Eq. (1). Where $f_{nB}(x)$ denotes opening operation and y denotes result eliminated background.

$$y = f(x) - f_{nB}(x) \tag{1}$$

Firstly, we found a structure element which had to be a little larger than the elements that we would like to remove. Secondly, we let that structure element run over the image and performed an erosion operation. When we erode with the structure element every object that is smaller than that structure element will disappear, but those holes will get bigger. Thirdly, we followed with dilation after the erosion. That combination is what we call the opening operation. Precisely, Opening operation is that the application of an erosion immediately followed by a dilation using the same structuring element. We have removed all the small items outside the object, but the elements inside the object are still there. Finally, we subtracted a morphologically opened image from the original image ($f(x)$). This can be used to enhance contrast in an image.

3.2 Thresholding

It is difficult to only analyze the features of interest only, because the filtered image is a gray-level image. Thus, it is necessary to transform the gray-level image into a binary image (Young Su Cha, 1998). In this paper, we used the method proposed by N. Otsu. The purpose of this method is to automatically divide a pixel value histogram into two distinct regions without any supervision, that is, without requiring a human to supply any threshold information. An Optimal threshold is important for extracting foreground objects when a histogram approach is employed. This method uses discriminant analysis to discriminate between foreground and background by maximizing the discriminant measure variable. The maximum value for the discriminant criterion can be found by simply using the Eq. (3). For this purpose, he let the pixels of a given picture be represented in L gray levels. The number of pixels at level i is denoted by n_i and the total number of pixels by N. In order to simplify the discussion, the gray-level histogram is normalized and regarded as a probability distribution.

$$p_i = \frac{n_i}{N} \tag{2}$$

where $p_i \geq 0, \quad \sum_{i=1}^{L} p_i = 1$

L : pixels at level n_i : Levels of gray i

N : total pixels

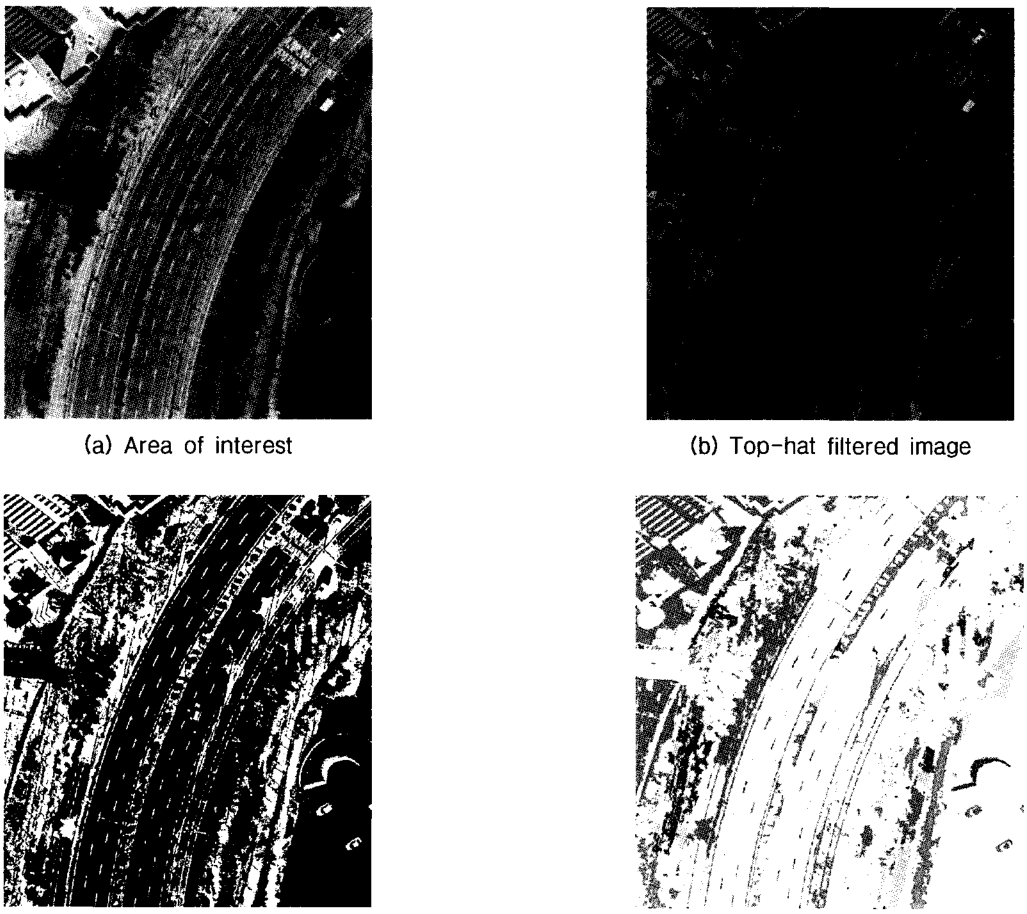
$$\sigma_B{}^2(k) = \frac{[\mu_T \omega(k) - \mu(k)]^2}{\omega(k)[1-\omega(k)]} \tag{3}$$

where $\omega(k) = \sum_{i=1}^{k} p_i$: Zeroth cumulative moment

$\mu(k) = \sum_{i=1}^{k} i \cdot p_i$: First cumulative moment

$\mu_T = \sum_{i=1}^{L} i \cdot p_i$: Total mean level

The optimal threshold k that maximizes Eq. (3) is selected in the following sequential search by using the simple cumulative quantities. This method is known to



(a) Area of interest

(b) Top-hat filtered image

(c) Thresholded image

(d) Labeled image

Fig. 2. Road markings extraction.

Table 1. Selected parameters (pixels)

	Theoretical value		Selected value	
	Area	Major Axis Length	Area	Major Axis Length
Min	28	28	35	29
Max	96	32	100	43

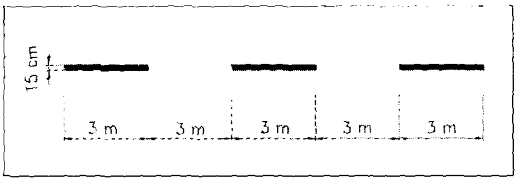


Fig. 3. Road markings standard.

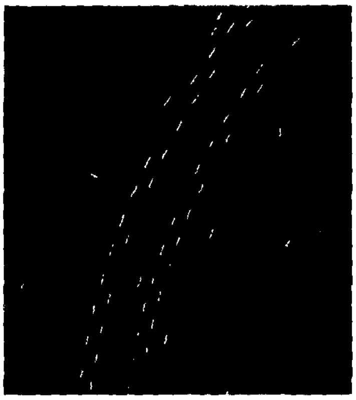


Fig. 4. Selected road markings.

have the merits. A selected threshold is stable, and it can be selected automatically, without any basis of the differentiation, not on the integration of the histogram (Otsu, 1979).

3.3 Lane separation line selection

The selection of parameters is a very important step in order to develop a generally applicable algorithm. The Seoul Regional Police Headquarter regulates "Road Markings Design Standard," as shown in Fig. 3. Because aerial photo used in this paper have 10 cm spatial resolution, we selected parameters as shown in Table 1, and the lane separation lines were selected, considering the similarity between the selected value and the true value as shown in Fig. 4.

4. Road extraction

4.1 Linking

Road can be extracted by linking the centroids. The orientation, which the angle (in degrees) between the

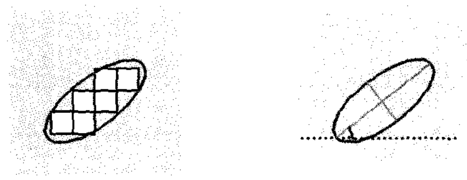


Fig. 5. Orientation of feature.

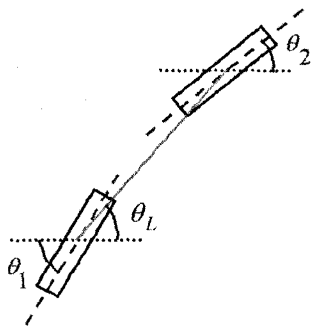


Fig. 6. Spatial relationship of lane separation line.

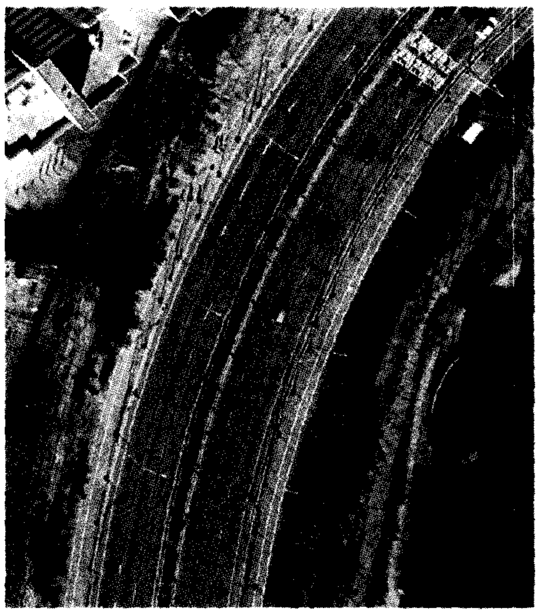


Fig. 7. Linked lane separation line.

x-axis and the major axis of the ellipse that has the same second-moments as the region, is the scalar. Fig. 5 illustrates the axes and orientation of the ellipse. The left side of the figure shows an image region and its corresponding ellipse. The right side shows the same ellipse, with features indicated in a graphical manner; the dotted black lines are the axes, and the orientation is the angle between the horizontal dotted line and the major axis.

First, we sought for the nearest centroid of lane separation line to link the selected lane separation line.

Secondly, we linked them and calculate Eq. (4). If the condition is satisfied, they are going to be connected iteratively.

$$|\theta_2 - \theta_L| \leq T \quad and \quad |\theta_1 - \theta_L| \leq T \qquad (4)$$

Fig. 6 illustrates θ_1, θ_2 and θ_L Where, T is predefined threshold. This is selected by considering of road curvature. We used the Matlab 6.5 for coding and testing the proposed method.

4.2 Pre-knowledge about road model

The road model illustrated in this paper compiles knowledge about topological and geometric characteristics of urban roads. The model represents the standard case, i.e., (1) most roads in urban areas are connected to one another. (2) The roads in urban areas have a center line. (3) Generally, a lane width in region of interest remains constant. We extracted road using these conditions. Therefore, there exist center line in the middle of the extracted lines and road edge in position added general road width to the extracted road width. Because the road is designed according to rules, if we use the knowledge that we have about the design standard, we would be able to extract perfectly the road network for the region of interest.

4.3 Road center line extraction

There exists a center line in the middle of the linked lane separation lines, as shown in Fig. 7. Theoretically, there exists road center line in the middle of the roads. To extract center line, we fitted a curve equation on linked lane separation lines. Precisely, the fitted curve equation is going to represent roads, because road center line is located with the center of lane separation lines group. Fig. 8 illustrated fitted road center line. We used exponential equation as the fitting equation. The equation is given by Eq. (5). The confidence bounds of the coefficients are 95%.

Fig. 8. Extracted Roads.

$$FIT(x) = a * \exp(b * x) + c * \exp(d * x) \qquad (5)$$

where a = 673.4, b = -0.001538
c = 114.8, d = 0.0003121

4.4 Evaluation

In this paper, road extraction depends on the number of selected lane separation line. It is easy to perform road extraction if road is extracted only lane separation

Table 2. The number of road markings

	Actual road marking	Extracted road marking	Percentage
number	51	47	92%

Table 3. Distance between extracted center line and reference point

No.	Reference point		Distance
	x	y	
1	261.53	1241.2	4.3341
2	266.1	1172.7	3.6388
3	277.51	1106.5	1.7915
4	284.36	1033.5	10.2609
5	293.49	967.29	12.9489
6	309.47	901.08	10.5351
7	325.45	834.88	1.6062
8	346	764.11	7.3196
9	366.54	700.19	5.3966
10	391.66	629.42	3.499
11	428.18	563.22	5.8313
12	457.86	497.02	2.8189
13	496.67	423.97	1.1258
14	526.34	364.61	11.5777
15	565.15	307.54	2.3646
16	601.68	250.47	11.8934
17	642.77	193.4	5.4282
18	683.86	143.18	4.7652
19	711.25	111.22	6.1181
20	768.33	45.016	14.2298
			6.4 pixel

line from image efficiently. Thus, it is important to perform accuracy assessment through a quantitative method in which we can compare the number of extracted lane separation lines to that of actual lane separation lines. Where, actual lane separation lines are numbered by visual inspection. The accuracy of road markings extraction reaches to 92%. Also, we assessed the accuracy of extracted road by calculating the pixel distance between the fitted road center and the actual road center in Table 3. The average distance of the extracted road center reached 6.4 pixels. Where, actual road center is extracted by manual digitizing.

5. Conclusion

In this paper, we extracted urban road by applying the top-hat filter to an aerial photo, and selecting road markings, considering geometric characteristics of lane separation lines, and linking selected road markings by considering knowledge of road systems. The method using pixel value or boundary detection has difficulty in terms of extraction of roads because of the complex ground features in case of high-resolution aerial photo. But, we were able to obtain good results by using the method that connect specific feature that is only observed in urban roads.

Furthermore, if we can distinguish between extracted and unextracted road markings by applying a proper threshold, we would be able to use this data for maintenance and management of road, such as in mending road markings. But, it is not as simple as it sounds. It is very difficult to extract every type of road markings because the different geometric characteristics of each road marking. The road markings in the area which is occluded by cars and buildings can be added by inducing cycle of road markings position that is symmetric and fixed distance by a center line. This method is appropriate to the road which has many ground features. Lastly, if we extract road and road markings with this proposed method and we have formed a broad model with pre-knowledge of design standard, we will be able to construct road map of urban area.

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