RUBBER-SHEETING OF HISTORICAL MAPS IN GIS AND ITS APPLICATION TO LANDSCAPE VISUALIZATION OF OLD-TIME CITIES: FOCUSING ON TOKYO OF THE PAST

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Abstract: Historical maps are precious materials, which show spatial distribution of land use, streets and so on at the time the maps were produced. However, the imprecision, in the geometrical sense, of the historical maps makes the task of comparison very difficult. This drawback brings us to the idea of incorporating the historical maps into GIS after rubber-sheet transformation, i.e. geometric correction, of them. It makes possible comparing and overlaying multiple maps from different time periods. Furthermore, it gives map-scales to the historical maps, and it will make possible overlaying of present contour lines on the historical maps. As a result, we can bring the viewpoints of quantitative consideration and three-dimensional visualization into analysis of historical maps. This paper shows the outline of our procedures and some applications, e.g., overlaying different maps from *Edo* period to present, quantitative analysis of land use in *Edo*, and visualization of landscape of *Edo*.

Keywords: historical maps, rubber-sheet transformation, GIS, landscape visualization

1. INTRODUCTION

Historical maps are precious materials, which show various spatial distribution of land use, streets and so on of the historical importance at the time the maps were produced. They may be a dependable source of information regarding concepts of city planning of the past. In analysis of historical maps, the most practical method is to compare them with the present ones, for instance, by overlaying them. However, the low precision, in the geometrical sense, of the historical maps makes the task of comparison very difficult. So far, overlaying historical maps on present maps has been done basically by hand (Kodama, *et al.*, 1994). Such a method, however, has following drawbacks: (a) the work is not efficient; (b) original information on historical maps is lacking; (c) the method is not sometimes objective.

It is important to point out here that research on rubber sheeting, that is, geometric correction of maps for conflation of maps from different sources has recently made much progress. Using these procedures, geometric correction of historical maps should become possible. It will make easy comparing and overlaying multiple maps from different time periods. Furthermore, it will give map-scales to the historical maps, which are not in general represented on the old maps, and if we allow ourselves to ignore the changes in terrain from past to present, it will make possible overlaying of present contour lines on the historical maps. As a result, we can bring the points of view of quantitative consideration and three-dimensional visualization into analysis of historical map. The value of historical maps as historical materials will much increase.

We have addressed applied research on such an incorporation of historical maps into GIS. We performed rubber-sheeting of some maps produced in *Edo* period to present map coordinate system in Japan by using the piecewise geometric transformation based on TIN and planar affine transformation. (The *Edo* period ran between 1603 and 1868. *Edo* was also the old name of Tokyo.) Since then, we have carried out applications, e.g., overlaying different maps from *Edo* period to the present, quantitative analyses of land use, and visualization of landscape of *Edo*. This paper shows the rubber-sheeting procedure and some examples which make use of historical maps.

2. RUBBER-SHEET TRANSFORMATION OF HISTORICAL MAPS

The piecewise rubber sheeting based on TIN and planar affine transformation (White and Griffin, 1985; Saalfeld, 1985) has been very popular as a possible and effective map conflation technique (Doytsher, 2000). We applied this technique to the rubber sheeting of historical maps (Fuse, *et al.*, 1998; Shimizu, *et al.*, 1999). More recently its implementations have been reported by Niederoest (2002) and Balletti (2000).

The rubber sheeting process we used is as follows (Figure 1).

1. Identify control points on a historical map and a present one. The point geo-features which would have not moved from past to present are set as the control points, for instance, temples, shrines, parts of castles and so on.

2. Form a TIN over all the control points on the historical map and on the present one respectively. Check whether or not the relationship between both TINs is homeomorphic. If not, reform one or the other TIN by hand. With this, triangle pairs are created

3. Perform a planar affine transformation for each triangle pair.

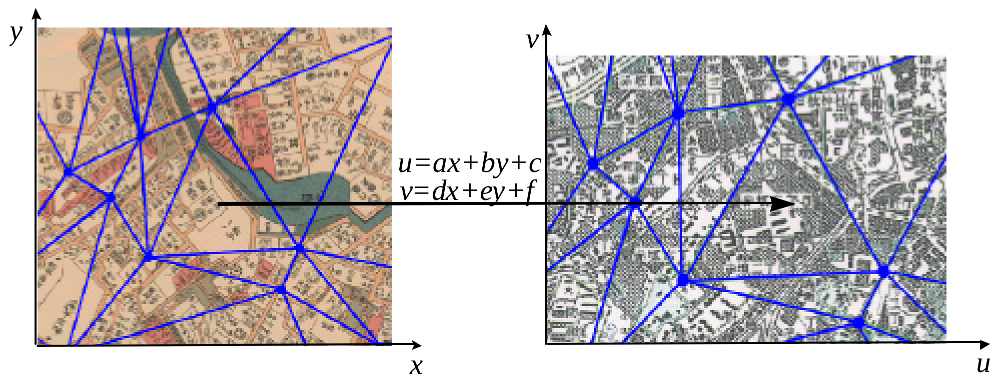


Figure 1 Piecewise Rubber Sheeting Based on TIN and Affine Transformation

The advantages of this method are summarized as follows.

1. The topological relationship between features on the historical map is maintained. This property is the most important one for the geometric correction of a map.

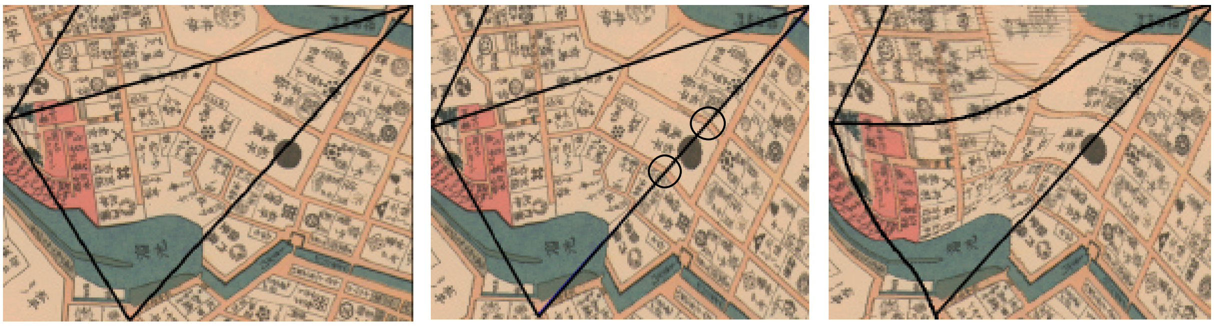
2. All control points are honored, that is, the control points on the historical map perfectly coincide with those of the present one. This property is important for easy comparison between the historical map and the present one.

Historical maps are not precise in the geometrical sense. To be more correct, historical maps are imprecise in the sense of relative positions of features. However, the straightness of objects such as road and moats may have been mapped with a fair degree of accuracy. If that is true, it is desirable to keep straightness of objects on the rubber sheeting of historical maps.

The affine transformation keeps linearity, and hence, straightness of streets and moats in a triangle is maintained. However linear objects across adjacent triangles may be bent. Figure 2 shows *Tameike* in *Minato* ward, Tokyo. A TIN was produced like in the Figure 2 (a). Figure 2 (b) shows the example that the street that would have been straight in Edo period undergoes bending.

When we want to maintain straightness of a street, we need to specify the ends of the street as control points. However to specify the ends of all streets as control points is not feasible. The piecewise linear rubber sheeting method cannot avoid this problem.

By the way, the piecewise nonlinear rubber sheeting algorithm has been suggested by Akima (1970) and Akima (1978). Instead of the affine transformation, this method employs the fifth order polynomial transformation with conditions such as continuity and smoothness of adjacent piecewise transformations. This method can avoid the sharp bending like a dogleg. However the linear features on the historical map are in general extremely distorted as shown in Figure 2 (c). We did not adopt this method because this characteristic is considered to be crucial in the sense that rubber sheeting extremely destroys primary or original information of a historical map.



(a) Original image (b) Affine transformation (c) Fifth-order polynomial transformation

Figure 2 Piecewise Linear and Non-Linear Transformation

3. APPLICATIONS

3.1 Comparison of Maps from Different Times

We performed rubber sheeting of the following maps from different times to the plane rectangular coordinate system of Tokyo.

(a) *Genroku-Edo-Zu* map (1693, *Edo* period)

(b) *Tenpou-Edo-Zu* map (1843, *Edo* period)

(c) *Jissoku-Tokyo-Zu* map (1892, *Meiji* period after *Edo* period)

Figure 3 shows the results together with some of the Tokyo GIS data at the areas surrounding *Tameike* in *Minato* ward, Tokyo. Japanese word *Tameike* means 'reservoir' in English. Actually, there was large natural reservoir around there in *Edo* period as shown in Figure 3 (a) and (b). *Tameike* was filled in, around 1880. The maps from different times show us visually the history of urban developments.

(a) *Genroku-Edo-Zu* map (1693)

(b) *Tenpou-Edo-Zu* map (1843)

(c) *Jissoku-Tokyo-Zu* map (1892)

(d) Tokyo GIS data

Figure 3 Historical Maps from Different Times

3.2 Analysis of Relationship between Land Use and Topography

There are no contour lines on the age-old maps produced in *Edo* period in Japan. The technique to represent landforms with contours was introduced into Japan in the early 1870s (after *Edo* period). We generated the contour lines by using point data of elevation in the Tokyo GIS data and overlaid them on the historical maps.

As an example, Figure 4 shows the geometrically corrected *Ban'en-Edo-Zu* map (1860), overlaid with five-meter-interval contour lines. This area is *Otowa* in *Bunkyo* ward, Tokyo. With such an implementation, we can consider the relationship between land use and topography in *Edo* period. For instance, we can see that *Edo* government would have developed major streets by making use of gentle slope along the ridge line and drainage line. Also, Figure 4 shows that *daimyos* (feudal lords) had their residences, which were large land lots in the north of *Kanda-gawa* river, at good environmental slope which faces south.

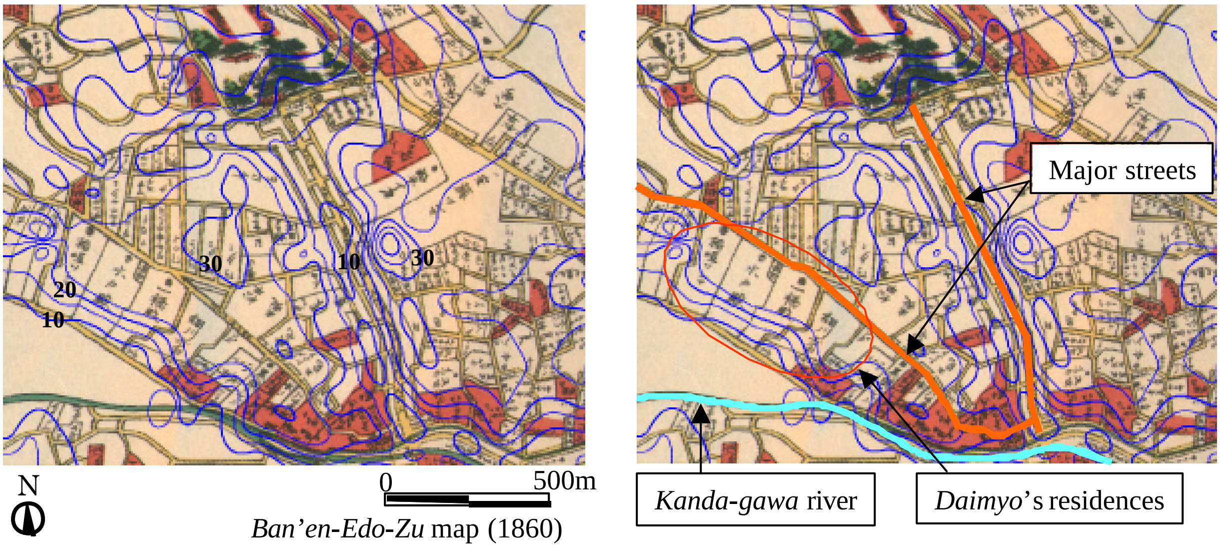


Figure 4 Overlay of Contours on Historical Map

We can read seven types of land use from *Ban'en-Edo-Zu* map; (1) *daimyo* (feudal lords), (2) *hatamoto* (direct retainers of the Shogun), (3) *kumi* (firemen), (4) *chonin* (commoners such as retailers and artisans), (5) temples and shrines, (6) streets, and (7) rivers. Figure 5 shows land use map of the same area as Figure 4 in 1860, which was produced by hand digitizing of lot boundaries. Using this data, quantitative analysis of relationships between land use and elevation becomes much easier. Over the whole Bunkyo ward we computed area ratio by elevation for each land use (Figure 6). We thought that higher rank people's residences such as *daimyo* and *hatamoto* were located on higher land than those of the lower rank people such as *kumi* and *chonin*. However, as far as *Bunkyo* ward is concerned, the remarkable difference was not found.

3.3 Reproduction of Bird's-Eye View of *Edo* City

We can produce the bird's-eye view of *Edo* city by relating historical maps with the digital elevation model. Figure 7 shows such an example; the bird's-eye view of *Edo* using *Tenpou-Edo-Zu* map (1843). At the end of *Edo* period, *Edo* city was a huge, sprawling city with over one million inhabitants. We can get a feeling of the extensiveness and variety of land terrain of *Edo* city. The area which is spread between the *Edo* castle and *Edo* bay was reclaimed at the beginning of *Edo* period. We can see some canals in the plain spread in the right side of the figure, which were developed for shipping and reclamation of water front.

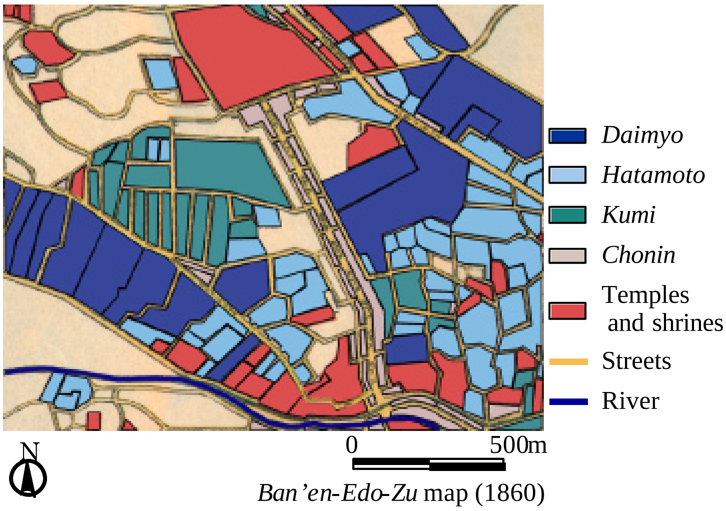


Figure 5 Land Use Map in 1860

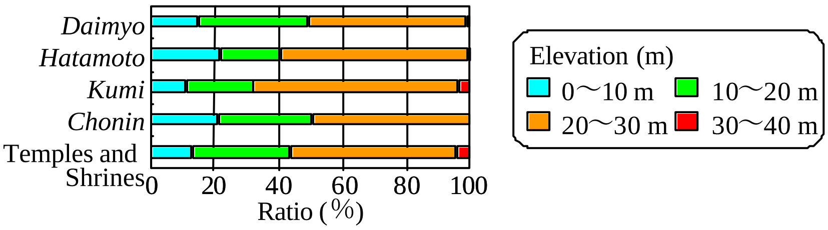


Figure 6 Land Use Area Ratio by Elevation

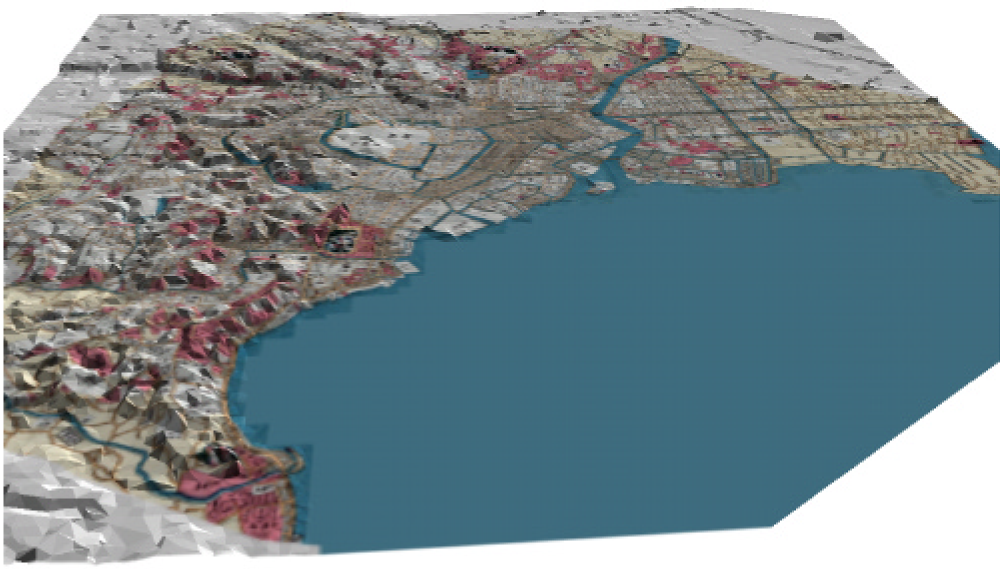
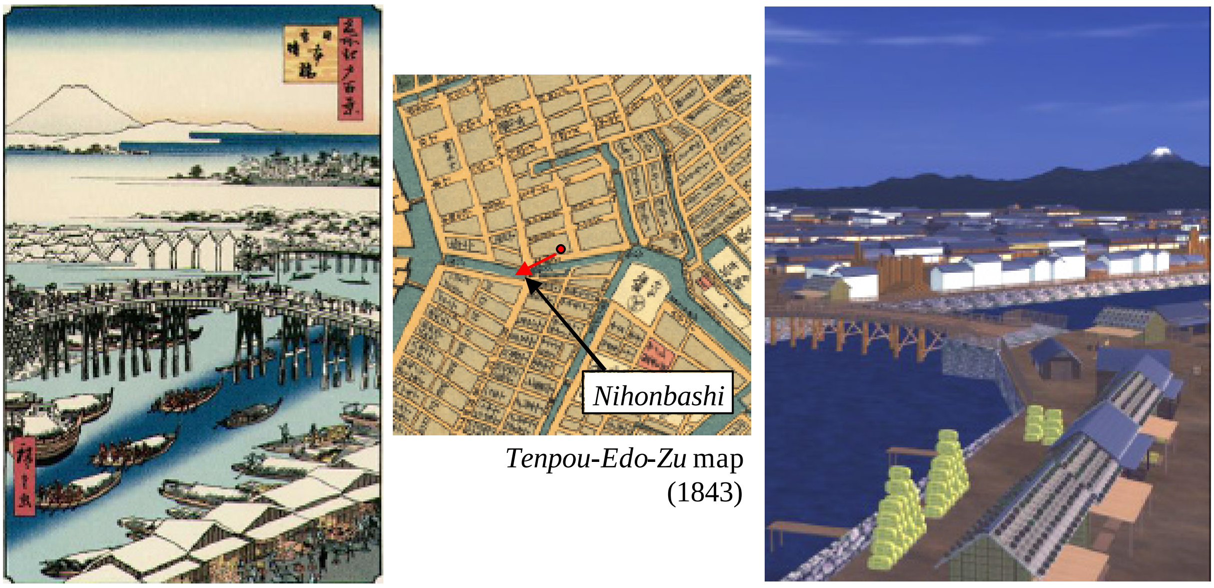


Figure 7 Bird's-Eye View of *Edo* City (1843)

3.4 Reproduction of Landscape of *Edo* City

Since we can treat terrain data with historical maps and we can read land use from the historical maps, if we prepare CG contents corresponding to each land use, we can roughly visualize the landscape of *Edo* from any viewpoints. In addition, we can involve the distant view of mountains by integrating DEM data that are prepared in the extensive area including the area covered by the historical map. The 50-meter DEM data, which was produced by the Geographical Survey Institute, are available all over the country in Japan.

Ukiyo-e (Japanese wood block print) artists created a lot of prints of landscapes of *Edo*. Among them, *Ando Hiroshige* (1797-1858), also known as *Utagawa Hiroshige*, is one of the most famous landscape artists. *Hiroshige's* work, along with *Katsushika Hokusai's*, greatly influenced Western art. We attempted to reproduce the landscape depicted by *Hiroshige's* prints. Figure 8 (a) shows his famous print titled *Nihonbashi-Yukibare* (Nihonbashi, Clearing After Snow) from his series called *Edo Meisho Hyakkei* (One Hundred Famous Views of Edo). *Nihonbashi* ('Japan bridge' in English) area was the center of *Edo*. The fish market was located there, along with storehouses, and it was a great symbol of plenty and wealth for the *Edo* Shogunate. Figure 8 (b) shows the reproduction of landscape depicted by *Nihonbashi-Yukibare*. We can imagine that *Hiroshige* would have deformed the composition (relative positions) of *Nihonbashi*, *Edo* castle and *Mt. Fuji* surely in order to include these three famous views in/from *Edo* in a sheet print.



Tenpou-Edo-Zu map (1843)

(a) Nihonbashi-Yukibare

(b) Reproduction of landscape

Figure 8 Reproduction of Landscape Depicted by *Hiroshige's Ukiyo-e*

Our ultimate goal is to reproduce landscape in *Edo* from any viewpoint and any direction and to explore the past concepts of city planning and urban developments, which we may have forgotten in the developments of Tokyo placing too much emphasis on economic efficiency. Figure 9 shows a view from *Edobashi* (*Edo* bridge) toward *Nihonbashi*. This view was not depicted by any *Ukiyo-e*. Needless to say, we cannot now have a view of *Mt. Fuji.*

4. CONCLUDING REMARKS

The most remarkable characteristic of GIS is that it combines a wide variety of geographic data by relating them with a common coordinate system. Age-old historical maps, as well as present maps and geo-information, can be important elements of GIS if they are geometrically corrected to the present coordinate system.

Any region is today exposed to inter-regional competition in various senses. In city planning and developments, a region is required to place more emphasis on its specific characteristics. The landscape made by the topography of a region would be the most characteristic features

Tenpou-Edo-Zu map
(1843)

Figure 9 Reproduction of Landscape not Depicted by *Ukiyo-e*

that distinguish the region from others. Historical maps that have been preserved in a region should become important sources in order to find the precious characteristics of the region. Historical maps will be inevitable geo-information in GIS, especially in the GIS that aims to assist with city planning and developments.

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