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A System for Automated Generation of Deformed Maps

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Abstract

This paper presents a prototype system for automated generation of deformed maps, based on a psychological model in the field of cognitive map. The system consists of two parts; map deformation and map database management. The map deformation part has two functions; road deformation and landmark relocation. In the road deformation process, each road segment is transformed in parallel and iteratively by four types of forces. Each force is generated by a potential function located at the road segment. In the landmark relocation process, each landmark is relocated by using the field morphing technique. In the paper, two types of algorithm for road deformation are proposed and their performances are evaluated comparatively and experimentally with real road map data.

1. Introduction

In guidance maps or advertising leaflets, simplified maps are used often for quick communication and space saving. In such maps, roads and streets are drawn straight and crossing roads are right-angled. We call such a type of maps "deformed map". Although the deformed map is one of useful media in human communication, still its generation process has never been investigated properly from the viewpoint of machine vision.

This paper presents a prototype system for automated generation of deformed maps, based on a psychological model called "road orthogonalization at crossing points" in the field of cognitive map[1]. This system employs a dynamic model with four types of forces for road deformation and the field morphing technique for landmark relocation. In subsequent sections, after overviewing the system, procedures for road deformation and landmark relocation are described. Also, experimental results with real road maps are shown.

2. System Overview

This system is divided into two parts; map deformation part and map database management part. The map deformation part consists of two functions; road deformation and landmark relocation. Previously, we have already proposed a sequential method for road deformation[2]. However, the deformed method had the following problems. The deformation results depend on the order of road segments to be deformed, and there is no reasonable way to determine the order. The method newly proposed here can deform the roads in parallel and iteratively. This method does not depend on the order of road segments to be deformed. In the landmark relocation process, original positions of landmarks in the map are relocated according to the result of road deformation. Basically, relocation is performed with keeping the relative distance from the landmark to the nearest road, by using the field morphing technique.

3. Road Deformation

In the road deformation process, roads and streets are straightened and roads at crossing points are right-angled. This process is performed by a parallel procedure. In this procedure, first an input road map is regarded as a network with road segments (edges) and crossing points (nodes). Then, each edge is transformed in parallel and iteratively based on a resultant of forces placed on each node. Each force is generated by a potential function[3] located at the edge.

3.1 Four Types of Forces

(i)Force 1:to turn the edge toward horizontal or vertical direction.

The first force named Force 1 makes each edge turn toward a quantum direction. The quantum direction is a discreet angle, for example which is 15, 30, 45 or 90 degrees. A user of the system can select a quantum direction. If 90 degrees is selected, the system makes each edge turn toward either horizontal or vertical direction which is called target direction. Fig. 1 illustrates Force 1 to an edge and its potential function. In this figure, the direction of the edge QR will be turned toward the horizontal direction. The force at the node R is calculated by using the potential function $P(x,y)$ shown as Eq. (1). The potential function is placed so that the bottom line of the function is directed to

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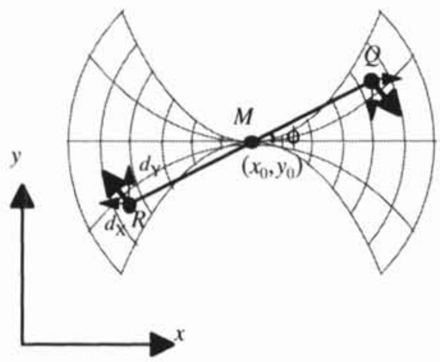


Fig. 1 Illustration of Force 1 and its potential function.

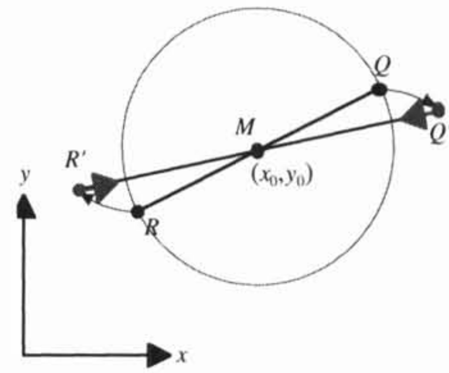


Fig. 2 Illustration of Force 2 and its potential function.

the target direction. $P(x,y)$ becomes small when R approaches the horizontal direction. d_x and d_y in Eqs. (2),(3) are the x and y components of the force put on the node R. The force is also put on the node Q in the same way. α,β,δ in Eqs. (1)-(3) are parameters about the shape of the parabola and the hyperbola, and the potential value of the origin (x_0,y_0), respectively. θin Eqs. (1)-(3) is an angle between QR and x-axis.

(ii) Force 2:to keep the initial length of the edges.

The second force named Force 2 keeps the initial length of each edge. QR in Fig.2 is an initial edge and Q'R' is the transformed one. The force at the node R' is calculated by using potential model. $P(x,y)$ shown as Eq. (4) is a potential function. $P(x,y)$ becomes small when the length of R'M approaches the length of RM. dx and dy shown as Eqs. (5),(6) are the x and y components of the force put on the node R'. The force is put on the node Q' in the same way. γ in Eqs. (4)-(6) is a parameter about the shape of the parabola, and L is a half of the initial length of the edge.

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

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

$$d_Y(x,y)=\frac{2\alpha\cos\theta\{(x-x_0)\sin\theta-(y-y_0)\cos\theta\}}{(x-x_0)\cos\theta+(y-y_0)\sin\theta+\delta^{-1}} +\frac{\sin\theta\left\{\alpha\{(x-x_0)\sin\theta-(y-y_0)\cos\theta\}^2+\beta\right\}}{\{(x-x_0)\cos\theta+(y-y_0)\sin\theta+\delta^{-1}\}^2} \quad (3)$$

(iii) Force 3:to make two near edges repulse each other.

The third force named Force 3 is for preventing two near edges at crossing point from overwriting each other by using Force 1. But this force is not applied when the connecting angle between the edges is more than 45 degrees. In the case of Fig. 3, because both of QR and UR will become to be horizontal together by Force 1, Force 3 is added to the node Q. But, Force 3 is not applied to the node U, because Q departs from horizontal line more than the node U. The potential function used here is the same to Eq. (1) with 45 degrees of the target direction.

(iv) Force 4:to straighten successive edges.

The final force named Force 4 makes successive two or three edges be straight. For example, QR in Fig.4 tries to become straight toward the average direction between RT and SQ. This force is put on the node Q and R. The potential function used here is the same to Eq. (1), but the target direction is set to the average direction between RT and SQ. If QR has only one successive edge, either RT or SQ, the target direction becomes the direction of the existing edge.

$$P(x,y)=\frac{\gamma\left(\sqrt{(x-x_0)^2+(y-y_0)^2}-L\right)^2}{2} \quad (4)$$

$$d_X(x,y)=\gamma\left(1-\frac{L}{\sqrt{(x-x_0)^2+(y-y_0)^2}}\right)(x_0-x) \quad (5)$$

$$d_Y(x,y)=\gamma\left(1-\frac{L}{\sqrt{(x-x_0)^2+(y-y_0)^2}}\right)(y_0-y) \quad (6)$$

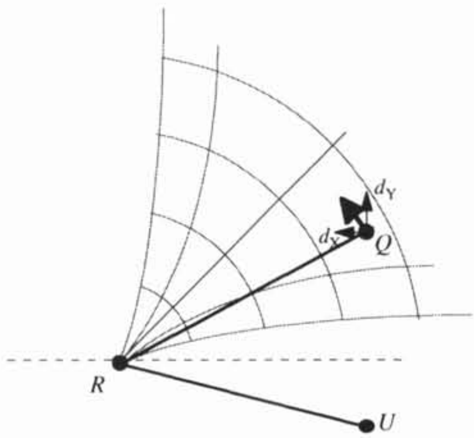


Fig. 3 Illustration of Force 3 and its potential function.

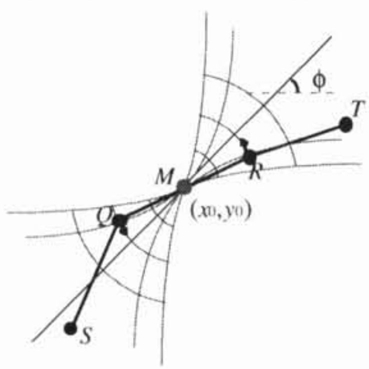


Fig. 4 Illustration of Force 4 and its potential function.

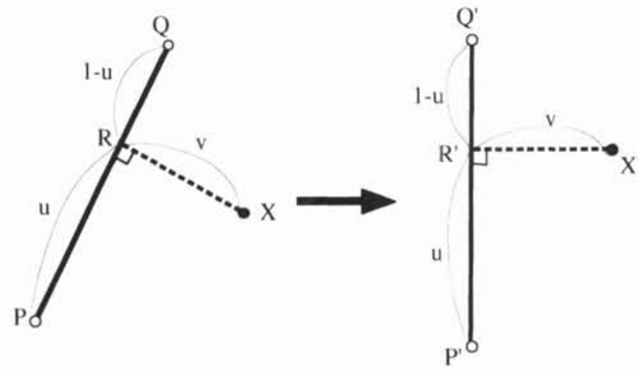


Fig. 5 Illustration of field morphing.

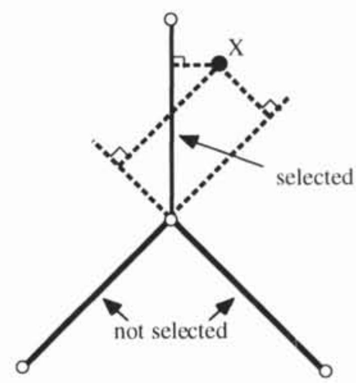


Fig. 6 Selection of road segments for relocation of the landmark X.

3.2 Deformation Algorithms

Two algorithms; Algorithm 1 and 2 are proposed here for road deformation. Algorithm 1 is very simple and Algorithm 2 is a modified version of Algorithm 1. The details are as follows.

[Algorithm 1]
Step 1: Set initial parameters.
Step 2: Calculate four forces on each node based on the corresponding potential function.
Step 3: Calculate the resultant force of each node.
Step 4: Move each node according to the resultant force.
Step 5: Calculate the total amount D of moving distance for all nodes.
Step 6: If the value of D is greater than a threshold value, go to Step 2. Otherwise, quit with output of result.

[Algorithm 2]
Algorithm 2 is the same as Algorithm 1 expect Step 3. In Step 3, force calculation results are weighted only for a few particular edges. This is from the fact that there are some edges to which some types of forces should not be applied in order to avoid unnatural deformation by applying all of forces. Such edges include parts of long streets which are running diagonally or are curving over a wide area on the map. Step 3 in Algorithm 2 consists of the following three substeps.

Step 3(a): Select a few particular edges from among all edges (by the user) based on the requirements mentioned above.
(b): Weight each force only for the selected edges.
(c): Calculate the resultant force.

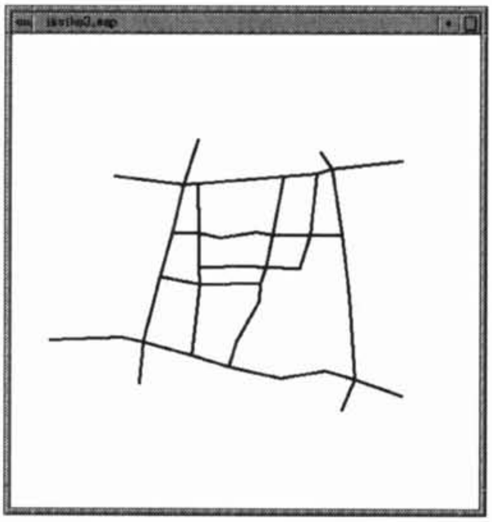
The practical weighting value for each force used in Step 3(b) is decided experimentally. To do so, the selected edges will be deformed moderately more than other edges.

4. Landmark Relocation

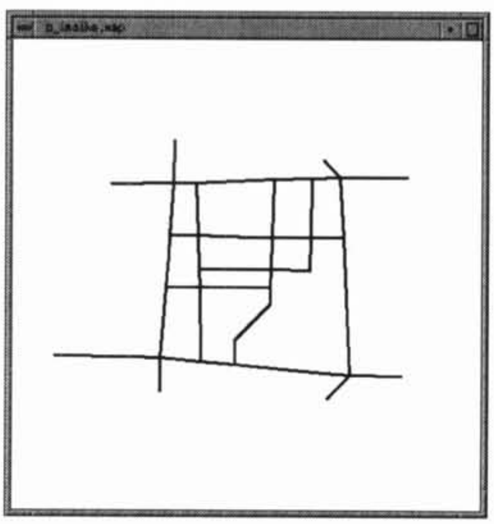
With road deformation, every landmark in the map must be moved to an suitable position. In this section, a relocation process of landmarks based on the field morphing technique is described.

4.1 Relocation Process

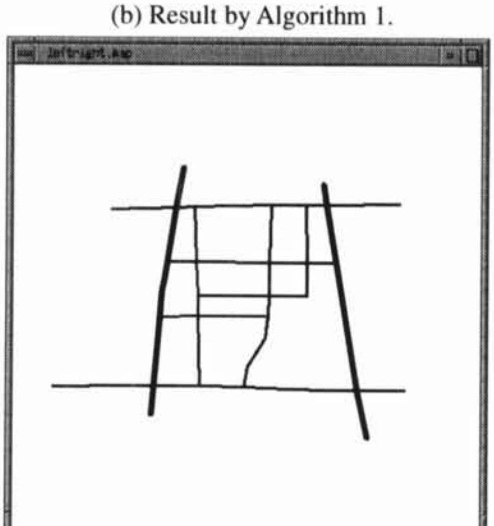
Suppose that a road segment PQ and a landmark X are given as the left figure in Fig. 5. If PQ is moved to P'Q' in the right figure of Fig. 5 by road deformation, X should be



(a) An input map.

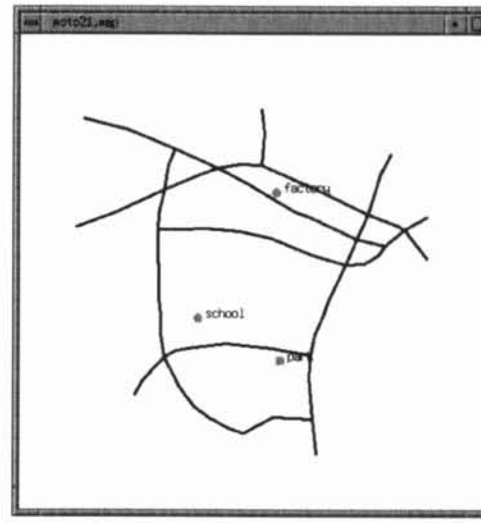


(b) Result by Algorithm 1.

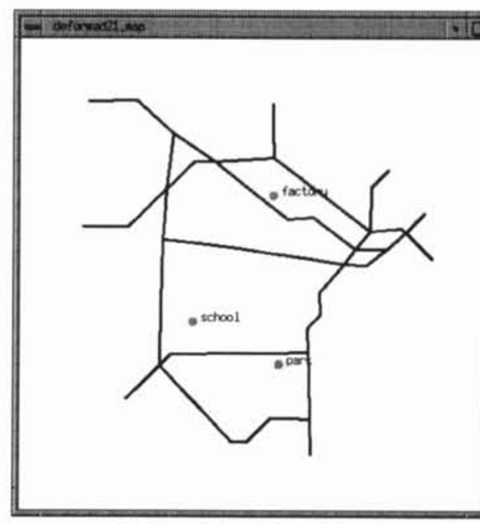


(c) Result by Algorithm 2.

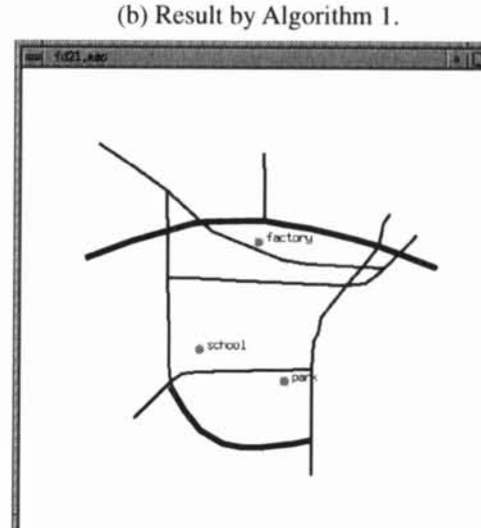
Fig. 7 Examples of road deformation results for a relatively simple road map.



(a) An input map with some landmarks.



(b) Result by Algorithm 1.



(c) Result by Algorithm 2.

Fig. 8 Examples of road deformation and landmark relocation results for a map including some curved roads.

moved to X', too. To do it, we take the following two conditions.
(1) The relative position of X against PQ in the direction of PQ is not changed regardless of the movement of X.
(2) The absolute distance of X from PQ is not changed regardless of the movement.

Under above conditions the landmark relocation process becomes equivalent to the well-known the field morphing process[4].

If the road segment PQ is moved to P'Q' by road deformation, the new position of the landmark X is given by,

$$X = p' + u(Q' - P') + \frac{v\perp(Q' - P')}{\|Q' - P'\|} \tag{7}$$

$$u = \frac{(X - P)\bullet(Q - P)}{\|Q - P\|^2}$$

$$v = \frac{(X - P)\perp(Q - P)}{\|Q - P\|^2}$$

where ⊥A means a perpendicular vector for the vector A. If there are two and more road segments, all of results from each segment are averaged according to the Eq. (8).

$$X' = X + \frac{\sum_k W_k (X'_k - X)}{\sum_k W_k} \tag{8}$$

$$W_k = \left(\frac{\|Q_k - P_k\|^p}{a + D_k} \right)^b$$

Where W_k's are the weighting functions, and D_k means the shortest distance between the corresponding road segment and the point X. The values of parameters a,b and p in W_k are determined experimentally.

4.2 Selection of Road for Landmark Relocation

In the above relocation process, it is not desired that a landmark is relocated by using road segments far from the landmark. Therefore, road segments suitable for each landmark should be selected for relocation. Here the following selection procedure is employed. First, the foot point from a landmark X to the line including a road segment is calculated. Then, only road segments which include the foot point are selected for relocation of the landmark X.

5. Experimental Results

The proposed algorithms were applied to some kinds of real road maps. Fig. 7(a) and Fig. 8(a) show examples of input map data. Fig. 7(b) and Fig. 8(b) are deformed maps obtained by Algorithm 1. Fig. 7(c) and Fig. 8(c) are ones obtained by Algorithm 2. The bold lines shown in Fig. 7(c) and Fig. 8(c) are the road edges selected by a user. In this experiment, the force put on the selected edges is the summation of Force 2, Force 3 and Force 4. Force 1 is not put on the selected edges. In Fig. 8(b), many roads are strongly directed to the vertical or horizontal direction. In Fig. 8(c), the result has many round lines and seems to be more natural than that in Fig. 8(b). The difference between Fig. 7(b) and Fig. 7(c) is a little because the input data is relatively simple. When a direction for the line of the input map is close to the horizontal or vertical, we can get stable results by both Algorithm 1 and Algorithm 2. As for the relocation of landmark, Fig. 8(b) and Fig. 8(c) shows good results. The relative position of landmark for road lines is maintained between a input map and the deformed map.

6. Conclusion

In this paper, a system for automated generation of deformed maps was presented. The deformation procedure in the system was developed based on a psychological model in the cognitive science field. The landmark relocation can be also performed by the technique same as field morphing. Experimental results using real maps are promising. Future works include improvement of map database management, development of graphical user interface and manipulation of other symbols and characters in the maps.

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