SEMI-AUTOMATIC ROAD EXTRACTION FROM HIGH-RESOLUTION SATELLITE IMAGE

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ABSTRACT:

In this research, a method is proposed to create and/or update road maps in urban/suburban area using high-resolution satellite images. “Road mask” is defined in this research as a mask of road pixels, which are discriminated from others using a commercial remote sensing software. “Road seed” is defined in this research as a directional point, indicating that a road is passing through the point along the direction. Road seeds are extracted from edge pixels. Road line extraction is conducted in a semi-automatic way by fusing both road mask and road seeds. Experiments are conducted using an IKONOS image of nearby KAWAGOE city, Japan, with a ground resolution of 1 meter, and four bands, i.e. red, green, blue, and near infrared. Experimental results show that the method is valid in extracting main roads in high dense building area and all roads in countryside efficiently.

1. INTRODUCTION

Since the launch of commercial satellites, such as IKONOS and QuickBird, high-resolution satellite imageries at the resolution close to that of aerial photograph are available periodically. One of the major expectations is in the use of updating urban/suburban maps, such as road network for car navigation system and other GIS applications. In this research, we propose a semi-automatic method for generating new and/or updating existing road maps of urban/suburban area.

1.1 Previous Works

Up to now, numerous methods have been proposed for the extraction of road features from space imagery.

Barzohar and Coopper 1996 proposed an automatic method of extracting main roads in aerial images. The aerial image is partitioned into windows, road extraction starts from the window of high confidence estimates, while road tracing is to perform a dynamic programming to find an optimal global estimate. Geman and Jedynak 1996 proposed a semi-automatic method, where given a start point and a start direction, a road is extracted from a panchromatic SPOT satellite image by playing “tests” about the “true hypothesis”. Gruen and Li 1997 formulated the problem using an active contour model in a least square context (LSB-Snake), where given a number of seed points, an initial road template is first generated then adjusted to optimised an energy function on both photometric and geometric characteristics. Fiset *et al*. 1997 proposed a map-guided method to update the map of road network using SPOT imagery. Latest research efforts can be found in Park and Kim 2001, where a semi-automatic road extraction is proposed using template matching.

Most of the existing methods are based on a road model, where the roads are assumed to follows a number of generalities. For example, in Barzohar and Coopper 1996, assumptions on a geometric-stochastic road model are clearly listed as follows.

1) Road width variance is small and road width change is likely to be slow.
2) Road direction changes are likely to be slow.
3) Road local average grey level is likely to vary only slowly.
4) Grey level variation between road and background is likely to be large.
5) Roads are unlikely to be short.

However they are not always true, as road images vary a lot with ground resolution, road type, density of surrounding objects and so on. A specific road model as well as a road extraction method is required for extracting road lines using high-resolution satellite image, e.g. IKONOS and QuickBird images, where a road model is preferable to have as less but generic assumptions as possible.

1.2 Outline of the Research

In this research, we propose a semi-automatic method of road extraction from urban/suburban scene using high-resolution satellite images, which have a ground resolution of about 1 meter, and four bands, i.e. red, green, blue, and near infrared. The method consists of three steps as shown in Figure 1.

A “road mask” is defined in this research as a mask of road pixels, which are generated by classifying road pixels of a multi-spectrum satellite image using a commercial remote sensing software.

A “Road Seed” is defined in this research as a directional point, indicating that a road is passing through the point along the direction. Road seeds are extracted by tracing edge pixels, as a long edge line with only a slow change of direction suggest a road or river passing through.

Road lines are extracted in a semi-automatic way, where given a starting point, a road line is traced by iteratively matching a road template with both road mask and road seeds, control points indicating the right directions are assigned by operator if the road line got lost.

1. Road Mask Extraction:
Road pixels are identified using an existing remote sensing software.

2. Road Seed Extraction:
Road seeds are extracted by tracing edge pixels.

3. Road Line Extraction:
Road is semi-automatic extracted using template matching.

Figure 1. Flow of road extraction

In the following chapters, we address each steps in detail. Experiments are conducted using an IKONOS image nearby KAWAGOE City, Japan. Experimental results and discussions are given subsequently, where road extraction and map generation are studied in detail at both dense building area and countryside.

2. EXTRACTION OF ROAD MASK

A pixel-based road mask is extracted using a commercial remote sensing software IDL/ENVI. Given the training values of vegetation, soil, building (concrete), water, express highway, main road and small road, image pixels of a multi-spectrum satellite image are classified into different groups using maximum likelihood method. As the multi-spectrum satellite image used in this research has four bands, i.e. red, green, blue and near infrared, classification result is much more reliable than those on three bands, i.e. red, green and blue, or less. Image pixels classified as express highway, main road and small road are exploited in this research to generate a “road mask”. A “road mask” is a binary image, where white pixel suggests that a road like object is most probably over there. The road mask is exploited in road line extraction.

1. Edge Pixel Extraction:
Edge pixels are extracted using *Canny* filter.

2. Tracing Edge Line Patches:
Continuing edge pixels are traced, and edge lines of sudden and/or fast change of direction are broken.

3. Jointing Edge Line Patches:
Edge line patches that are on a continuous line of a slow change of direction, and with only a limited blanks between them are jointed.

Figure 2. Flow of extracting road seed

3. EXTRACTION OF ROAD SEEDS

Road seeds are extracted in three steps as shown in Figure 2.

Edge pixels extracted by *Canny* filter reflect not only the boundaries of roads, buildings, rivers, or shadows, but also any other local rapid changes of photometric characteristics. Although especially in central town, edge pixels of buildings, trees and shadows are mixed with that of roads, so that road boundaries are not as clear as to be extracted, a long edge line with only a slow change in direction do strongly suggest the boundary of a road or a river. Thus, they are extracted in this research as “road seed” (see Figure 3), and exploited as the complimentary information of “road mask” in road line extraction.

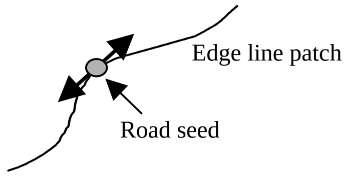


Figure 3. Definition of “Road Seed”

Applying *Canny* filter on satellite image results in a binary image of edge pixels, where edges are thinned to a width of single pixel. Extraction of long edge lines from the binary image of edge pixels is conducted in two steps, tracking and jointing edge line patches. Road seeds are generated for any edge pixels on the edge line patches, where two directions of the road seed, indicating two ways of the road line, are calculated using the tangential line of the edge line patch at the edge pixel.

3.1 Tracking Edge Line Patches

The binary image of edge pixels is examined row by row from top-left to bottom-right. Whenever an edge pixel is met, if it is an isolated one (there is no other edge pixel in its 8-neighbors as shown in Figure 5), the edge pixel is removed form the binary image, and tracking procedure continues in looking for other edge pixels. Otherwise an edge line patch is tracked from the edge pixel as shown in Figure 4. Iteration continues until no edge pixel is found in the binary image.

1. Linking Edge Pixels:
Edge pixels that are continue in their 8-neighbors or with a few blanks in its local extensions are linked together.

2. Breaking Edge Line Patches:
Edge line patches are broken down as the pixel of sudden and/or fast change of direction.

3. Post Process:
Edge line patches shorter than a given threshold are discarded, while others are recorded for further process.

Figure 4. Flow of tracking edge line patches

Suppose p_k is the *k*th edge pixel of an edge line patch, and it is the n_k-th neighbour of its previous pixel p_{k-1}, where both p_k and p_{k-1} have been removed from the binary image of edge pixels. In order to find the *k*+1th edge pixel of the edge line patch, the 8-neighbors of p_k are examined, where the neighbour having a direction near to n_k has a higher priority, so that is examined first. If the *k'*th neighbour of p_k is found an edge pixel, it is accepted as the *k*+1th edge pixel of the edge line patch. On the other hand, if no edge pixel is found in the 8-neighbours of p_k, an examination along the extension of n_k from p_k is conducted. If the blanks from p_k to edge pixel *q* in Figure 5(b) is less than a given threshold, *q* is accepted as the *k*+1th edge pixel. If no edge pixel is found in all the above examinations, the procedure of linking edge pixels of the edge line patch stops.

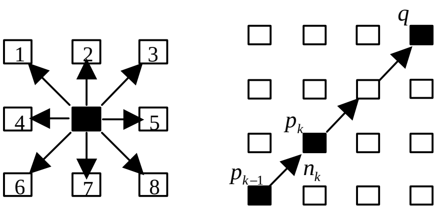
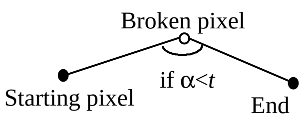
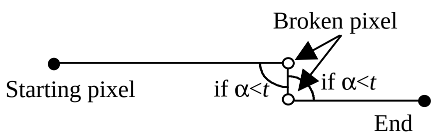


Figure 5. Searching in 8-neighbors and along the extension of local direction.

Breaking edge line patches is conducted, where the edge line patch is broken down at the pixel of the rapid change of direction at either local or/and global level. For any pixel in the edge line patch, if the angle from starting pixel to the pixel to end pixel is smaller than a given threshold *t*, then the pixel is regarded as a broken pixel at global level (see Figure 6(a)). In addition, for any pixel *k* in the edge line patch, given a value *s* for local length, if the angle from pixel *k-s* to pixel *k* to pixel *k+s* is smaller than the threshold *t*, then pixel *k* is regarded as a broken pixel at local level (see Figure 6(b)).



(a) Broken pixel at global level



(b) Broken pixel at local level

Figure 6. Breaking edge line patches

3.2 Jointing Edge Line Patches

For any edge line patch e_p, it is jointed with other edge line patches in an iterative way as follows. Given two thresholds *L* in pixel and λ in degree, a searching space is defined at each terminal point *p* as shown in Figure 7(a), where l_1 is the extensional direction of e_p at *p*. For any edge pixel *q* in the search space, where *q* is on an edge line patch e_q, a cost is calculated as follows (see Figure 7(b)).

$$E(q) = |a_1| + |a_2| \tag{1}$$

Where, l_2 is a line passing through *p* and *q*, l_3 is the tangential line of e_q at *q*, a_1 is the angle between l_1 and l_2, and a_2 is the angle between l_2 and l_3. If an edge pixel *q* yielding the minimal cost $E(q)$ is found, e_p is jointed to e_q as shown in Figure 7(c).

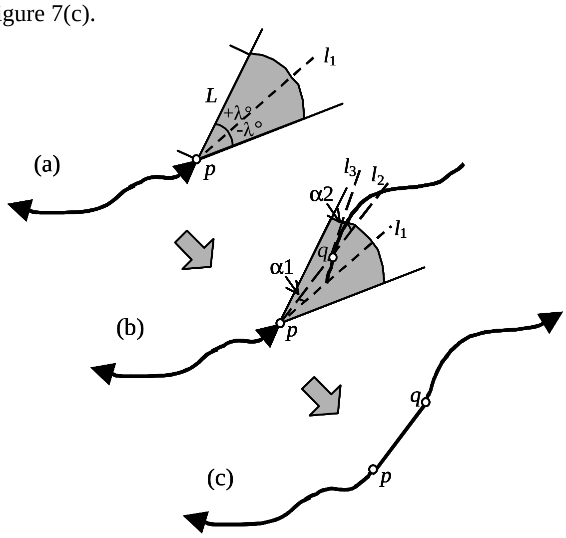


Figure 7. Jointing edge line patches

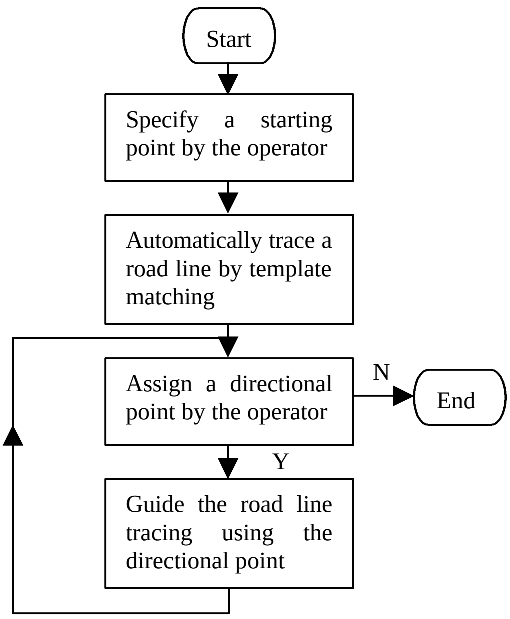


Figure 8. Flow of semi-automatic road line extraction

4. ROAD LINE EXTRACTION

In this research, road lines are extracted in a semi-automatic way by matching a road template with both road mask (*M*) and road seeds (*S*). The flow of road line extraction is shown in Figure 8. At the beginning, a starting point is specified by the operator. A road line is extended from the starting point in an iterative way, where in each iteration, a rectangular road template (T) of a pre-defined width (W) and length (L) is rotated at one of the terminal point of the road line and matched with the integrated image of road mask and road seed to find the next road line point (see Figure 9). The procedure stops when matching result reduces to a level lower than a give threshold. At this point, the operator examines whether the road line is correct, or run to a wrong direction, or loss its way in a local maximum. A control point is assigned whenever necessary by the operator to guide the road line extraction. In this research, matching cost of the road template at an image point p with a rotation angle α is defined as follows.

$$f_T(\alpha, p) = \sum_{(i,j)\in T} ((i',j') \in M) \mid ((i',j') \in S) \tag{2}$$

$$\begin{pmatrix} i' \\ j' \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} i \\ j \end{pmatrix} + \begin{pmatrix} p.x \\ p.y \end{pmatrix} \tag{3}$$

In the followings, we address the algorithms of automatically tracing a road line from a starting point and guiding the road line tracing using a directional point in details.

4.1 Tracing a road line from a starting point

Given a starting point $p_0 = (x_0, y_0)^T$, road line extraction consists of two steps, i.e. finding the starting direction and extending the road line in an iterative way.

Finding the direction that a road is most probably pass through p_0 is conducted as follows. If there are road seeds near p_0, the directions of road seeds are re-sampled using a histogram. The most often appeared directions $\alpha_1 \in [0,360°)$ and $\alpha_2 \in [\alpha_1 - \Delta\alpha, \alpha_1 + \Delta\alpha)$ are estimated, where $\Delta\alpha$ is a pre-defined angle based on the maximum permissible curvature of a road line. On the other hand, if there is no road seed near p_0, matching of road template is conducted in the range of [0, 360°]. Angles α_1 and α_2 are estimated subsequently, which yields $f_T(\alpha_1, p) = \max_{\alpha\in[0,360°)} f(\alpha, p)$ and $f_T(\alpha_2) = \max_{\alpha\in[\alpha_1+180°-\Delta\gamma, \alpha_1+180+\Delta\gamma)} f(\alpha, p)$ respectively. α_1 and α_2 are the directions to extend the road line from p to the opposite sides. Let $p_1 = p_0 + L*(\cos\alpha_1, \sin\alpha_1)^T$ and $p_2 = p_0 + L*(\cos\alpha_2, \sin\alpha_2)^T$, p_1 and p_2 with the extensional direction α_1 and α_2 are added to the road line as new road terminal points (see Figure 9(a)(b)).

Extending the road line from a terminal point p_k with the extensional direction of α_k is conducted as follows. If there are road seeds near p, and their directions belong to the range of $[\alpha_k - \Delta\alpha, \alpha_k + \Delta\alpha]$, the most often appeared direction α_{k+1} of the road seeds is found using histogram. On the other hand, if no road seed is found with a direction in $[\alpha_k - \Delta\alpha, \alpha_k + \Delta\alpha]$, matching of road template is conducted in the range of $[\alpha_k - \Delta\alpha, \alpha_k + \Delta\alpha]$. An angle α_{k+1} that yields $f_T(\alpha_{k+1}, p) = \max_{\alpha\in[\alpha_k-\Delta\alpha, \alpha_k+\Delta\alpha]} f_T(\alpha, p)$ is estimated. Let $p_{k+1} = p_k + L*(\cos\alpha_{k+1}, \sin\alpha_{k+1})^T$, p_k with the extensional direction α_{k+1} is added to the road line as a new road terminal point (see Figure 9(c)(d)).

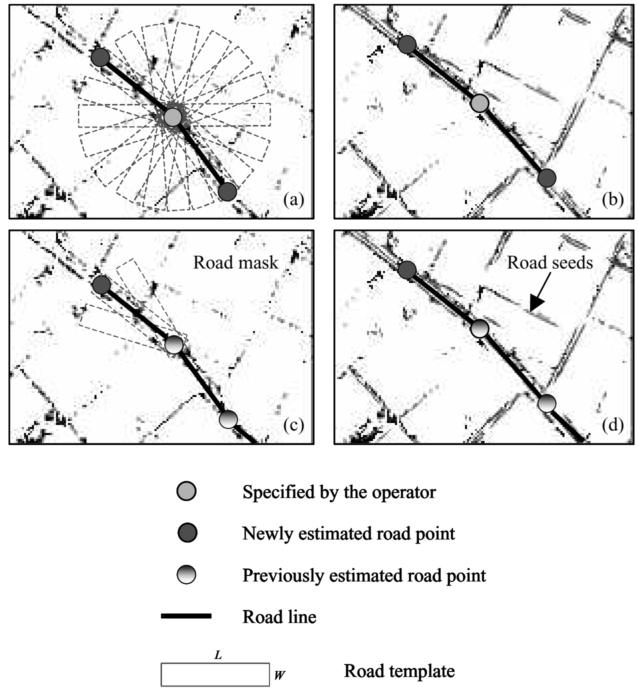


Figure 9. Tracing a road line, (a)(b) estimation of the starting direction by template matching and using road seeds, (c)(d) extending a road line by template matching and using road seeds.

4.2 Guiding the road line tracing using a directional point

A control point is assigned whenever necessary by the operator to guide the road line extraction. If the control point is on the road line that has been extracted, it means that the road should stop at the point, so that the road line is cut down (see Figure 11(a)). Otherwise the control point works as a directional point, where the road line is guided to go pass through the control point and extend further away (see Figure 11(b)). In the followings, we address the second case in detail.

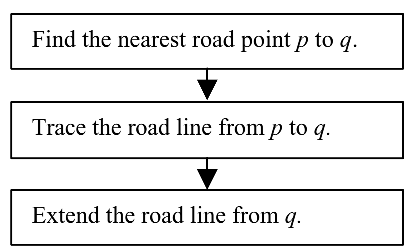


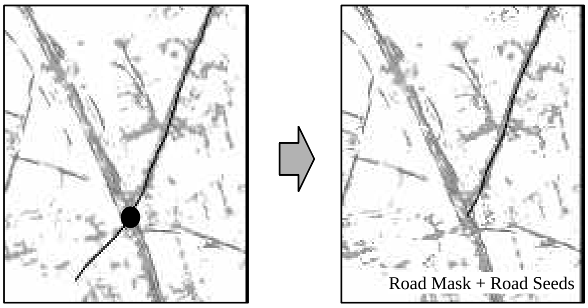
Figure 10. Flow of guiding a road line tracing using a directional control point q.

Given a directional control point q, the road line is modified and further extended as shown in Figure 10. The distance from any road point p_k to q is calculated as follows.

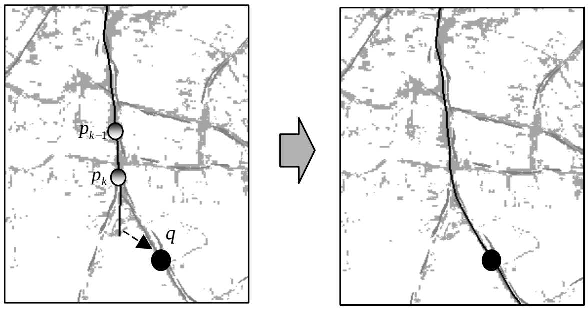
$$D(p_k, q) = \omega_\eta * (180° - \eta) + \omega_d * \|p_k - q\| \tag{4}$$

Where η is the angle between $\overrightarrow{p_{k-1}p_k}$ and $\overrightarrow{p_k q}$. The nearest road point p to q is the one that satisfies

$$D(p, q) = \min_k D(p_k, q) \tag{5}$$



(a) The road line is broken down by the control point



(b) The road line is modified and extended by the control point

Figure 11. Guiding a road line tracing using a control point.

Extending road line from q is conducted in the same way as addressed in previous section, while tracing the road line from p to q is different at the following two places.

1) In each iteration, the extensional direction of road terminal point p_k is assigned by $\overrightarrow{p_k q}$.
2) Matching cost of the road template at an image point p with a rotation angle α is defined as follows.

$$f_s = h \Big/ \left\| p_k - q \right\| \tag{6}$$

$$f_T' = w_T * f_T - w_s * f_s \tag{7}$$

5. EXPERIMENTS AND DISCUSSIONS

In this research, an IKONOS image nearby KAWAGOE City, Japan is used to test the validity and efficiency of the algorithm. Pixel size of each band is 1 meter. There are four bands, i.e. red, green, blue and near infrared. A road mask is generated using a commercial remote sensing software IDL/ENVI, where road pixels are discriminated from others using maximum likelihood method. Road seeds are extracted by tracing edge pixels. For easier operation, interface of the software is designed as follows. The IKONOS image is overlaid on both road mask and road seeds. The operator directly work on the IKONOS image, while road lines are extracted from road mask and road seeds. In order to examine the accuracy of the result, a 1:25,000 road map that produced for car navigation system by Tokyo Cartographic Co. Ltd is exploited.

5.1 Extracting a road line

A result of extracting a main road is shown in Figure 12. The road line is extracted by assigning a starting point and two directional control points subsequently by the operator (see Figure 12 (a-c)). The road line ran to wrong directions at points "A" and "B", where multiple roads conjunct together. Points "A" are enlarged at Figure 12(d-f), where road line extraction, IKONOS image, the road mask (grey) and road seeds (black) are listed. The operator examined the result of road line extraction, and assigned directional control points to guide the road line extending to right ways. In this case, the road line extends 2772 pixels at the starting point, 450 pixels at the 1st directional control point, and 783 pixels at the 2nd directional control point. The road line lasts totally 4005 pixels (≈4005 meters). It sounds that the method is rather efficient in extracting long road lines.

5.2 Generating road map of a specific area

Generating road maps of a dense building area is shown in Figure 13(a). The skeleton of most of the main roads can be easily identified from road mask that generated (Figure 13(a), Left #1, grey), whereas road mask on small roads are intermittent and imperceptible. On the other hand, road seeds on both main and small roads are not as clear as that shown in Figure 12(b) and Figure 13(b), as the road boundaries are mixed with the surrounding buildings, trees and shadows. Road line extraction of main roads relies most on road mask, whereas most of the small roads failed in extraction.

Generating road maps of a countryside area is shown in Figure 13(b). It can also be found that most of the main roads is sketched by road masks, whereas small roads got lost. On the other hand, road seeds reflect not only main roads and small roads, but also other rapid changes of photometric features. By properly selecting starting and directional control points, road lines succeeded in both main and small roads.

6. CONCLUSION

In this research, a method is proposed to create and/or update road maps in urban/suburban area using high-resolution satellite images. A road mask is generated by discriminate road pixels from others using a commercial remote sensing software. Road seeds are extracted by tracing edge pixels. Road line extraction is conducted on both road mask and road seeds. Experiments are conducted using IKONOS images with a ground resolution of 1 meter. Experimental results show that the method is valid in extracting main roads in high dense building area and all roads in countryside efficiently.

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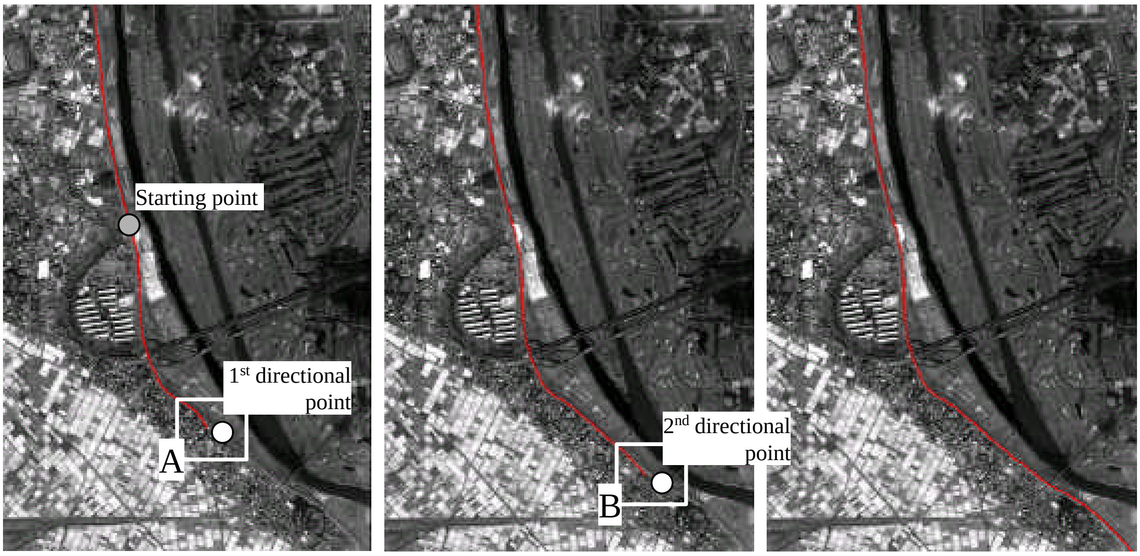
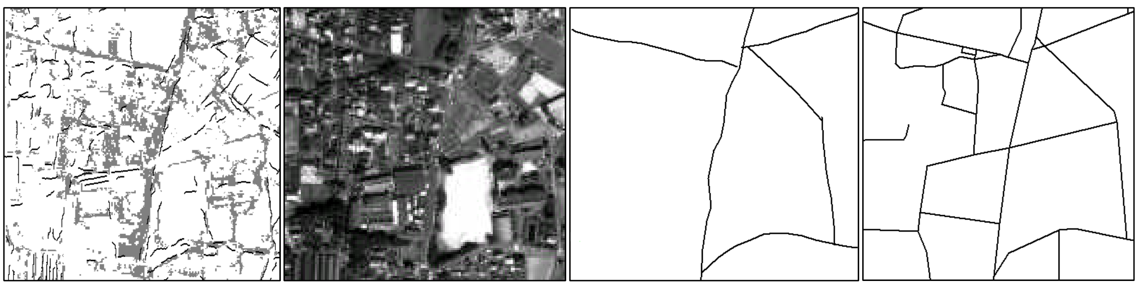


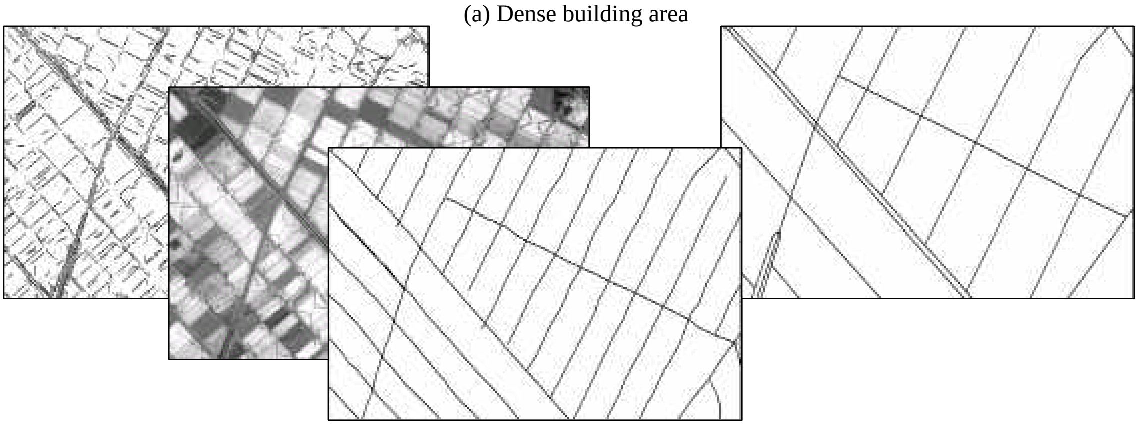
(a) Three steps of interactively extracting a road line, (Left #1: result after assigning the starting point, Left #2: result after assigning the 1st directional point, Right #1: final result)

(b) Enlarged figure of area "A", (Left #1: result of road line extraction, Left #2: IKONOS image, Right #1: road mask and road seeds).

Figure 12. Extracting a road line



(a) Dense building area



(b) Countryside

Figure 13. Generating road map of a specific area (Left #1: road mask and road seeds, Left #2: IKONOS image, Right #2: road lines that are extracted, Right #1: 1:25,000 road map)