Landmark-Aware Map Deformation Using Graph Drawing Techniques

Fumiya Sato, Hsiang-Yun Wu, Shigeo Takahashi, and Masatoshi Arikawa

Abstract Recent development of web mapping services such as Google maps provides us with easy access to geographically accurate maps on demand. On the other hand, distorted maps drawn by hand have long attracted our interest because they can naturally draw our attention to specific areas of interest. In this paper, we present a novel method for emphasizing geographical features such as landmarks by deforming the entire map while respecting the original spatial relations among the landmarks. For this purpose, we employ *graph drawing techniques*, which effectively allows us to retain aesthetic layout among the landmarks by taking into account their mutual proximity. In the proposed method, representative landmarks and their mutual relations are associated with nodes and edges in the graph representation, respectively, so that we can rearrange them on the 2D screen space in a visually plausible manner using the conventional *force-directed algorithm*. The feasibility of the method is demonstrated with several design examples, where the distorted maps successfully put more emphasis on a specific set of landmarks.

1 Introduction

Geographic information systems (GIS) automatically generate local maps in which each user is interested. Google Maps, for instance, provides us with a part of satellite photographs on which various kinds of extra information are overlaid. In addition, such GIS services are reliable because they have accurate geographic information, i.e., the geographic features on the generated maps are placed while keeping their accurate relative position.

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On the contrary, most of the maps widely used in the world do not have accurate geographic information. For example, most of hand-drawn guide maps support straightened or smoothly curved roads and represent only famous sightseeing spots. As a result, these maps are often extremely distorted. Nevertheless, it does not mean that all the distorted maps are useless. In fact, when we read a map, we are only interested in a partial area within the whole map. In other words, it is important for maps to allow us to naturally focus our attention to areas of interest. Although general geographic maps are hard to have this advantage, distorted maps can have it because they can emphasize particular geographic feature areas through the geographical deformation. In spite of this fact, there are few GIS services that provide us with maps with appropriately distorted geographic information.

In this paper, we present a method of emphasizing geographic feature areas by distorting a given map. Moreover, we try to keep the readability by retaining their spatial relations in original map through a conventional method, that is *force-directed graph drawing*.

Force-directed graph drawing is a well-known method to draw a graph on a screen space. Graph is a mathematical structure studied in *graph theory* to model pairwise relations between a set of objects. One graph is composed of nodes as objects and edges as relations between two objects. Because graphs themselves are abstract structures, they are visualized by such a graph-drawing algorithm as force-directed graph drawing, in which forces are applied among the nodes and the edges. The purpose of force-directed graph drawing is to draw a given graph beautifully, i.e., to place nodes scattered uniformly and symmetrically. In this paper, force-directed graph drawing is employed to distort a geographic map so as to rearrange geographic features in the map.

When we attempt to apply force-directed graph drawing to map distortion, one of the main challenges is how to convert geographic features into a graph. We try to resolve this problem by referring map layout of *Hatsusaburo Yoshida*, who is a Japanese well-known bird's-eye view artist. The reason why he is referred is because he has made many maps that are quite distorted and let us focus our attention to specific areas of interest. Another reason is because there are many researchers who try to classify his ways of the placement into several patterns. Therefore, we refer one of these researches and define the way to construct a graph from geographic features according to the rules based on the referred research [6].

Before describing our algorithm, we first clarify the location of this paper in Section 2. We next present the major components of our method in Section 3: As our main contribution, we will then provide users with an interface to select interested geographic features on a map, show two methods to construct a graph from the features according to the prior researches about Hatsusaburo Yoshida, and explain how we associate node placement among the graph by force-directed graph drawing for map distortion. In Section 4 we present details of our implementation and the results generated by our prototype system. Finally, we conclude this paper and show several possible future extensions in Section 5.

2 Related Work

Distorting a map to emphasize particular characteristics has been one of the main topics especially in the area of cartography. Dougenik et al. [2] proposed an algorithm to distort a map to stress the characteristics for each drawn country. This idea had a great impact and many subsequent researches have been conducted [7]. Though there are not many approaches about distortion in order to emphasize particular feature areas in a map, this motivation has been often given in the studies about *metro map design*. Wu et al. [11] presented an approach to straightening a single selected metro line and place it to the center of the map domain. But their approach did not particularly connect map layout with studied in the area of *Graph Drawing*.

In this paper we use one of the most fundamental method, force-directed graph drawing, as a method to place geographic features as nodes. However, there are naturally many approaches for developing this fundamental method. Gansner et al. [4] considered labeled nodes in a graph and developed force-directed graph drawing to avoid overlaps. Our approach can essentially replace the fundamental force-directed algorithm with any graph layout algorithm.

In fact, the connection between graphs and cartography has a long history. In case of map design with a mathematical approach, graphs are frequently used to simplify the relations between objects drawn on a map [10]. Nevertheless, there are not many researches to try to associate graphs with the techniques of a specific map designer. In particular, to the best of our knowledge, there are few studies such as the works of Hatsusaburo Yoshida are dealt with mathematically. On the other hand, he has been a well-known person in the field of geography. Yoshida himself has left his approach to designing the maps [12] and Hotta [6] proposed several patterns of the way of Yoshida to place the geographic features on the map. In this paper, we basically follow his idea.

Moreover, there are approaches to assuming imaginary maps in order to visualize some abstract structures intuitively. Gronemann et al. [5] presented *Topographic Maps* to visualize a clustered graph as a terrain. Furthermore, Weber et al. [9] visualized scalar functions as a terrain. The purpose of these approaches is to express abstract objects easily and intuitively. Therefore, they can bring us splendid ideas for drawing real maps with good layout. For example, Fabrikant et al. [3] considered effect of the natural landscape metaphor in the area of *information visualization*.

3 Map Distortion Using Force-directed Graph Drawing

As mentioned earlier, the present algorithm is purposed to distort a given map so as to emphasize local areas where users are interested. For this purpose, in this section, we explain the procedure for distorting the map. We first provide users with an interface to let them give an origin map and noticed geographic features within the map as inputs in Section 3.1. We second consider how to construct a graph from the given features in Section 3.2. We finally apply the force-directed algorithm in order to transform a triangular mesh generated from the graph and the map image in Section 3.3.

3.1 Interface for Assigning Geographic Features

Before providing the interface, we briefly explore what type of geographic features can be defined. First, we can consider a dot on the map chiefly as a building. In the case of a small-scale map, the whole town can be drawn as a dot. This type of geographic feature is called a *dot feature*. Second, we can come up with a line on the map mainly as a railroad, which is called a *line feature*. Line features are naturally connected with any pair of dot features. Although we can consider those geographic features with a wider area, say *area features*, we do not assume them because they can make the proposed method quite complicated. Thus we assume only dot features and line features as geographic features.

In this study, we implemented the system that allows users to assign a map image and geographic features. While users can give any kinds of images as an origin map, it is desirable to set some accurate map for our purpose. In the interface, by clicking a specific point, users are required to input any place name and an icon image representing the place. Then the corresponding geographic information is automatically assigned by the system through the referred service of geocoding [1]. Moreover, by selecting a pair of dot features and inputting an icon image representing any line feature users can assign line features. The assigned geographic features will be used to construct a graph in the next step.

3.2 Graph Construction

As shown before, in order to construct a graph from geographic features, we use the prior study by Hotta [6] about Hatsusaburo Yoshida as a reference. Before explaining the procedure for the graph construction, we concisely sum this study up. While Hotta categorized the way of Yoshida to place geographic features into five patterns, they can be integrated again into two patterns. First of all, in both of the two patterns, it can be said that any dot features are placed as they keep the spatial relations only with neighboring line features. It is because users are only interested in the limited geographic information around a particular area. Keeping this in mind, we then describe the difference between the two patterns.

One pattern is to place a particular sequence of line features at the center of the map. In the study of Hotta, this sequence corresponds railway lines or rivers. It is thought that this type of map emphasizes the geographical feature areas around the line features and is preferred by those who use these line features as means of transportation. We call this pattern *Central Line Model*. The other is to place

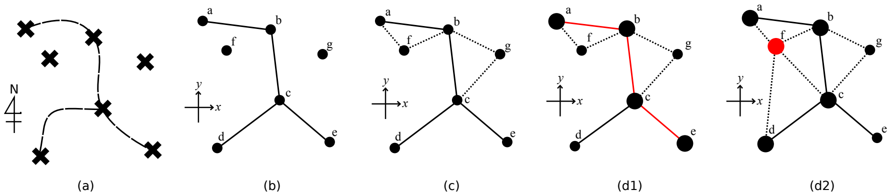

Fig. 1 An example for graph construction. (a) Seven dot features and four line features are assigned by users. (b) In this case, seven nodes are contained in V and four edges that belong to E_{line} as solid lines are contained in E. The coordinates of each node are calculated by latitude and longitude of the corresponding dot feature. (c) Because node f and g have no connected edge, they are connected with two supplemented edges that belong to E_{prox} as dotted lines. (d1) If users choose Central Line Model and notice the three line features as red lines, weight of each node is decided, where the bigger nodes have M as weight and the smaller nodes have m. (d2) If users choose Central Dot Model and notice node f, the spring constant of edges $\{a, f\}$ and $\{f, b\}$ are renewed, edges $\{d, f\}, \{f, c\}$ are added to E_{prox} and weight of each node is decided. A spring constant for $e \in E_{\text{line}}$ is k and that for $e \in E_{\text{prox}}$ is calculated by length of edges in E_{prox}.

a particular dot feature at the center of the map. In the prior study, this feature corresponds some towns, mountains, islands, plateaus, or coasts. In this type of maps, the area around one specific dot feature is especially emphasized. We call it *Central Dot Model*. A graph is constructed according to either of them and which model is used depends on the decision of users. Then, we formulate each of these two models as an algorithm to construct a graph as follows:

We first recall the definition of a graph. We assume a graph $G = (V, E)$ with a set of nodes V and a set of edges E. In order to apply the force-directed algorithm to G, we let $v \in V$ have two attributes, that is $p_v \in \mathbb{R}^2$ as a position on a 2D plane and $w_v \in \{m, M\}$ as weight, where m and $M \in \mathbb{R}$ are constants. In particular, p_v corresponds the real position of the geographic feature for v; in other words, p_v is calculated by latitude and longitude of the geographic feature for v. Also, for each $e \in E$, an attribute is given, that is $k_e \in \{k\} \cup \mathbb{R}$ as a spring constant, where $k \in \mathbb{R}$ are also constants. Moreover, we suppose that the natural length of spring is extremely short.

Fig. 1 shows an example for graph construction. V corresponds all the assigned dot features (Fig. 1(b)). In this paper, E has two subsets as E_{line} and E_{prox}. E_{line} corresponds all the assigned line features (Fig. 1(b)), where we suppose that $^{\forall}e \in E_{\text{line}}$ is connected with $v \in V$. Consequently, G has the same V and E_{line} in both cases of the two models. On the other hand, E_{prox} indicates a set of supplemented edges to express the proximity of a dot feature and a line feature (Fig. 1(c)). Recall that dot features are placed to keep the spatial relation only with the neighboring line features in the maps of Yoshida. That is to say, $e \in E_{\text{prox}}$ serves to tie any of dot features and line features. E_{prox} has different elements and $v \in V$ and $e \in E$ have different attributes in each of the two models.

In Central Line Model, E_{prox} is given as follow:

1. Substitute $E_{\text{prox}} = \emptyset$.

2. Define V' where $v \in V'$ is connected with no edge.
3. For each $v \in V'$, give $v_1, v_2 \in V - V'$ where v_1 and v_2 are the nearest and the second nearest nodes to v.
4. For each $v \in V'$, add $e_1 = \{v, v_1\}$ and $e_2 = \{v, v_2\}$ to E_{prox}. For $l_1 = \text{length}(p_v, p_{v_1})$ and $l_2 = \text{length}(p_v, p_{v_2})$, $k_{e_1} = \frac{l_1+l_2}{2l_1}k$ and $k_{e_2} = \frac{l_1+l_2}{2l_2}k$.

In addition, we assume $E_{\text{cent}} \subseteq E$, which corresponds a link of line features users notice, where E_{cent} needs to be composed of one path (Fig. 1(d1)). Other attributes are given as follow:

- Give M to w_v where $v \in e \in E_{\text{cent}}$.
- Give m to w_v otherwise.
- Give k to k_e where $e \in E_{\text{line}}$.

On the other hand, in Central Dot Model, we assume $v_{\text{cent}} \in V$, which corresponds a dot feature users notice (Fig. 1(d2)). In this case, E_{prox} is also given by the same procedure in Central Line Model, but several edges are added to E_{prox} again as follow:

1. Define V' where $v \in V'$ is close to v_{cent}, i.e., $e' = \{v_{\text{cent}}, v\}$ does not intersect any $e \in E_{\text{line}}$.
2. For each $v \in V'$, add $e = \{v_{\text{cent}}, v\}$ to E_{prox}. In the case that $l_1 = \text{length}(p_v, p_{v_1}), \ldots,$ and $l_n = \text{length}(p_v, p_{v_n})$, $k_{e_1} = \frac{\sum_{i=1}^{n} l_i}{n l_1}k, \ldots,$ and $k_{e_n} = \frac{\sum_{i=1}^{n} l_i}{n l_n}k$. If k_e has been already given, renew the value.

Other attributes are given as follow:

- Give M to w_v where $v \in \{v_{\text{cent}}\} \cup V'$.
- Give m to w_v otherwise.
- Give k to k_e where $e \in E_{\text{line}}$.

By applying the above method, we can get a graph to which the force-directed algorithm can be applied. In Section 3.3, we associate this graph with the map image.

3.3 Transformation of Triangle Mesh by Force-directed Algorithm

We distort the map image by using the force-directed algorithm for the constructed graph. Fig. 2 shows an example for map distortion. If a graph $G = (V, E)$ is given (Fig. 2(a)), a *Delaunay triangulation* is built by referring to the representative points of p_v contained by $v \in V$ (Fig. 2(b)). Furthermore, in order to draw the whole map image, four corner points of the map image are added to the set of the representative points. When the force-directed algorithm is applied to G, each triangle is transformed according to the motion of the representative points (Fig. 2(c)); namely the fixed point on the map is drawn on the coordinates on which vertices of each triangle are placed and the other points are drawn by the following interpolation.

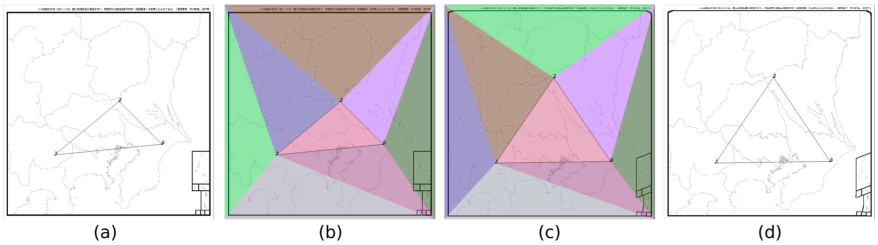

Fig. 2 An example for map distortion using a blank map [8] expressing Kanto region in Japan. We suppose that Sosa city labeled 0, Tsuru city labeled 1, and Koga city labeled 2 are assigned as dot features and the roads between them are assigned as line features. By the algorithm in Section 3.2, we can get a graph that contains three nodes and three edges. (a) First, these nodes and edges are drawn on the map image. (b) The three nodes and the four corner points of the map are used as the representative points to perform a Delaunay triangulation. In this figure, each triangle is colored at random for the explanation. (c) Then the force-directed algorithm is applied to the graph and each triangle is transformed. (d) As a result, a distorted map is drawn.

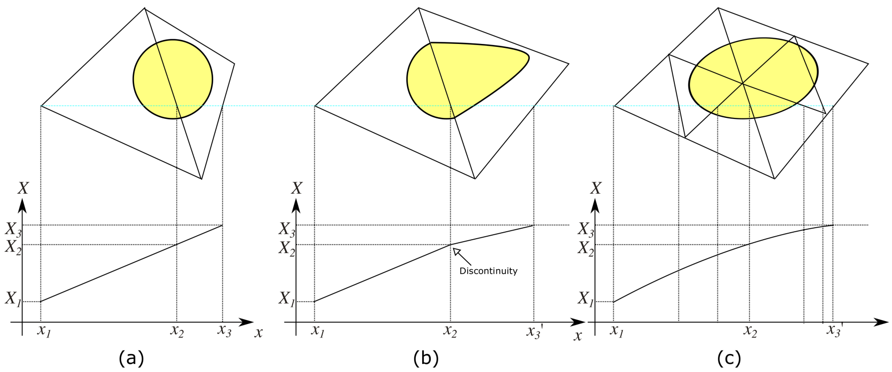

Fig. 3 The outline of ideal interpolation. (a) The upper figure means two triangles expressing a yellow circle and the lower means a graph between x-coordinate in the screen space and X-coordinate representing the corresponding texture coordinate. The inside of triangles are drawn by linear interpolation. (b) When the right representative point moves, the arc of the circle has discontinuity. (c) In order to avoid discontinuity, each triangle is recursively subdivided into four triangles and newly generated points are corresponded to the interpolated texture coordinates.

3.4 Interpolation of Texture Coordinates within Triangle Mesh

One of the most common way to interpolate appropreate pixels within triangle meshs is linear interpolation. However, we have observed in our precede experiments that the result images by using linear interpolation have remarkably bad quality. Assume that we use linear interpolation in Fig. 3. Before the triangle meshs are distorted, the attached image is smoothly shown (Fig. 3(a)). This appearance can be supported by the transition of texture coordinate value in the lower graph. Neverthe-

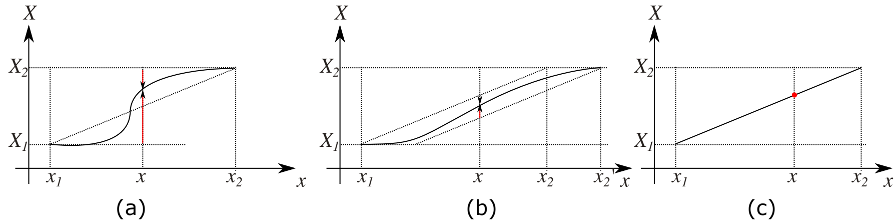

Fig. 4 The comparison between RBF interpolation (a) and our interpolation (b,c). (a) x_1 and x_2 are origin x-coordinate points and x is a interpolated point. In general, because x is interpolated by using only the distance from x to x_1 and x_2, the transition of X-coordinate becomes not linear. Thus, the texture coordinates are never interpolated without distorting the output image even if the triangle mesh is not transformed at all. (b) Assume that the origin point x_2 is moved to x_2' and x will be interpolated. In our interpolation we store the offset of X-coordinate corresponding the displacement from x to x_1 and x_2. Moreover, we interpolate X within the range restricted by these offsets. It allows us to more linearly interpolate the texture coordinates than RBF interpolation. (c) In particular, when the triangle mesh is not transformed, the transition of X-coordinate becomes always linear.

less, in the case that parts of representative points are moved, the attached image has discontinuity (Fig. 3(b)) and it causes remarkable deterioration of readability of the output image. Therefore, we will interpolate smoothly the interior of each triangle by subdividing each triangle recursively and corresponding texture coordinates so that the transition of texture coordinates becomes smooth (Fig. 3(c)). In this paper, we only show the intuitive image about interpolation to simplify the explanation.

Radial Basis Function (RBF) interpolation is one of the most general way for smooth image interpolation. However, it is possible that conventional RBF interpolation causes to spoil the appearance of the input image strikingly. Fig. 4 shows the comparison between RBF interpolation and our interpolation. In our interpolation we consider the offsets of the texture coordinates corresponding the displacement of transformation of the triangle mesh. The advantage of our interpolation is that the input image is not distorted at all before the transformation of the triangle mesh.

4 Results

In this section, we explain about a prototype system we implemented to achieve the proposed method. This system was implemented on a MacBook Air with a 1.7GHz Intel Core i7 CPU and the codes were written in C++ using OpenGL and cURL. OpenGL was used for drawing an output picture and cURL was used for Geocoding [1]. The system receives a map image and icon images representing geographic features as inputs and shows a distorted map image as an output.

In this experiment, the prototype system distorted a simple map image in Fig. 5. In Fig. 6, 16 dot features are given in the input map image that represents the region around Tokyo Sky Tree. In order to create these images, we used Inkscape

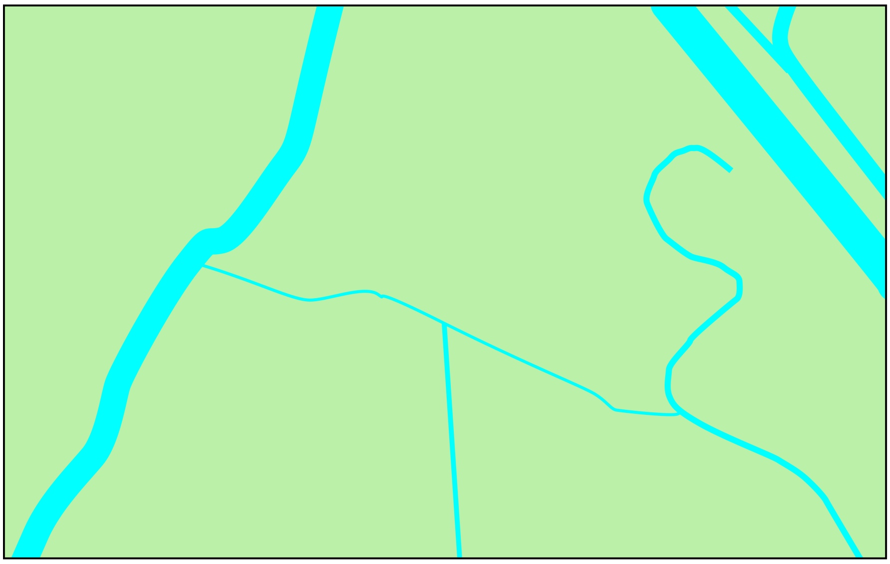

Fig. 5 Input map image expressing the region around Tokyo Sky Tree before distorting.

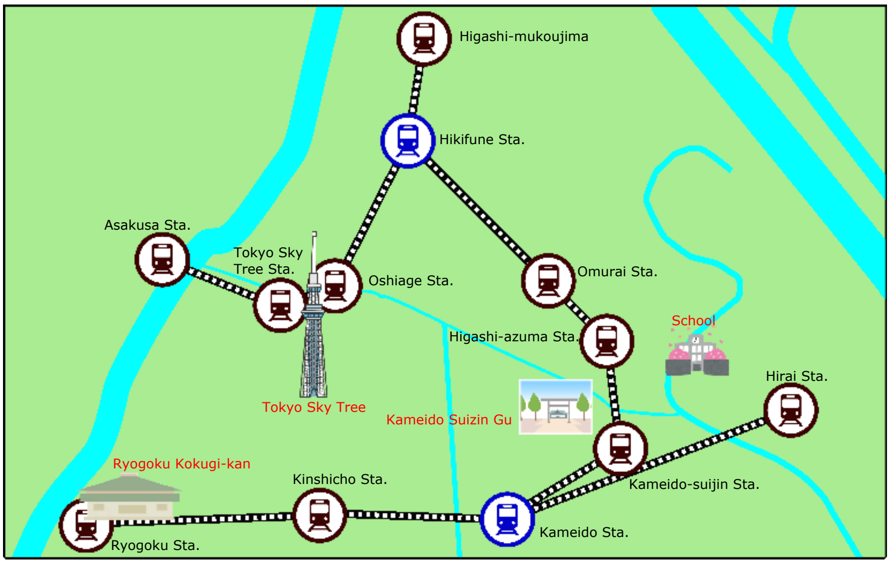

Fig. 6 Input map image with geographic features. There are 16 dot features and 11 line features.

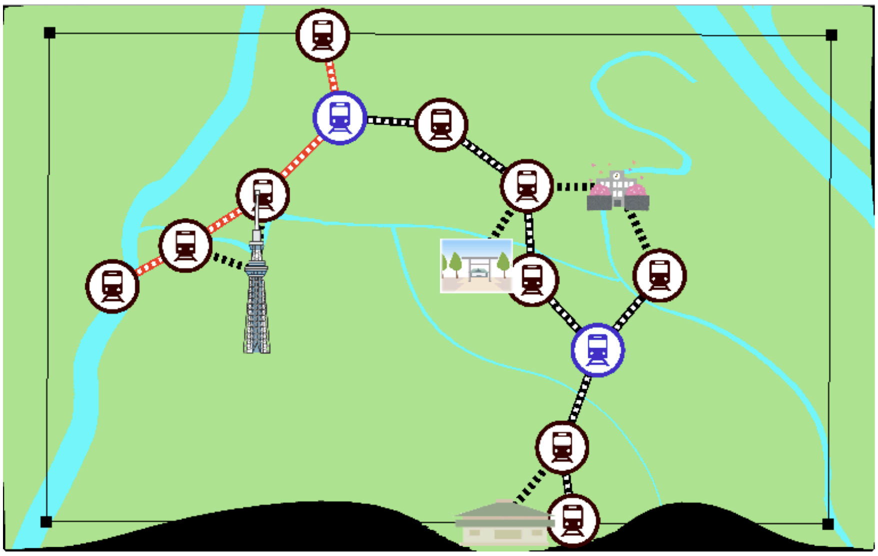

Fig. 7 Distorted map image as a result. The four noticed line features (Tokyo Sky Tree Line) correspond red edges are noticed. The black rectangle frame means the range the nodes can move.

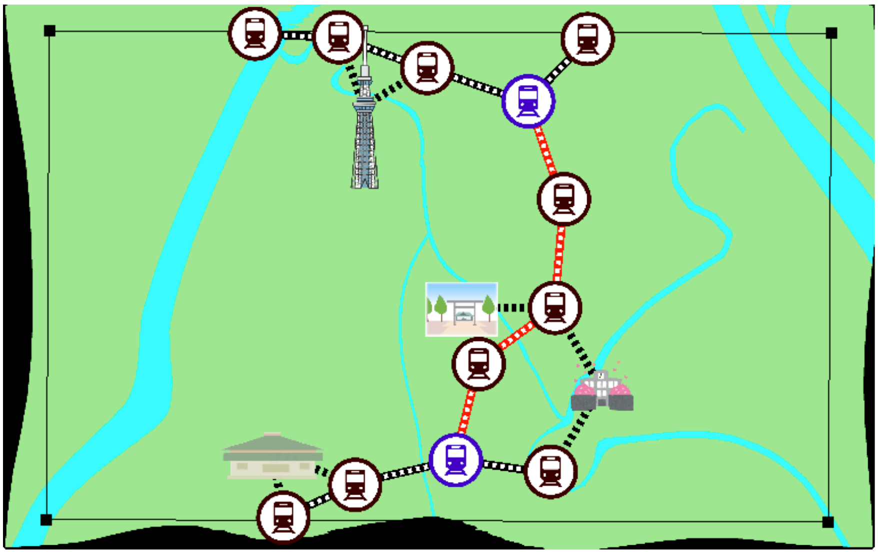

Fig. 8 Distorted map image as a result. Tobu Kameido Line are noticed.

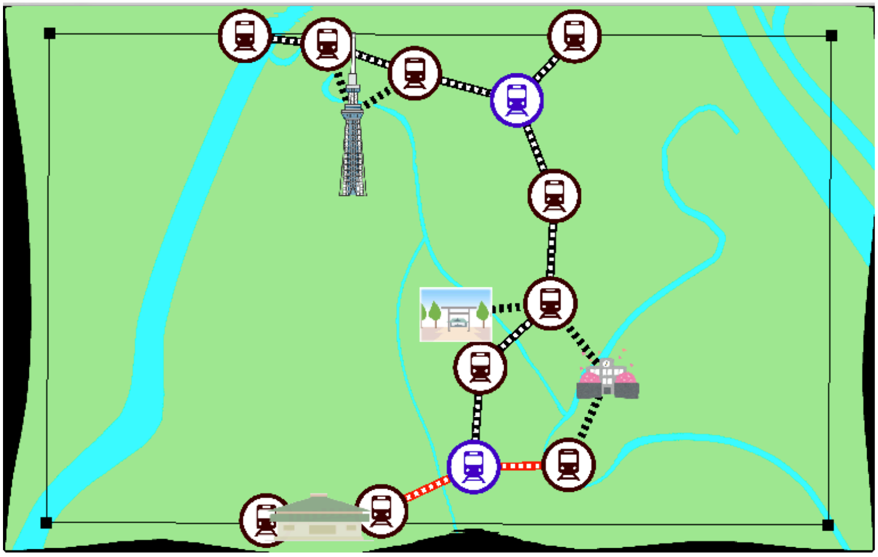

Fig. 9 Distorted map image as a result. JR Sobu Line are noticed.

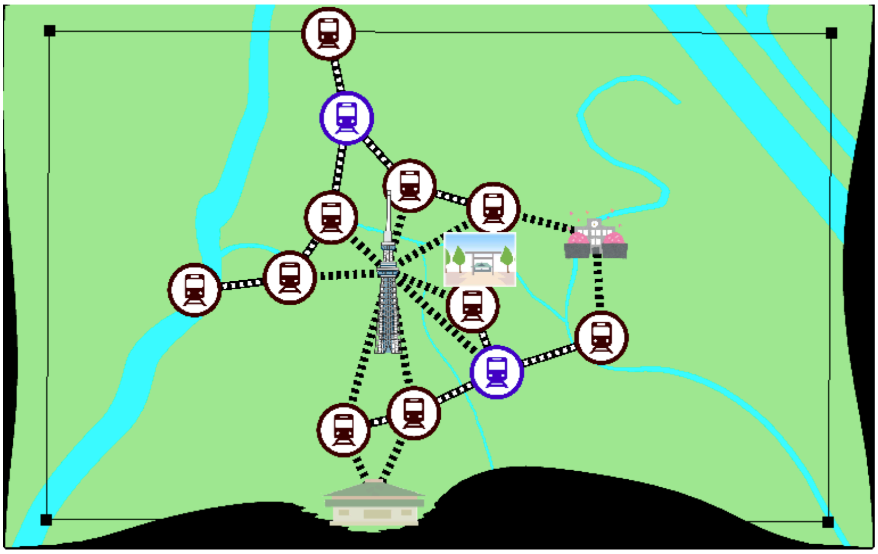

Fig. 10 Distorted map image as a result. Tokyo Sky Tree is noticed.

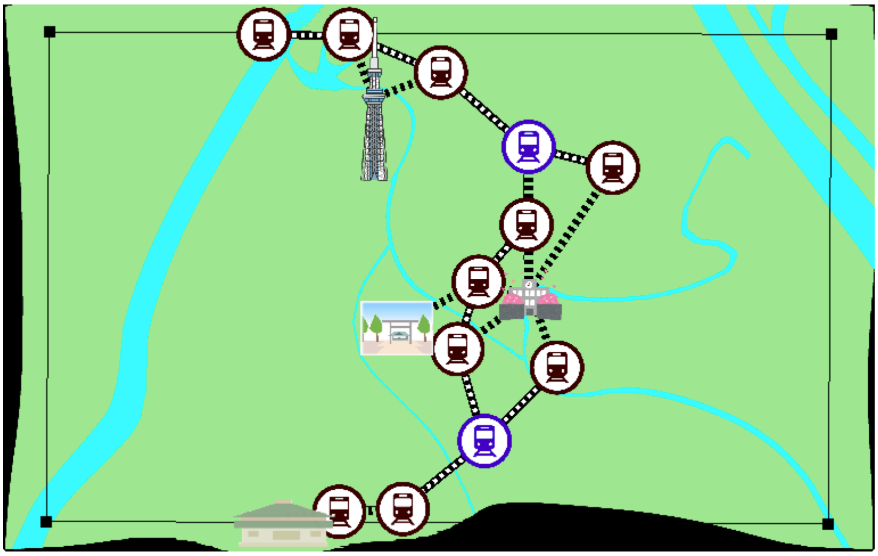

Fig. 11 Distorted map image as a result. A school is noticed.

and several provided illustration tools. The icon images shaped like a train mean stations and transfer stations are colored blue. Note that annotated place names are added afterward. By applying the proposed method and seeing output images, we validated the feasibility of the present method. In our experiment, the constants for the force-directed algorithm are given as follow: Coulomb power $= 0.02$, $M = 20.0$, $m = 1.0$, and $k = 1.0$.

In Fig. 7, Fig. 8, and Fig. 9, particular line features, i.e., Tokyo Sky Tree Line, Tobu Kameido Line, and JR Sobu Line, are noticed as red edges. Also, supplemented edges are colored green. Seeing Fig. 8, we can find that the area around noticed line features are relatively expanded and consequently this area can attract attention of users. However, it is difficult to predict what kinds of results we can get before conducting the experiments because of the nature of the force-directed graph drawing. Therefore, we cannot always get the expected results.

In Fig. 7 and 8, particular dot features, which are Tokyo Sky Tree and a junior high school in Edogawa Ward, are noticed. As showing in Fig. 10, we can discover that the several dot features are placed around Tokyo Sky Tree. It means that this map emphasizes the area around Tokyo Sky Tree.

5 Conclusion and Future Work

In this paper, we have presented our approach for distorting a given map for emphasizing the particular feature areas within the map. Besides the use of the prior study about Hatsusaburo Yoshida to construct a graph from noticed geographic features, we showed how to distort the map by using the force-directed algorithm and a Delaunay triangulation.

One of the main problems in the proposed method is the difficulty in the control of the node movement. It is because that the initial node positions are remarkably changed by force-directed algorithms. While we use the fundamental force-directed algorithm for graph construction, it is natural that there can be more suitable graph drawing method for map distortion. The other is to request different scale map image from a map-offer service, say *Google Maps*, each time the distorted map is drawn. In addition, although we considered only dot features and line features, it is desirable to consider other geographic features with a wider area like the sea in the future. Finally, we are eager to figure out another method to formulate the experience of Hatsusaburo Yoshida.

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