Watermark Embedded in Polygonal Line for Copyright Protection of Contour Map

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Summary
In GIS system, we often use vector contour map to show or locate position on the earth. Since such map data is very worthy of value, it is necessary and important to protect its copyright. In this paper, we propose a new method to embed watermark into the angle parameter of polygonal lines or curves in a contour map after its parameterization. The watermark can be detected as proof of the ownership or authority of the map by hypothesis test.
Key words:
Digital watermark, Contour map, Polygonal line, Parameterized circle, Hypothesis test

1. Introduction

With the development of GIS system and Digital Earth, digital contour map found wide applications to show or locate position on the earth in the system. Such map data is very worthy of value because it is difficult or expensive to collect the information. Furthermore, such digital map is often military confidential information needed to be strongly protected and be traceable of the source. Digital watermark is a possible approach to be applied to those aims. A watermark is hidden information within a digital signal, used primarily for copyright protection of important data of government, military, intelligence, and commerce. For example, traceability of watermark can be provided through invisibly embedding a unique ID or a logo image, referred to as a digital fingerprint, to each copy of a map before distributing to users [1], [2]. Its imperceptibility of the imposed modifications and its persistence against processing (attacks) may result in its removal, either intentionally or unintentionally. Cox et al [1] provides an excellent overview of the watermarking principles and techniques.

There are two kinds of map -- raster map and vector map. Since the raster map is an image with pixels as the basic component, most of digital watermark algorithm developed for digital images can be applied to raster digital maps. There already has been much research work on image watermark algorithm based on image processing or signal processing. Compared with raster map, vector maps are consist of a set of geometric primitives, i.e. points, polygonal lines, curves, and so on. It is characterized by little data and high precision, and also is fit for scaling and rotation without loss of quality. Despite of the importance of protecting vector maps in many applications, little research work has been done in watermarking vector graphics data. The specialties of vector data also make it more difficult to embed watermark data into the maps.

Ohbuchi [3] proposed a method, which divides an image into a set of rectangular area in which the density of vertices is even, watermark is embedded by displacing an average of coordinates of a set of vertices in these areas. It belongs to the spatial domain algorithm. Solachidis et al [4], [5] proposed method for embedding the watermark in the Fourier descriptor of the polygonal lines, causing invisible distortions to the vertices coordinates. Ohbuchi [6] also presented method to embed copyright marks into spectral analysis of mesh models with high complexity. These two belong to the transform domain algorithm.

In this paper, we present a method to embed watermark into polygonal lines, which are key graphics primitive in vector graphics data. We adopt detection by binary hypothesis based on likelihood function.

The paper is organized as follows: Embedding and detection algorithm are discussed respectively in Section 2 and 3. Section 4 simply demonstrates the experimental results of our method before and after watermark embedding. Finally, conclusions are drawn in Section 5.

2. Embedding Algorithm

Solachidis [5] constructed complex signals with Cartesian coordinates of each vertex for the following Fourier transform, and embedded watermark data into the Fourier descriptor magnitude. We will present a new method to embed watermark in this section.

2.1 Parameterize Polygonal Line to a Circle

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Let L be a closed polygonal line that consists of N vertices P_k, k = 0, 1, …, N-1. We will construct a circle which is topological same with the polygonal line. Also the circumference of the circle $cir(L)$ equals to the total length $len(L)$ of the polygonal line, i.e.

$$len(\overline{P_1P_2}) = len(\widehat{P'_1P'_2}). \qquad (1)$$

as shown in Fig. 1. So the radius of the circle r is

$$r = cir(L)/2\pi = len(L)/2\pi . \qquad (2)$$

Each vertex of polygonal line is mapped to its image point on the circle by vector $\overrightarrow{P_kP'_k}$, k = 0, 1, …, N-1. The set of vectors $\{\overrightarrow{P_kP'_k} \mid k = 0, 1, \ldots, N-1\}$ will be used for reverse mapping after watermark embedding. And the vertices on the circle are naturally parameterized into polar coordinates as $P'_k\ (r, \theta_k)$. The digital watermark data would be embedded on the parameter $\{\theta_k \mid k = 0,1,\ldots,N-1\}$ discussed in the following.

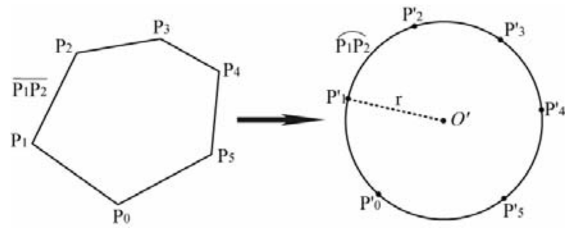


Fig. 1 Construct parameterized circle

2.2 Watermark Construction and Embedding

Using a pseudorandom generator, we create a bi-valued ±1 random sequence and use it to produce a watermark. A bi-valued ±1 random sequence has zero mean value and unit variance, and thus we construct the watermark W as $\{w_k \mid k = 1,2, \ldots, N-1; w_k = \pm 1\}$.

Let $\Delta\theta_k$ represents $\angle P'_kO'P'_{k-1}$, O' is the center of the circle, then

$$\Delta\theta_k = \theta_k - \theta_{k-1} \quad , \quad (k = 1,2,\ldots,N-1) . \qquad (3)$$

The watermark data is embedded as:

$$\Delta\theta'_k = \Delta\theta_k \cdot (1 + \alpha w_k) , \quad (k = 1,2,\ldots,N-1) . \qquad (4)$$

where α is the factor to control embedding strength of the watermarking. In order to keep $cir(L)$ unchanged, we don't change $\Delta\theta_0$ with $w_0 = 0$, i.e. $\Delta\theta'_0 = \Delta\theta_0$. It can be easily yielded that:

$$\sum_{k=0}^{N-1} \Delta\theta'_k = \sum_{k=0}^{N-1} \Delta\theta_k = 2\pi \quad . \qquad (5)$$

This means the circumference length of the circle is same as that before watermark embedding, as well the total length of polygonal line $len(L)$, but the length of each segment of the line is changed. After the embedding step, we can do reverse transform with reference of the set of vectors $\{\overrightarrow{P_kP'_k}\}$ recorded before.

3. Watermark Detection Algorithm

Since we keep the total length of the polygonal line during the watermark embedding, our method can resist geometric attacks the algorithm is robust to several geometrical transformations, as well as to their combinations [1]. These transformations are:

(i) *Translation* of the line L (by a quantity Dx on the x-axis and Dy on the y-axis) affects only the location of the line, nothing to the total length and position on the circle.
(ii) *Rotation* of L by an angle θ around the center of the gravity results in rotation of the circle without any change to the total length and relative position of the points on the circle.
(iii) *Scaling* of L by a factor s leads to scaling of the total length of L, as well as the radius r of the circle, but the angle between each two neighbor points on the circle doesn't change.
(iv) *Changing* the starting vertex for traversing the closed polygonal line won't results in any change of the total length and relative position.
(v) *Mirroring* L causes mirroring of the parameterized circle, but nothing to the angles.
(vi) *Inversion* of the traversal direction of the line causes mirroring of the coordinates of the line.

3.1 Binary Hypothesis Test Based on Likelihood Ratio Test

The detection algorithm is based on the Bayes decision theory, and the subsequent likelihood ratio test (LRT). As it was described in [7], for the observed polygonal map data, the watermark detector is constructed to verify whether it hosts a certain watermark W or not. The watermark detection can be expressed as a hypothesis test:

H_0: The polygonal line does not host watermark W, the probability density function (pdf) is $p(\Delta\theta''_k|H_0)$

H_1: The polygonal line hosts watermark W, the pdf is $p(\Delta\theta''_k|H_1)$

We suppose that the pdf of each $\Delta\theta''_k$ is random variable and follows Rayleigh distribution. LRT in this case can be defined as:

$$T_{LRT} = \frac{p(\Delta\theta'' \mid H_0)}{p(\Delta\theta'' \mid H_1)}, \quad (k = 1,2,\ldots,N-1). \tag{6}$$

If each element of the vector -- $\Delta\theta''_k$ is assumed to be independent, the LRT has the following form:

$$T_{LRT} = \frac{\prod_{k=0}^{N-1} p(\Delta\theta''_k \mid H_0)}{\prod_{k=0}^{N-1} p(\Delta\theta''_k \mid H_1)} \ . \tag{7}$$

For hypothesis test H_0, there are no watermark data at all,

$$p(\Delta\theta''_k|H_0) = p(\Delta\theta_k) \ . \tag{8}$$

and for H_1,

$$p(\Delta\theta''_k \mid H_1) = p(\Delta\theta'_k)/(1+\alpha) \ . \tag{9}$$

By substituting the Eq. (8) and Eq. (9) in Eq. (7), we can calculate the T_{LRT}. For a given threshold λ, if $T_{\mathrm{LRT}} > \lambda$, we accept H_1; otherwise, we reject it.

The watermark detection performance can be measured in terms of the probability of false alarm P_{fa} (i.e. the probability to detect a watermark in a signal that is not watermarked or, is watermarked with a different watermark) and the probability of false rejection P_{fr} (i.e. probability of erroneously neglecting the watermark existence in the signal). ROC curve is often used for this purpose with different thresholds λ.

3.2 Probability Density Function of the Angles

For Eq. (8) and Eq. (9), the probability density function (pdf) of the angles must be decided at first. From the experiments, it is reasonable to assume that the angles follow Rayleigh distribution in [8] as Eq. (10).

$$p(\Delta\theta_k) = \frac{\Delta\theta_k}{\sigma_k^2}\exp\left(-\frac{\Delta\theta_k^2}{2\sigma_k^2}\right). \tag{10}$$

where σ_k^2 is the variance. Mean and variance could be estimated as the way discussed in [7] with reference in detail.

4. Experimental Result and Analysis

4.1 Watermark Embedding Result

In order to verify the watermark embedding and detection algorithm, different tests were performed over several sample polygons. Among these polygons, there was the shape of an area obtained from GIS data (Fig. 2). In the

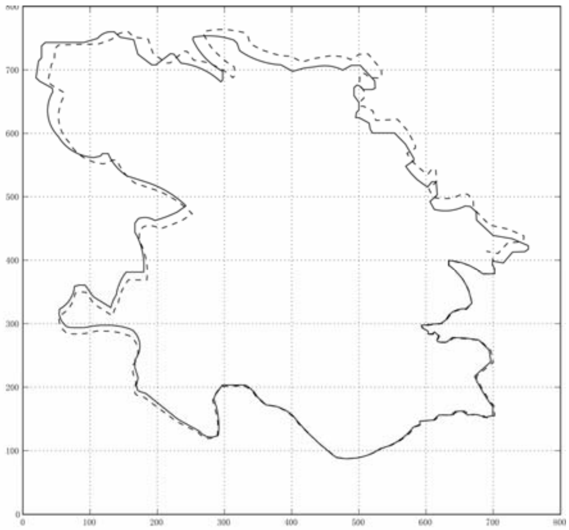


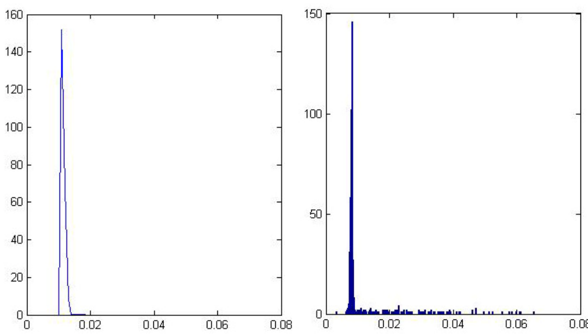
Fig. 2 polygonal line in contour map
solid line – original line; dash line – watermarked line

performed tests, an embedding strength factor $\alpha = 0.04$ was used. We also set one vertex is unmoved to simplify the resolving process without any loss of accuracy.

Comparing with the experiment result in [5], our algorithm keeps the total length of the line unaltered during watermark embedding, thus the distortion of the polygonal line introduced by watermark is more less than [5].

4.2 Probability Density Function

After parameterizing the polygonal line into a circle according to Eq. (2), we investigated the pdf function of the angel array $\{\Delta\theta_k\}$, and compared with Rayleigh distribution function, shown in Fig. 3. It is reasonably to assume that the pdf of $\{\Delta\theta_k\}$ follows Rayleigh distribute function.



(a) (b)

Fig. 3 Probability density function of $\Delta\theta$
(a) Rayleigh function, with $\sigma = 0.001$, scaled by 0.25
(b) Statistic histogram of $\Delta\theta$

4.3 Receiver Operating Characteristic

False alarm P_{fa} and false rejection P_{fr} are the two specifications used to evaluate the watermark detection performance. We can evaluate the Receiver Operating Characteristic (ROC) curve by values of P_{fa} and P_{fr}, i.e. plot the graph of the probability of P_{fa} versus P_{fr} probability of for different thresholds λ.

To estimate P_{fa} and P_{fr} is really a difficult work. Such work actually involves counting the number of errors (false alarm and false rejection) after a large amount of experiments for different thresholds λ.

Watermarked and not watermarked polygonal lines were estimated through a set of experiments performed on several contour maps, each involving 10000 trials. Polygonal line maps consisted of a number of vertices between 400 and 5000. The ROC curves for the test polygons shown in Fig. 4. There is also a ROC curve by correlation-based watermark detection method for different thresholds λ. As we know, the correlation based method is good for additive watermark embedding algorithm, and we embedded watermark using multiplicative algorithm as Eq. (4) previously. It is obviously that likelihood based detection method is better than correlation based one from fig. 4.

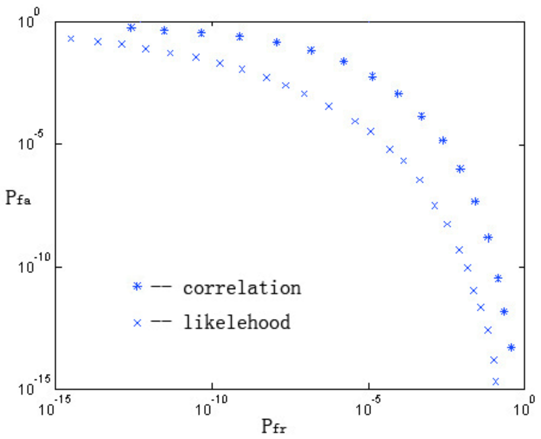


Fig. 4 ROC curves for different λ.

5. Conclusion

In this paper we proposed a new method for watermarking polygonal lines. This algorithm can be applied in GIS data or contour maps. It also fits for other kind of vector graphics composed of polygonal lines. Since we embed watermark data by multiply operation, we adopt the hypothesis test detection algorithm based on likelihood ratio test, instead of correlation based algorithm. Due to its geometric naturality, it can resist common geometric transform (attacks).

The lack of the algorithm currently is not robust enough to the vertex removal (polygonal line simplification) or addition operation. If original data are involved in, such problem is more easily to be solved, but it must greatly weaken the security of the original data. Future work will try to deal with this shortcut.

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