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Street Arrangement for Computer-Aided Map Deformation System

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Abstract. This paper presents a new method deformation of road networks developed for the automated generation of rough guide maps seen in advertisements and leaflets. To address the same problem, we have already developed a parallel method which arranges road segments (edges) by quantizing the direction of each edge in parallel and iteratively. However, this previous parallel method has a problem in that it cannot always obtain good results from a global viewpoint because road transformation is performed edge-wise. In the new parallel method, road transformation is performed street-wise. As a result, the new method can greatly transform a cluster of edges from a global viewpoint and streets can be transformed differently according to their shape and direction. In the experiment using 88 real road maps, all results obtained using the new method were more comfortable than those obtained by using the previous one.

1. Introduction

In advertisements and leaflets, rough guide maps are often used for quick communication and space saving. In such maps, roads and streets are drawn straight and crossroads are right-angled. We call these maps "deformed maps". Although the deformed map is one of the useful media in human communication, its generation process has yet to be investigated properly from the viewpoint of machine vision. We think that it is useful to generate deformed maps automatically and to reveal the human technique for generation of deformed maps.

For this purpose, we aim at implementing an automatic generation system of deformed maps. We have already developed both a sequential method (KAJITA *et al.*, 1996) and a parallel method (YAMAMORI *et al.*, 2000). However, the sequential method has a problem in that a latter transformed edge is more restricted within a narrow space than a former one because each is transformed sequentially. As a result, the moving distance of the nodes is changed mainly in a small local region. On the other hand, the parallel method has a good characteristic in that the moving distance of the nodes can be changed with total balance because each edge is transformed in parallel and iteratively. However, this edge-wise based parallel method has a problem in that it cannot always obtain good results from a global viewpoint, because the transformation operates on an edge locally in relation to adjacent edges. Moreover, the edge-wise method cannot greatly transform a cluster of edges that are connected as a nearly straight line. In this paper, we propose a new parallel method for generation of deformed maps, which transforms road networks street-wise.

The street used here is a sequence of edges which are connected as a nearly straight line. The street is extracted under the consideration that long straight lines should be regarded as the most important. The street used here is different from one which is mapped by government or used by regional residents.

In the previous parallel method, virtual forces are applied to each edge and each node is moved according to a force. In the new proposed method, virtual forces are applied to each street. The force applied to each edge included in the street is calculated from the virtual force which is applied to the street. Then each node is moved according to that force. The street-wise method proposed here has the following merits.

(1) It can greatly transform a cluster of edges from a global viewpoint.

(2) Streets can be transformed differently according to their shape and direction.

The preliminary study to confirm validity of the street-wise method is described in HONDA *et al*. (1998).

Here, our targeted maps are the sort of maps, often seen in advertisements and leaflets, which show two-dimensional road networks. They do not include maps which show only one pass route from a departure point to a destination. We target maps that consist of several tens of road segments and which are reduced uniformly with one scale per map.

There are other studies concerning deformation that aim at generating route information from a departure point to a destination (BABAGUCHI *et al*., 1996). Although they transform road segments partially, they do not maintain the two-dimensional relation of the road segments. Our method, on the other hand, maintains does.

2. Street-Wise Road Transformation

2.1. System overview

This system is divided into two parts: a map deformation part and a map database management part. The map deformation part consists of two functions: road deformation and landmark relocation.

In the road deformation process, there are three processing steps: preprocessing, main processing, and postprocessing. Figure 1 shows the entire processing procedure of the road deformation process. In preprocessing, the entire map is rotated so that the rate of edges, which are in a horizontal or vertical direction within an angle tolerance of ±5 degrees, is increased. This is performed in order to avoid edges, which are neither horizontal nor vertical, being made into peripheral edges greatly transformed in main processing. In main processing, parameter setting, street extraction, street classification, and street transformation are repeated. In postprocessing, parallel transformation, which is similar to main processing, is done in order to make near straight streets become straighter. The details are described later.

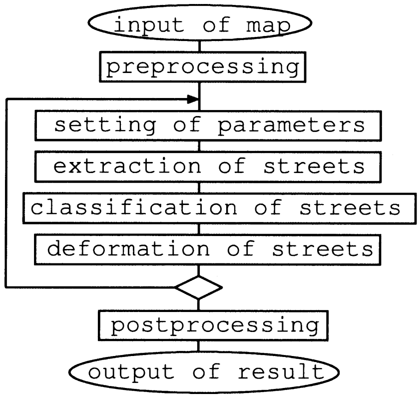
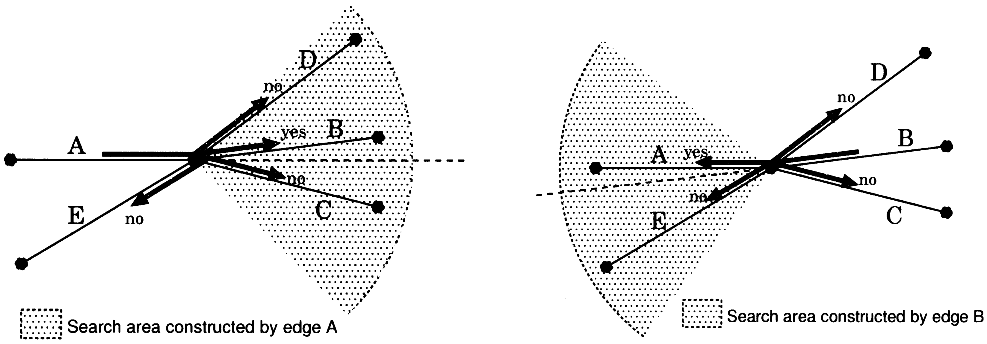


Fig. 1. Process overview.



(a) Search from edge A

(b) Search from edge B

Fig. 2. Extraction of the street. (a) Search from edge A. (b) Search from edge B.

2.2. Definition and extraction method of the street

The street is an edge or a sequence of edges which consists of the three following conditions.

(1) The deviation angle between two edges is less than a threshold.

(2) At intersections or turning points, edges are connected to be the most excellent straight line.

(3) None of the edges are shared.

The extraction method is explained in Fig. 2. First of all, edge A selects edge B as the candidate for the edge which composes a street because the deviation angle between the two edges is less than a threshold and is minimum among other edges. Next, edge B selects edge A as the candidate for the same reason. Then, edges A and B are fixed as the edges which compose a street. In the same way, edges D and E are the edges which compose a street.

However, edges C and A are not edges which compose a street because edge A has selected edge B as the candidate.

2.3. *Problems of street extraction and solutions*

The first problem that we had to consider in street extraction is what degrees of angle among connected edges are permitted in order to extract a sequence of edges as a street. It seems that extracted edges should be compared relatively with the connection shape of other edges by examining all edges, in order to extract a characteristic sequence of edges. Moreover, judgment about extraction is different according to the person or the map, and this decision is complex. Therefore, it is difficult to fix the allowance angle among connected edges.

Next, we considered the range of the allowance angle among connected edges. We use two streets which are extracted by a wide allowance angle and a narrow one. The former is called a weak street and the latter is called a strong street. Hereafter, this range of the allowance angle is called the angle tolerance for street extraction.

2.4. *Transformation policy of each street*

We think that a near straight line should be transformed completely, a curved line should be transformed to a smoother curved line, and a near horizontal or vertical line should be transformed fairly horizontally or vertically in order to imitate the deformation technique used by humans. Therefore, we classify streets according to their shape.

2.5. *Street classification*

Figure 3 shows the classification of streets. First of all, the street that should be transformed into a straight line is called a straight street. The other type of street is called a curved street. Training samples are prepared for each type of street. On the other hand, the automatic classifier uses the following equation.

$$\text{Distance in a straight line/Sum of all edge lengths which construct the street.} \tag{1}$$

If this value is more than a threshold, then it is classified as a straight street; otherwise, it is classified as a curved street. The value of the threshold, at which the false negative rate of the curved street becomes zero, is selected using the training samples. That is, we select the value of the threshold at which no street is classified as a straight street, that is, which

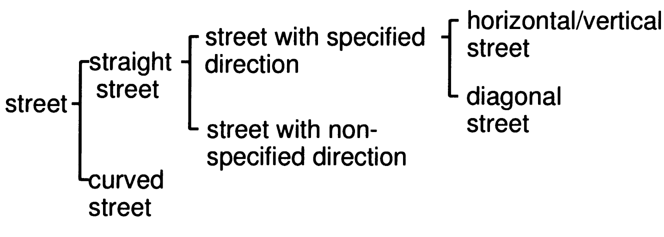


Fig. 3. Classification of streets.

would not be transformed to a straight line according to human judgement.

This reason for this selection is that the curved shape of a street, which had been classified as a straight street, cannot be maintained. This is because the street, which has been classified as a straight street, is transformed to become a complete straight line even if a human judges that it should not be transformed into a straight line. Furthermore, the reason for the selection is that the transformation is done according to the shape even if the straight street has been classified as the curved street, because curved streets are not transformed to emphasize the curve shape especially. Hereafter, we call the threshold value of Eq. (1) a linearity ratio.

Straight streets are classified into streets with specified direction and streets with non-specified direction. Streets with specified direction are classified into horizontal/vertical streets and diagonal streets. The street with specified direction is a straight street where the direction of the street exists in the range of the angle tolerance from the quantized direction. The quantized direction means the discrete direction (for example, 0, 45, 90, 135, 180, 225, 270, and 315 degrees) nearest to the direction. The street with non-specified direction is a straight street where the direction of the street exists over the range. Hereafter, we call this range the range of the angle tolerance of specified direction. The horizontal/vertical street is a street with specified direction where the direction of the street is near the horizontal or vertical direction. The diagonal street is a street with specified direction where the direction of the street is near the specified direction except for the horizontal and vertical direction.

2.6. Street transformation

Transformation is done alternately using two kinds of street, the weak street and the strong street. In the parameter setting of main processing, the value of the angle tolerance for street extraction is switched at the cyclic stage in odd and even numbers. At the cyclic stage in odd numbers, weak streets are extracted. At the cyclic stage in even numbers, strong streets are extracted.

By using the weak street, a comparatively long street is rotated to the specified direction as a cluster and straightens the street slowly. Successively by using the strong street, a comparatively short street is straightened. As a result, the use of the weak street chiefly contributes to the process where many edges are transformed to quantize the direction. The use of the strong street chiefly contributes to the process where an original near straight line parts of streets are maintained and transformed to straighten further.

In addition, the force to transform a street is different depending on whether the street is horizontal/vertical, diagonal, with non-specified direction, or curved. In the case of the horizontal/vertical street and the diagonal street, the force for quantizing the edge direction is strongly applied. This is valuable for making the direction of the edges become near the specified direction. Especially, because the gap from the horizontal or vertical direction is evaluated as worse, the force for quantizing edge direction is strongly applied to the horizontal/vertical street more than to the diagonal street. In the case of the street with non-specified direction, the force for straightening edges is strongly applied. This is valuable for making the shape of the street become straight. In the case of the curved street, the force for quantizing edge direction is not applied and the force for straightening edges is applied a little. This is valuable for making the curved street become a smooth curve. The forces are controlled by adjusting the weight coefficient of each force.

After the cyclic stage in even numbers, the movement vector of each node, which is from the position before transformation by a weak street to the one after transformation by a strong street, is calculated. And the entire map is slid to the position at which the average of the movement vectors becomes zero. After that, the average of the amount of the movements of each node is calculated. The processing loop is stopped when that value becomes below a threshold. Hereafter, we call this threshold the amount of node movement needed for stopping the processing loop.

Moreover, the processing loop is also stopped by checking whether the transformation becomes periodic because the position of nodes periodically returns to the former position, and the transformation becomes periodic easily in the case where both weak streets and strong streets are used. The time limit of the processing loop, which seems to be large enough, is set because the processing loop is not often stopped.

The assessment as to whether the transformation becomes periodic is performed by checking the average of the moving distance of the nodes. Concretely, the average of the moving distance of the nodes is preserved every time by checking whether the value goes below the amount of node movement needed for stopping the processing loop. Then, the values of the latest 16 points are taken out including the current point. Next, the Fourier transform (FFT) is calculated from the 16 values after those average values are subtracted, and the power spectrum of each frequency is obtained. The transformation is periodic if the following values are more than the threshold, where $f(i)$ is a power spectrum of the FFT of index i.

$$\sum_{i=3}^{8} f(i) \Big/ \sum_{i=0}^{15} f(i). \tag{2}$$

Here, the value of the threshold is 0.5 which is taken when the shape of waves becomes the shape of the teeth of a saw.

Conveniently, this judgement process is performed only when the value of the current moving distance of the nodes is not less than the value of the moving distance of the nodes 16 points before. Normally, this assessment is rarely performed because the value of the moving distance of the nodes becomes small, step by step.

3. Details of Processing

3.1. Forces applied to edges

We suppose that streets should be transformed by forces. Five kinds of force: (1) for quantizing edge direction, (2) for straightening edges, (3) for keeping the initial length of an edge, (4) for repulsing a near edge based on angle, and (5) for repulsing a near edge based on distance, are applied to each edge. Forces are calculated using potential functions. Each force has a weight coefficient (assumed to be Kd, Ks, Kl, Kr, and Km respectively). In particular, the force for quantizing edge direction and the force for straightening edges change the weight coefficient according to the class of street.

The moving distance and direction of the nodes are obtained from the resultant force applied to each edge. The resultant force is regarded as the moving vector of the nodes because the purpose here is not to simulate dynamic movement and therefore a mechanics

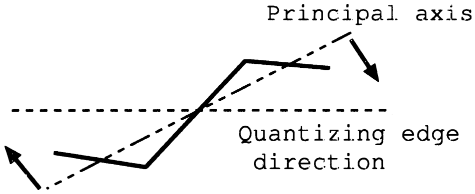


Fig. 4.

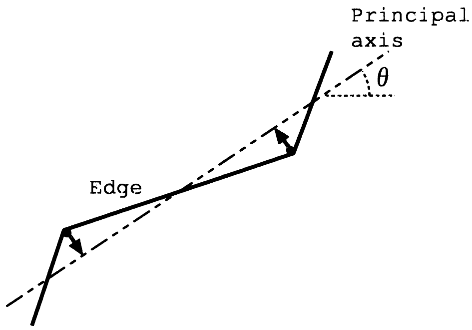


Fig. 5.

Fig. 4. Transformation with force for quantizing edge direction.
Fig. 5. Transformation with force for straightening edges.

model does not have to be introduced.

However, if the phase structure is broken after the movement, then the broken node is not moved. Moreover, if the direction of the edge is rotated from an initial direction with more than 75 degrees, then the nodes of the starting point and the terminal point of the edge are not moved, in order to obtain a deformed result stably.

(1) Force for quantizing edge direction

This is a force to rotate the edge to the quantized direction. This force rotates the entire street to make the principal axis of the straight street turn toward a quantized direction (see Fig. 4). The principal axis of the street is a straight line with the direction where the sum of the square of the perpendicular vector's length from each node to the line is minimized and the line passes the gravity center of the node which composes the street. The rotation center is the gravity center. The rotation angle is calculated from the following step. First, the nodes of the starting point and the terminal point, which compose the street, are projected to the principal axis of the street. Next, the virtual edge connected between those two nodes is extracted. Then, the force for quantizing edge direction is adapted to the virtual edge so that the rotation angle can be calculated. All the nodes which compose the street are relatively moved to rotate the virtual edge with the same rotation angle. The equation of force is shown in Eqs. (A2) and (A3) of Appendix A.

However, because the node of the terminal point is easily moved, a weight coefficient, which is less than 1, is multiplied by the moving vector of the nodes. Hereafter, we call this weight coefficient the coefficient of the terminal point. Moreover, if the length of the minimum edge among the adjacent edges is less than 10 per cent of the edge itself, then a weight coefficient, which is less than 1, is multiplied by the moving vector of the node because the minimum edge is rotated too easily. Hereafter, we call this weight coefficient the coefficient of the minimum edge. The force for quantizing edge direction is not usually applied to curved streets. However, if users specify a weight coefficient which is non-zero, then the edge-wise based force is applied to each edge.

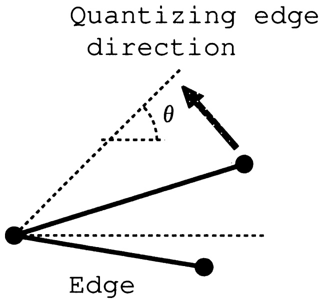


Fig. 6.

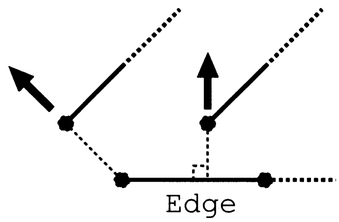


Fig. 7.

Fig. 6. Transformation with force for repulsing a near edge based on angle.
Fig. 7. Transformation with force for repulsing a near edge based on distance.

(2) Force for straightening edges

This force makes each edge straighten among adjacent edges. For the straight street, edges become straight in the direction of the principal axis of the street (see Fig. 5). The force is applied in order to rotate each edge in the direction of the principal axis. The rotation center is a middle point of the edge. The equation of force is the same as that shown in Eqs. (A2) and (A3) of Appendix A. However, if the direction of the principal axis is near the horizontal or vertical direction within 1 degree, then the target direction is set to the horizontal or vertical direction.

For the curved street, each edge is turned to the direction of the line connected between two middle points of both adjacent edges. If there is only one side of adjacent edges, then the direction of the line connected between a middle point of the existing adjacent edge and one of the edge itself is used.

(3) Force for keeping the initial length of an edge

This force makes the length of each edge return to the initial length. The size of the force is proportioned to the difference between the length after transformation and the initial length of the edge. The equation of force is shown in Eqs. (A5) and (A6) of Appendix B. It is the same equation as for the force which is calculated as if the edge is a spring.

(4) Force for repulsing a near edge based on angle

This force prevents two edges from overwriting each other because two edges connected with one node occasionally try to rotate to the same direction by the force for quantizing edge direction (see Fig. 6). First, two edges that are connected with the smallest angle at each node are selected. If the angle between the two edges is smaller than the angle quantizing direction, then this force is applied to the edge which is further from the target direction than the other edge. If two edges have the same quantized target direction, then the force to go toward the next quantized direction, which is adjacent to the original quantized target direction, is applied. If two edges have a different quantized target direction, then the force to go toward the original quantized direction is applied. The rotation center is the node at which the two edges are connected. The equation of force is the same as the equation shown in Eqs. (A2) and (A3) of Appendix A, in which (X_0, Y_0) are assumed to be coordinates of the rotation center.

(5) Force for repulsing a near edge based on distance

This force makes the node repulse from the neighbor edges because the phase structure seems to break if the node is too close to the neighbor edges (see Fig. 7). If the distance between the node and the nearest edge, except the edge which includes the node, is within a threshold, then the force of repulsion is applied to the node. Hereafter we call this threshold the adjacent distance limit. The distance between the node and the edge is calculated from the Euclid distance, that is, length between the node and the foot on the perpendicular of the edge in the case where a foot is on the edge. If the foot is not on the edge, the length between the node and the near side node of the edge is used. The direction of repulsion is the direction of the line used to calculate the distance.

The size of the force is proportioned to the difference between the distance after transformation and the adjacent distance limit. The force is applied if the distance is smaller than the adjacent distance limit. However, the force is not applied if the distance is larger than the adjacent distance limit. It seems as if a spring, which prevents the length from becoming smaller than the adjacent distance limit, exists in that space. The coefficient of the spring is set to 1 in order to separate the edges surely. The equation of force is the same as the equation shown in Eqs. (A5) and (A6) of Appendix B and set as $\gamma = 1$; L = the adjacent distance limit.

If the initial distance is smaller than the adjacent distance limit, then the initial distance is used as the adjacent distance limit between the node and the edge. This is because, when the initial distance is smaller than the adjacent distance limit, it is necessary to prevent repulsion by an excessively large adjacent distance limit.

3.2. Details of preprocessing

In preprocessing, rotation of the entire map is performed so that the sum of the length of the straight streets located horizontally and vertically within the angle tolerance of ±5 degrees becomes the maximum. The definition of the street length is the length of the segment connecting the terminal nodes of the edges which construct the street. The direction of this segment is called the direction of the street.

However, if the value of that sum is less than 10 per cent of the sum of all the street lengths, then the entire map is not rotated. The purpose of this is to avoid rotating mainly by a street which has a short length. In order to extract straight streets, strong streets are used. One might think one would use the straight street in the weak street. However, we use the straight street in the strong street because there is a case where the straight streets in the weak street may not exist in the map. And also because there is a case where straight parts of the curved street should be turned to horizontal or vertical directions if a curved street has a refraction shape that consists of two straight parts.

3.3. Details of postprocessing

The straight street often does not become completely straight after main processing. In this case, people feel dissatisfied with the result. Especially, this evaluation is severe for the horizontal/vertical street which is not completely straight. Therefore, postprocessing makes near straight streets become straighter.

For this implementation, one might think of applying sequential transformation. However, this is not a good idea because a sequential method may destroy the phase structure of the edges and cannot maintain the length of edges relatively. Therefore, parallel transformation, which is similar to main processing and has different parameters, is performed.

To put it more concretely, four kinds of force: (1) for straightening edges, (2) for keeping the initial length of an edge, (3) for repulsing a near edge based on angle, and (4) for repulsing a near edge based on distance, are applied to each edge of a straight street in a strong street without distinction between the odd and even numbers of the cyclic stages.

However, if the direction of the principal axis is near the horizontal or vertical direction within 1 degree, then the target direction is set to the horizontal or vertical direction. The weight coefficient of the force for straightening edges is set to 1 for the horizontal or vertical direction. For the other direction, the weight coefficient is set to $1/s$ ($s > 1$). As a result, the horizontal/vertical street is transformed to become a straighter line with the horizontal or vertical direction. The force for keeping the initial length of an edge, the force for repulsing a near edge based on angle, and the force for repulsing a near edge based on distance are applied in order to prevent the phase structure of the edges being broken so that the weight coefficients of those forces can be set to small values. The force for keeping the initial length of an edge is $1/n$ ($n > 1$) times as large as that in main processing. The force for repulsing a near edge based on angle is $1/m$ ($m > 1$) times as large as that in main processing. Moreover, the time limit of the processing loop is half that of main processing.

4. Experiment

4.1. Method

The map used in the experiment is derived from 88 maps selected from areas in cities (for example, Nakagawa-ku, Midori-ku, etc. in Nagoya-city) whose roads do not consist of only horizontal and vertical lines. The road segments are extracted manually by referring to the deformed maps often seen in advertisements and leaflets. The discreet angle for quantizing edge direction was assumed to be 45 degrees from the details in the maps. Moreover, the range of the angle tolerance of the specified direction was assumed to be 45/6 degrees. Therefore, if the direction of a street exists in the range of ±45/6 degrees from the quantizing angle, the street is judged to be a street with specified direction.

The angle tolerance for street extraction, which is the deviation angle between two edges, was set to 45 degrees to extract the weak street. This is the same value as that of the discreet angle for quantizing edge direction. To extract the strong street, the angle tolerance was set to 5 degrees. The reasons for selecting 45 degrees for the weak street are as follows.

(1) If an angle of more than 45 degrees is selected when the discreet angle for quantizing edge direction is 45 degrees, then two edges which have a different quantized target direction may exist adjacently in a street and they will not become complete in the quantized direction.

(2) If more than 45 degrees is selected, then the edges in a street have a different quantized target direction. In this case, the target direction to straighten the street cannot be fixed at the stage of street extraction.

(3) At the stage of street extraction, it cannot be determined whether straightening will

result in a good transformation if the edges in a street have a different quantized target direction. On the other hand, the reasons for selecting 5 degrees for the strong street are as follows.

(1) It is desirable that the extracted streets have long lengths to some extent.

(2) It is desirable that the extracted streets be almost straight.

(3) Tolerance of the angles between connected edges is considered to be necessary to some extent.

Next, the linearity ratio was assumed to be 0.991 for the weak street. To calculate this value, 1005 weak streets in 88 maps were classified by a human into 801 straight streets and 204 curved streets. Additionally, by using Eq. (1), the false negative rate and the false positive rate were drawn using a ROC curve* (METZ, 1986). As a result, a ROC curve was drawn smoothly and the threshold was 0.991 when the false negative rate of the curved street became 0. In the same way, 88 maps were used to calculate the linearity ratio for the strong street. In this case, 2325 strong streets in 88 maps were classified by a human into 2325 straight streets and 0 curved street. Therefore, the minimum value of Eq. (1) can be employed as a linearity ratio for the strong street, i.e., 0.997. Moreover, the adjacent distance limit of the force for repulsing a near edge based on distance was set to 6 from the details in the map used for the experiment. Both the coefficient of the terminal point and the that of the minimum edge were set to 0.8 from the experiment using 88 maps in order to get transformation results stably.

In the same way, the defaults of the weight coefficient of the force for quantizing edge direction were set to 0.1, 0.01, 0.01, and 0 in order of horizontal/vertical street (Kdv), diagonal street (Kda), street with non-specified direction (Kdn), and curved street (Kdc), respectively so that a comparatively good result could be obtained stably. Moreover, the defaults of the weight coefficient of the force for straightening an edge were set to 1, 1, 1, and 0.5 in order of horizontal/vertical street (Ksv), diagonal street (Ksa), and street with non-specified direction (Ksn), and curved street (Ksc), respectively. Other weight coefficients, Kl, Kr, and Km were set to 1, 0.1, and 1, respectively as defaults. Moreover, the parameters used by postprocessing, s, n, and m were set to 5, 10, and 5, respectively as defaults.

The amount of node movement needed for stopping the processing loop was set to 0.005 and the time limit of the processing loop was set to 10 000 so that the processing loop using the default parameters in 88 maps became steady. In the experiment using 88 maps, only 6 maps took up to the time limit of the processing loop using default parameters.

The values of α, β, δ, and γ, which were the parameters to calculate the force applied to an edge, were set to 200, 1, 0.001, and 0.05, respectively. They were the same values used experimentally by the previous parallel method.

In this system, there are many parameters. These parameters can be classified into two types. One is for parameters which should optimize the value according to the map. The other is for parameters which are almost fixed and which can generate a steady result that does not depend on the map. The former type includes Kdv, Kda, Kdn, and Ksc parameters.

In this case, this system was implemented on a PC (CPU Pentium III 800 MHz, Memory 320 MB, OS Windows 2000 professional, development language Visual C++). The time for processing one map using this system was about 4 seconds on average.

*Two-dimensional graph of two-class classification, where the mis-identification rate of each class is taken in horizontal and vertical axis.

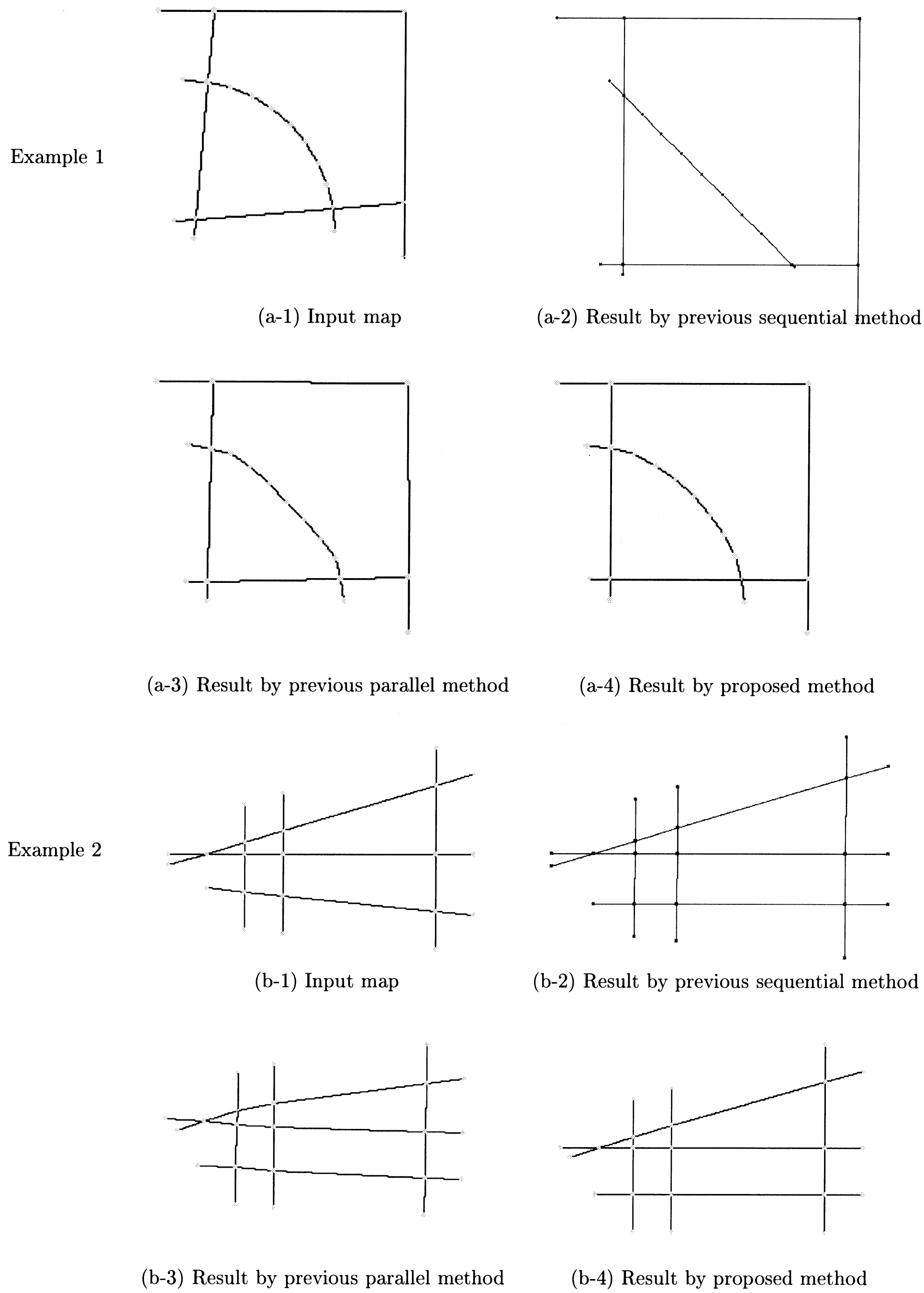
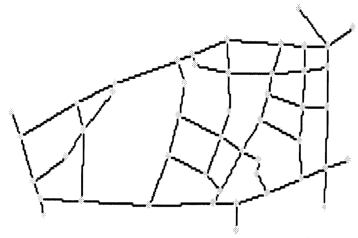
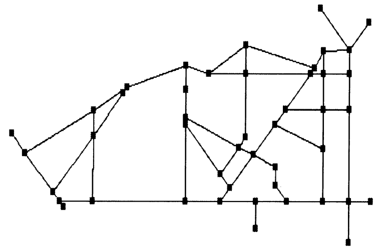


Fig. 8. Examples of road transformation results (4 input maps).

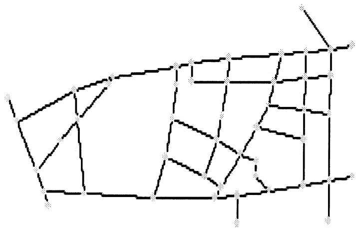
Example 3



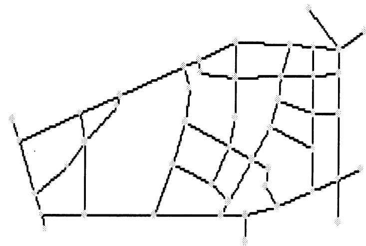
(c-1) Input map



(c-2) Result by previous sequential method

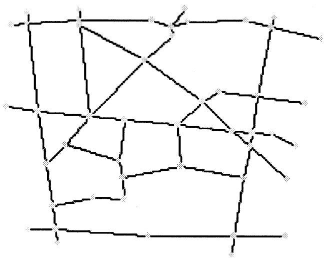


(c-3) Result by previous parallel method

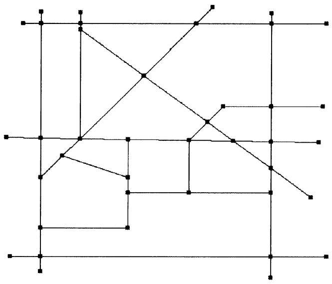


(c-4) Result by proposed method

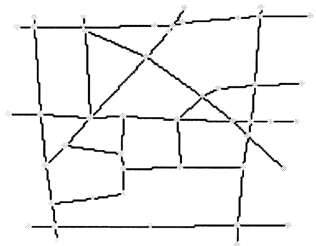
Example 4



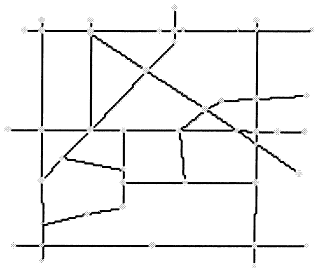
(d-1) Input map



(d-2) Result by previous sequential method



(d-3) Result by previous parallel method



(d-4) Result by proposed method

Fig. 8. (continued).

4.2. Results and consideration

Figure 8 shows examples of the experiment results. Examples 1 and 2 are for handmade maps which were processed in order to compare the proposed method with previous methods. Examples 3 and 4 are the two examples selected from 88 real maps.

The parameters of the weight coefficient of each force were arranged according to input maps.

Example 1 shows that it is possible for the proposed method to maintain a curve shape of a circular arc part. A circular arc part is collapsed by the previous parallel method because the force for quantizing edge direction is evenly applied to all edges. Moreover, the previous sequential method cannot maintain the curve shape. However, the proposed method makes it become a smooth curve because the circular arc part is distinguished from others as a curved street and the force for quantizing edge direction is not usually applied to a curved street. Moreover, if users desire the result achieved by the previous sequential method, the proposed method can generate almost the same result by adjusting the parameters.

Example 2 shows that the proposed method can maintain the straight line of diagonal streets. When there is both a straight street, which is required to become horizontal or vertical, and a diagonal straight street which is required to become straight, the previous parallel method could not achieve both requirements simultaneously. Especially, because the force for quantizing edge direction performs on long edges strongly and performs on short edges weakly, it was difficult to turn edges toward the quantized direction while maintaining their straight shape. However, in the proposed method, it is easy to maintain their straight shape because the force for quantizing edge direction is applied to streets not edges. Thus, the proposed method makes both become straight and turn toward the desired direction.

Example 3 shows that the proposed method can maintain the refraction shape of a street. The previous sequential method generated an undesirable result because each edge is transformed sequentially. The input map here is regarded as too complex for the previous sequential method. On the other hand, the previous parallel method can stably transform a complex input map. However, the previous parallel method made the refraction part curve smoothly because the force for straightening an edge is applied to each edge evenly. In the proposed method, it is possible to treat the street that has a refraction shape as a weak street consisting of two strong streets, so that the refraction shape can be maintained.

Example 4 shows that the proposed method can greatly transform streets and it is possible that the street, which is required to become horizontal or vertical, is turned toward

Table 1. Parameter values used for obtaining results in Fig. 9.

Results	Parameter values
Result 1	Kdv = 0.01, Kda = 0.01, Kdn = 0.01, Ksc = 1
Result 2	Kdv = 0.1, Kda = 0.01, Kdn = 0.01, Ksc = 0.5
Result 3	Kdv = 1, Kda = 0.01, Kdn = 1, Ksc = 0.5
Result 4	Kdv = 1, Kda = 1, Kdn = 1, Ksc = 0.5
Result 5	Kdv = 1, Kda = 1, Kdn = 1, Ksc = 0.1

the direction. In the previous parallel method, even if the force for quantizing edge direction is applied strongly and edges are required to become horizontal or vertical, its achievement is difficult because the transformation of edges receives restraint from the neighbor edges. However, its achievement is easy by the proposed method because the force can be applied to each street strongly.

In the results by the proposed method, horizontal/vertical streets might have small gaps from horizontal or vertical lines. This is a phenomenon which can happen in case where there is a balance between the force for quantizing edge direction and the force for straightening an edge trying to transform edges to become horizontal or vertical, but the length preservation force and so on try to restrain the transformation. If such a gap has to be removed, we think that, for this special case, it is efficient to add postprocessing.

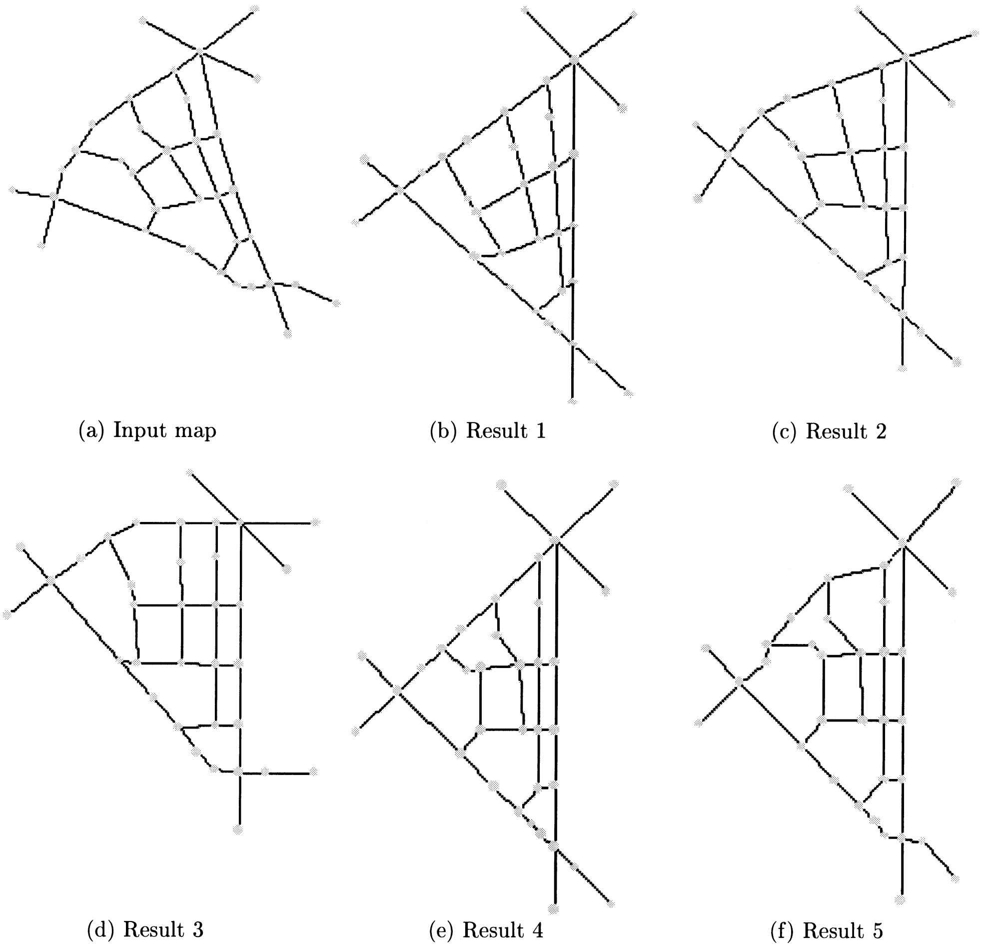


Fig. 9. Examples of results generated according to parameter values of Table 1.

Moreover, we obtained much more excellent results in all 88 real maps by using the proposed method than by using the previous parallel method even though the assessments were made by a human. The improved points seen frequently in 88 maps are as follows.

(1) The near straight street became straighter and is turned toward the quantized direction, as shown in Example 4.

(2) The shape of the street, which has a refraction part, can be maintained, as shown in Example 3.

Figure 9 shows some experimental results. Figure 9(a) is an input map and each result (Figs. 9(b) to (f)) is obtained from the same input map by using the corresponding set of four parameter values in Table 1. Figure 9(c) is a result by the default set. Figure 9(b) is a result showing that street shape become more straight by setting the value of Ksc to 1. In Fig. 9(d), edge direction is transformed so as to become more horizontal/vertical by setting the value of Kdv to 1. In Fig. 9(f), it can be seen that edge direction are quantized more strongly by setting values of Kdv, Kda and Kdn to 1s. From many experiments, it is known that above four parameters can control straightness and direction of street very effectively. Even other seven parameters can control them, but are less effective and not easier to use than above four parameters.

In conclusion, it can be said that the proposed method achieves transformation from a global viewpoint so that a long sequence of edges can be treated as a cluster. The proposed method can transform according to the shape and direction of the street, and can generate much more excellent results than the previous method.

5. Conclusion

The previous edge-wise based parallel method cannot always obtain good results from a global viewpoint because transformation is locally operated. Therefore, in this paper, we proposed a new street-wise based generation method for road transformation in deformed maps. The street-wise based transformation has merits in that it can transform edges while maintaining the shape of connected edges and can also transform according to the shape and direction of each street. By using this method, we performed an experiment to generate a deformed map from real maps. As a result, much more excellent results than those by the previous method were obtained. The proposed method can generate much more excellent results because it can transform from a global viewpoint which treats a long sequence of edges as a cluster.

We think that suppressing transformation to some degree is also necessary because when the transformation is excessive, the phase structure of edges is broken according to the parameter values. The development of automatic parameter setting remains a matter to be discussed further.

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Appendix A. Potential Function for Force for Quantizing Edge Direction

Let us explain the force to turn the edge QR toward the horizontal direction, as shown in Fig. A1. This applies the potential function used in the study by YAMADA *et al.* (1988). First of all, where M is the middle point of edge QR and is also the rotation center of edge QR, the potential function, which makes the potential energy become small in order to make node R approach the horizontal direction, is calculated. The force is applied to node R so that edge QR goes toward to the direction where the potential energy becomes small. In the same way, the force is applied to node Q so that edge QR goes toward to the opposite direction. The equation is shown as follows. Where α, β, δ, θ are parameters on the shape of the parabola, the shape of the hyperbola, the potential value of the origin, and the target direction (this is a measured angle in an anti-clockwise direction from the positive direction of the x-axis), respectively.

$$P(x,y)=\frac{\alpha\left\{-\left(x-x_0\right)\sin\theta+\left(y-y_0\right)\cos\theta\right\}^2+\beta}{\left(x-x_0\right)\cos\theta+\left(y-y_0\right)\sin\theta+\delta^{-1}}, \tag{A1}$$

$$\begin{aligned}d_x(x,y)=&\frac{-2\alpha\sin\theta\left\{\left(x-x_0\right)\sin\theta-\left(y-y_0\right)\cos\theta\right\}}{\left(x-x_0\right)\cos\theta+\left(y-y_0\right)\sin\theta+\delta^{-1}}\\&+\frac{\cos\theta\left\{\alpha\left\{\left(x-x_0\right)\sin\theta-\left(y-y_0\right)\cos\theta\right\}^2+\beta\right\}}{\left\{\left(x-x_0\right)\cos\theta+\left(y-y_0\right)\sin\theta+\delta^{-1}\right\}^2},\end{aligned} \tag{A2}$$

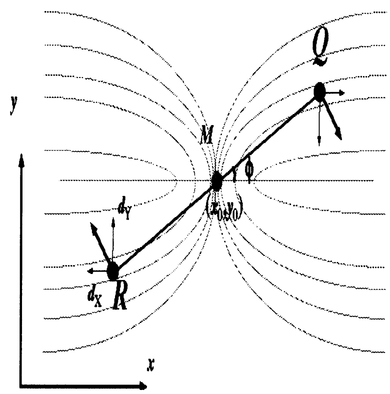

Fig. A1. Illustration of the force turning to a quantum direction.

$$d_y(x,y) = \frac{2\alpha\cos\theta\left\{(x-x_0)\sin\theta-(y-y_0)\cos\theta\right\}}{(x-x_0)\cos\theta+(y-y_0)\sin\theta+\delta^{-1}} + \frac{\sin\theta\left\{\alpha\left\{(x-x_0)\sin\theta-(y-y_0)\cos\theta\right\}^2+\beta\right\}}{\left\{(x-x_0)\cos\theta+(y-y_0)\sin\theta+\delta^{-1}\right\}^2}. \quad \text{(A3)}$$

Appendix B. Potential Function for Force for Keeping the Initial Length of an Edge

First of all, the potential function, which makes the potential energy become large in order to make node R move away from the initial length L between nodes R and M, is calculated, where M is the middle point of edge QR. The force is applied to nodes R and Q so that they both equally adjust their positions to the length where the potential energy becomes small. The equation is shown as follows. Where L is the half length of the initial edge length and γ is a parameter which represents a steep shape of the potential curve.

$$P(x,y) = \frac{\gamma\left\{\sqrt{(x-x_0)^2+(y-y_0)^2}-L\right\}^2}{2}, \quad \text{(A4)}$$

$$d_x(x,y) = \gamma\left\{1-\frac{L}{\sqrt{(x-x_0)^2+(y-y_0)^2}}\right\}(x_0-x), \quad \text{(A5)}$$

$$d_y(x,y) = \gamma\left\{1-\frac{L}{\sqrt{(x-x_0)^2+(y-y_0)^2}}\right\}(y_0-y). \quad \text{(A6)}$$

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