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EXTRACTION AND RECONSTRUCTION OF ROAD SEGMENTS BY SPATIAL FILTERS

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ABSTRACT

In general, it is very difficult to design a spatial filtering neural network which can extract all the target features without being contaminated by other false features. In the previous works, the authors have proposed a neural network architecture which can extract road segments without noises in general situations. The road segments, however, were extracted as broken at the region where they are overlaid and occluded by characters and other map symbols. Few studies have been carried out to complete road segments which are interrupted by map symbols. In this paper, a novel approach for the completion of road segments interrupted by map symbols, including a brief explanation of the extraction process, is proposed by spatial filters. The system is applied to 1/25,000 scaled maps published by the Geographical Survey Institute of Ministry of Construction of Japan. It is shown that the system can extract and complete road segments in various cases successfully.

I. INTRODUCTION

Computerized map reading is one of the most important application areas in image processing. A map data base can be used for a wide range of social activities. Data in a typical map consist of lines and symbols that represent roads, rivers, contour lines, geographical boundaries, cities, etc. Among these entities, road information is regarded as both important and valuable one, thus, a number of works extracting road information have been reported[1][2][3]. In this paper, a novel approach for the extraction and reconstruction of road information is proposed using spatial filtering neural network.

It is very difficult to design a spatial filtering neural network which extracts complete and noiseless road information. It may be relatively easy, however, to design a system which can extract a complete set of road information, regardless of additional false features. It may also be easy to design another system which extracts incomplete but noiseless road information. The former system provides *sufficient*-feature in the sense that it contains at least complete road information. The latter provides *necessary*-feature in the sense that it contains at most road information which is incomplete but noiseless. One of the objectives of this paper is to report a novel spatial filtering network architecture[4] which extracts noiseless and complete set of road information by exploiting both necessary and sufficient feature.

Extracted roads, however, are cut off in the region where roads are overlaid by other map symbols. Moreover, which will be discussed later, they are broken in the neighborhood of crossings. Thus, these separated segments of roads must be completed in some way. Note that these segments of roads have their own preferred orientations and the two terminals of them have opposite directions. The second objective is to construct spatial filtering neural network system that connects segments of road.

II. EXTRACTION OF ROAD SEGMENTS

A road is symbolized by a pair of parallel lines. For simplification of the reconstruction process which is followed by the extraction process, single line, that is, skeleton of parallel lines is extracted instead of parallel lines. In this paper we call this skeleton image *road segments*.

Road segment extraction system, as shown in Figure 1, consists of three networks, namely, necessary-feature, sufficient-feature and integrating networks. Labels (a)~(e) denote the processing stages whose example output images are shown in Figure 7(a)~(e).

2.1 NECESSARY-FEATURE NETWORK

The purpose of this network is to extract only the road segments under relatively strong constraints. This network consists of the following three processing steps.

The first step classifies road symbols from non-road symbols by the thickness of line segments constituting map symbols. Most of symbols on a map are represented by line segments, and the thickness of line segments is determined by standards[5]. Therefore, symbols can be classified according to the thickness of their constituent line segments. This *a priori* knowledge is used for the preprocessing of the necessary-feature network. The classification is performed by spatial filtering. A set of two dimensional circular symmetric DOG filters is used. These filters correspond to an on-center and off-surround receptive fields found in a mammal's retinal[6].

A road is represented by a pair of parallel lines whose interval is determined by standard[5]. The second step extracts a pair of parallel line segments with specific interval. This process begins with the extraction of orientation of line segments by a set of asymmetrical two dimensional DOG filters for eight preferred orientations. The filters with eight preferred orientations ϕs are defined by:

$$\mathrm{DOG}(x,y) = \left(e^{-x^2/2\sigma_e^2} - \frac{\sigma_e}{\sigma_i}\cdot e^{-x^2/2\sigma_i^2}\right)\cdot e^{-y^2/2\sigma_{en}^2} \quad (1)$$

$$\mathrm{DOG}_\phi(x,y) = \mathrm{DOG}(x\cos\phi - y\sin\phi, x\sin\phi + y\cos\phi) \quad (2)$$

$$\phi = \frac{\pi}{8}\times d\ [\mathrm{rad}], (d = 0,1,2,\cdots,7) \quad (3)$$

where σ_e and σ_i represent the space constants of excitatory and inhibitory regions, respectively, and the ratio of space constants σ_i/σ_e=1.6. This ratio gives a close approximation to the ideal Laplacian operator[7]. And σ_{en} determines the sensitivity of preferred orientation of the filter. Figure 2 illustrates an example of this filter. This filter corresponds to a simple cell receptive field found in a mammal's visual cortex[8]. Extraction of orientation of line segments is followed by the identification of a pair of parallel lines as a road. This identification is performed by simple logic operation. Figure 7(b) shows the result extracted parallel lines.

Since something contacting the road may interfere even with the extraction of the line segments, parallel line segments extracted in the necessary-feature network may not contain all of the road segments. Thus, the lacking segments must be recovered in some way. They are recovered by extending the road segments of necessary-feature network in the direction indicated by that of sufficient-feature network. For this purpose, since the extension of single line is easier than that of parallel lines, the skeleton image is used instead of parallel lines. The extraction of the skeleton is performed by a set of off-center even-symmetric filters with

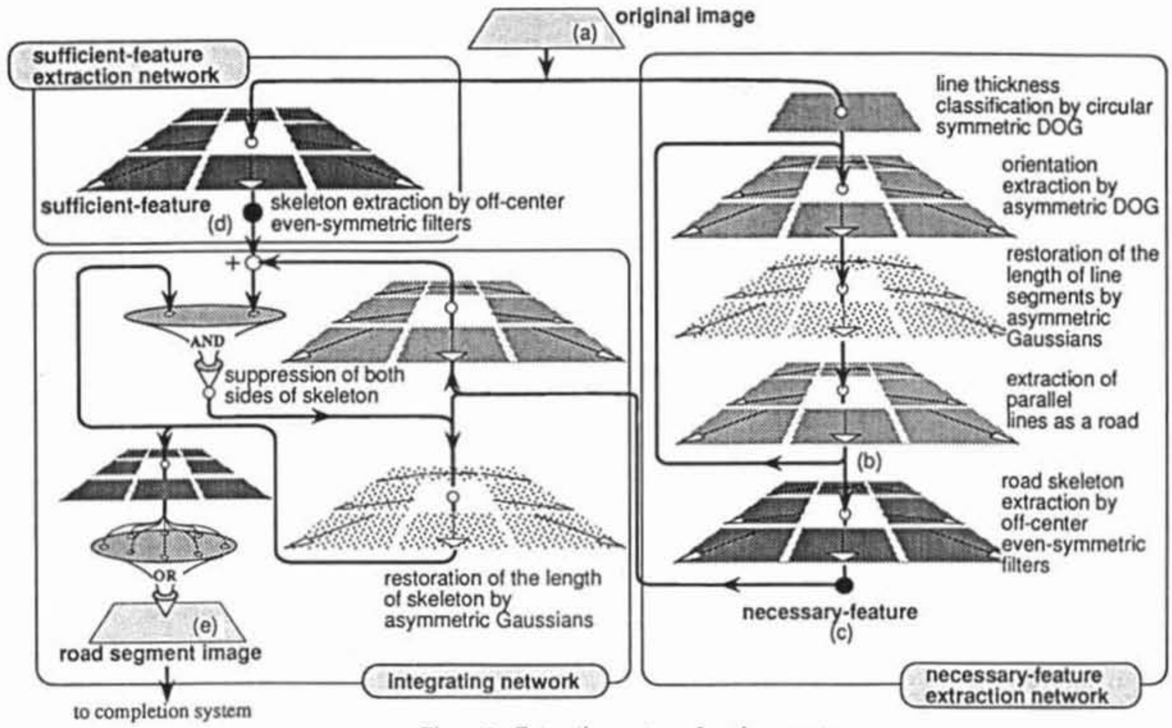

Figure 1. Extraction system of road segments.

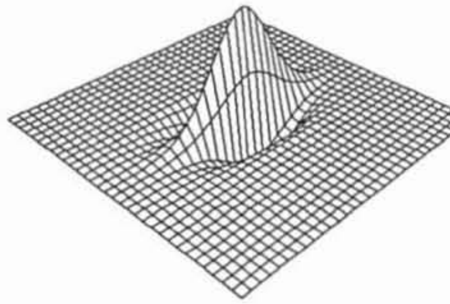

Figure 2. Two-dimensional profile of asymmetric DOG filter.

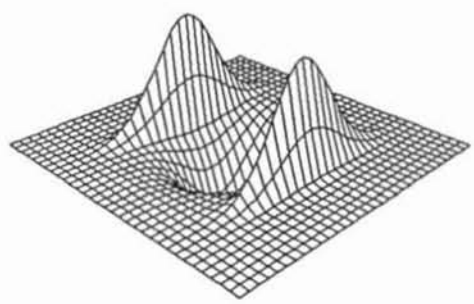

Figure 3. Two-dimensional profile of even-symmetric skeleton extraction filter.

eight preferred orientations. Figure 3 illustrates the example of the two-dimensional profile of this filter. The distance between two positive peaks corresponds to the road interval. As shown in the figure, the structure of this filter is similar to another type of simple cell receptive fields found in a mammal's visual cortex[6]. Figure 7(c) shows road segment image of necessary-feature network.

2.2 SUFFICIENT-FEATURE NETWORK

The task of the sufficient-feature network is to extract entire road segments, regardless of the extraction of false features. Skeletons of parallel line segments are directly extracted from the original image by the skeleton extraction filter used in the necessary-feature network. Figure 7(d) shows road segment image of sufficient-feature network.

2.3 INTEGRATING NETWORK

By using skeleton image of the necessary- and sufficient-feature networks, incomplete road segments of the necessary-feature network are extended according to the road segment image of the sufficient-feature network. This extension is carried out by low-pass filtering the road segments of the necessary-feature network, and multipling it by that of the sufficient-feature network. Before the extension operation, false sufficient features around necessary-features are suppressed. Figure 7(e) shows final road segment image obtained by combining both images (c) and (d). As shown in this image, the skeleton extraction filter gives small gaps in the parts where the roads intersect each other. These small gaps in addition to occluded area are completed in the following process. Figure 7(f) shows road image completed.

III. COMPLETION OF ROAD SEGMENTS

As can be seen in Figure 7(e), road segment image contains small and long distance gaps. Small gaps, caused by the characteristic of the skeleton extraction filter occur in the parts where roads intersect each other, and long distance gaps occur in the area where roads are overlaid and occluded by map symbols. Reconstruction of the road segments in these areas can be performed by connecting them which have no contradiction in direction, based on the directional information of the terminals of each roads segments. Thus, completion process, begins with the detection of terminals of road segments, consists of two processing steps: **(1) interpolation of facing terminals**, which connects all pairs of terminals that have no contradiction in direction, **(2) extrapolation of isolated terminals**, which extends the isolated terminals to the direction of the terminals' preferred direction. Figure 4 illustrates the completion system of road segments. The system consists of three layers, namely, input layer, terminal extraction layer, and interpolation layer. Road segment image is read into input layer, then terminal extraction layer extracts terminals from road segments. Interpolation layer connects all the pairs of terminals which have no contradiction in the direction, based

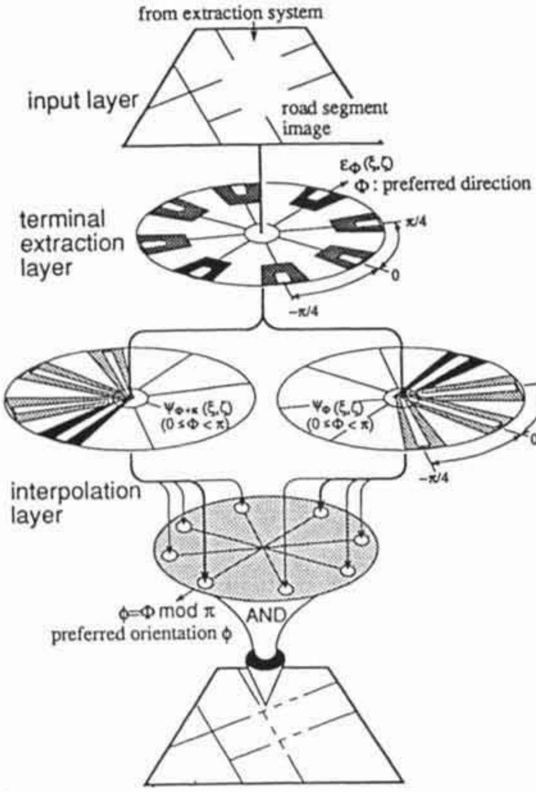

Figure 4. Completion system of road segments.

on the directional information of terminals extracted.

3.1 DETECTION OF TERMINALS

Road segments in the image have their own preferred orientations and the two terminals of each segments have opposite directions. Extraction of terminals $E_\Phi(x,y)$ can be performed by convolving road segment image $I(x,y)$ with terminal detection filter $\mathcal{E}_\Phi(\xi,\zeta)$:

$$E_\Phi(x,y) = 1\left[I(x,y) * \mathcal{E}_\Phi(\xi,\zeta) - \theta\right] \quad (4)$$

$$\Phi = \frac{\pi}{36} \times d \text{ [rad]}, \quad (d = 0,1,2,\cdots,71) \quad (5)$$

where $*$ is the convolution operator and θ is threshold. And Φ indicates preferred direction. The function 1[ ] is defined by the following.

$$1[x] = \begin{cases} 1 & (x > 0) \\ 0 & (x \leq 0) \end{cases} \quad (6)$$

As shown in Figure 5, terminal detection filter has the shape of excitatory region in the center and C-shaped inhibitory surroundings. The opposite direction of the hollow of the filter determines the direction of the terminals extracted.

3.2 INTERPOLATION OF FACING TERMINALS

In the interpolation layer, all the pairs of terminals which faced with each other in the opposite directions are connected. The connection is carried out by convolving the terminal image $E_\Phi(x,y)$ with a pair of interpolation filter $\psi_\Phi(\xi,\zeta)$ and $\psi_{\Phi+\pi}(\xi,\zeta)$, and multipling the twos:

$$H_\phi(x,y) = 1\left[E_\Phi(x,y) * \psi_\Phi(\xi,\zeta) - \theta\right] \times 1\left[E_{\Phi+\pi}(x,y) * \psi_{\Phi+\pi}(\xi,\zeta) - \theta\right] \quad (7)$$

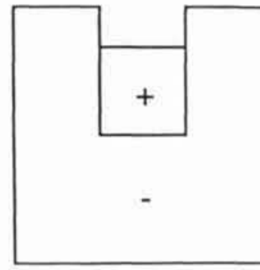

Figure 5. Terminal detection filter $\mathcal{E}_\Phi(\xi,\zeta)$.

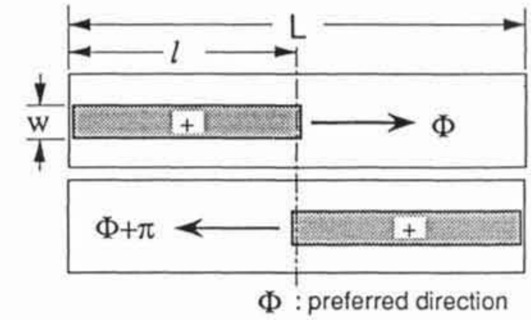

Figure 6. Interpolation filter $\psi_\Phi(\xi,\zeta)$.

where ϕ indicates preferred orientations and represented as $\phi = \Phi \bmod \pi$. Figure 6 illustrates a pair of interpolation filters, with the center of each excitatory being shifted to the preferred direction by $\pm l/2$ from the center of the filter, respectively. The magnitude l determines the maximum distance of gaps which can be interpolated. Therefore, short and long distance gaps of terminals in the image can be interpolated by preparing two different sized of filters.

3.3 EXTRAPOLATION OF ISOLATED TERMINALS

Since terminals extracted from road segments of L-shaped corners or T-shaped intersections have no partners in the same orientations, they are left unconnected. These isolated terminals can be extended to their preferred directions Φs by convolving them $E'_\Phi(x,y)$ with asymmetric DOG filter $\mathrm{DOG}_\phi(\xi,\zeta)$ given in equation(2).

$$H^{i+1}_\phi(x,y) = H^i_\phi(x,y) + 1\left[E'_\Phi(x,y) * \mathrm{DOG}_\phi(\xi,\zeta) - \theta\right] \quad (8)$$

$$\phi = \frac{\pi}{36} \times d \text{ [rad]}, (d = 0,1,2,\cdots,35) \quad (9)$$

i is iteration number of the process. The process is repeated until the image H^{i+1}_ϕ collides with the existing road segments or the edge of image frame. The next thing to do is to check the existence of intersections between extended line segments from isolated terminals, and carry out the following process.

•IF there are no intersections among the extended line segments, they are regarded as proper road segments reconstructed, and the process stops.

•IF not, only the line segments between the intersection and every isolated terminals are regarded as proper road segments. If there are more than one intersections in a specific direction of line segment, the farthermost one is selected as an intersection.

IV. EXPERIMENTAL RESULTS

In order to show the performance of the system, extensive experiments have been carried out for various map areas. A 1/25,000 scaled map which is published by the Geographical Survey Institute of Japan, is used for the experiments. A small map area was read into a work station by a 5 bit gray scale scanner with 300 dpi resolution. A map image has 256 pixels. Examples of the experiments are shown in

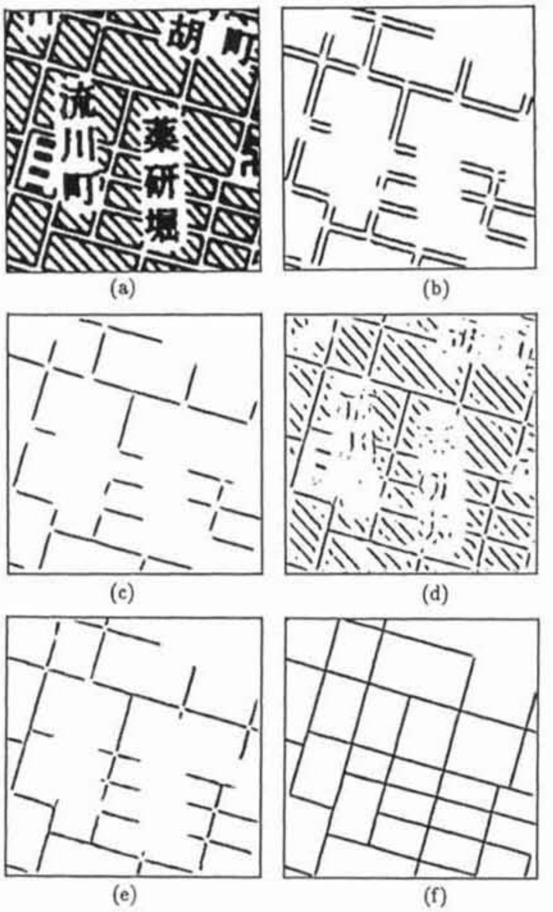

Figure 7. Experimental results. (a) Original image. (b) Extracted parallel lines. (c) Road segments extracted as necessary-feature. (d) Road segments extracted as sufficient-feature. (e) Road segments by combining both necessary- and sufficient-feature. (f) Completed road segments.

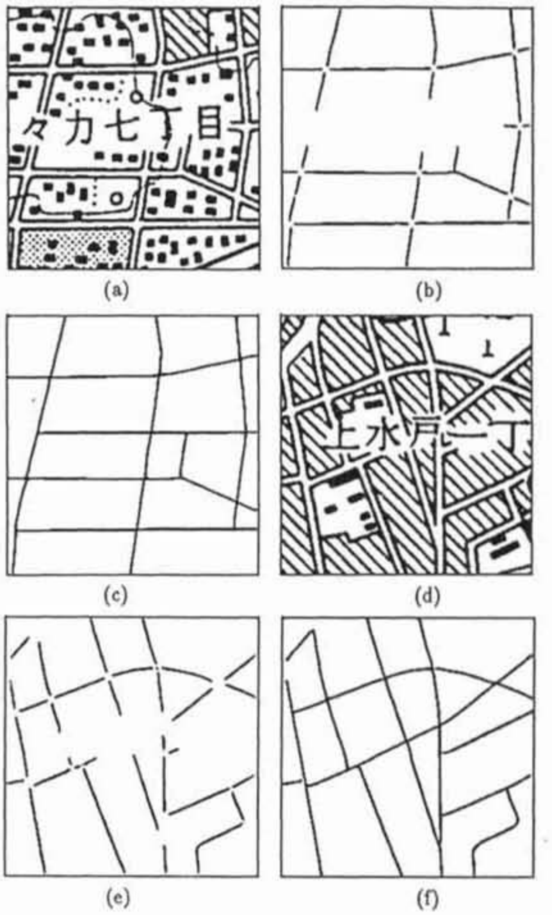

Figure 8. Another experimental results. (a),(d) Original image. (b),(e) Extracted road segments. (c),(f) Completed road segments.

Figure 7 and 8. As can be seen in these examples, almost all the road segments are extracted and reconstructed. These results show efficiency and generality of the system.

V. CONCLUSION

A novel approach for the extraction and reconstruction of road segments from map image is proposed. The experimental results show that the performance of the system is very successful. The key idea is to abandon sequential processing for heterogeneous parallel processing, as like our visual systems do. It is not an easy task but it is not impossible to design a set of filters to extract specific features from an image in a complete and noiseless manner. The approach proposed in this paper may provide an effective solution to this problem.

Some problems, however, are left for a future work. Interpolation and extrapolation of road segments with curvature or cranky road are among such examples.

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