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A Watermarking Scheme for Shapefile-Based GIS Digital Map Using Polyline Perimeter Distribution

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ABSTRACT

This paper proposes a robust watermarking scheme for GIS digital map by using the geometric properties of polyline and polygon, which are the fundamental components in vector data structure. In the proposed scheme, we calculate the lengths and th perimeters of all polylines and polygons in a map and cluster them to a number of groups. Then we embed the binary watermark by changing the mean of lengths and perimeters in an embedding group. For improving the safety and robustness, we permute the binary watermark through PRNS(pseudo-random number sequence) processing and embed it repeatedly in a model. Experimental results verified that our scheme has a good invisibility, safety and robustness to various geometric attacks and also our scheme needs not the original map in the extracting process of watermark.

Key words: GIS Map, Vector Data, Shapfile, Length, Perimeter, Polyline, Polygon

1. INTRODUCTION

GIS (Geographic Information System) is a computer based information system used to digitally represent and analyze the geographic features that present on the Earth surface and the events, which are non-spatial attributes linked to the geography under study. GIS digital maps can be classified into raster-digital map or vector-digital map.

A raster digital map represents a map as raster image data by 2D array of pixels. A vector digital map employs geometrical primitives such as points, lines, and polygons to represent objects, such as building outlines, roads, rivers, and contour lines. But a GIS digital map is easy to be updated, duplicated, and distributed by any user. Therefore it must be protected by any scheme. Digital watermarking is a core technology and an effective method to counter such abuses. Most of image watermarking schemes can be applied to the raster digital maps. In a vector digital map, geometric connectivity among objects and vertex coordinates are specified explicitly and also distances between vertices are irregular. Consequently, general techniques such as Fourier or Wavelet-based image watermarking schemes can not be applied readily. For solving these difficulties, some researchers presented GIS vector map watermarking schemes [1-6].

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This paper presents an invisible blind and robust watermarking scheme for the copyright protection of GIS vector digital map by using the polyline and polygon geometric characteristics. The proposed scheme is based on the polyline/polygon type data of ESRI shapefile, which is a popular geo-spatial vector data format for GIS. In our scheme, we calculate the length and perimeter of all polylines and polygons in a map and cluster polylines and polygons to some groups by using the uniform step of length and perimeter dynamic range. And we generate the watermark message from PRNS (pseudo-random number sequence) for improving the security. Then we embed the generated watermark bits by changing local means of lengths or perimeters in the selected groups. For getting more the robustness, the watermark bits can be embedded repeatedly in a map. The watermark key, such as PRNS, is needed for the watermark extracting. From experimental results, we confirmed that the watermark cannot be observed perceptually and also it is not damaged or detected and it is robust against geometric attacks like as translation, rotation, random noise, insert and delete vertex, scrambling of order of geometric primitives in a data file, and cropping.

2. SHAPEFILE BASED GIS DATA

2.1 GIS data

GIS data consists of spatial data and attribute components. In spatial component, the observations have two aspects in its localization: absolute localization based in a coordinates system and topological relationship referred to other observations. A GIS can manage both of them but computer assisted cartography packages only manage the absolute one [7]. In attribute components, the variables or attributes can be studied considering the thematic aspect (statistics), the locational aspect (spatial analysis) or both. For example, a polygon represents a lake but the attribute of the lake may contain perimeter, area, depth of the lak or water quality and pollution level.

Spatial data includes two data types of raster data and vector data. A raster type data uses a set of cells located by coordinate; each cell is independently addressed with the value of an attribute. Each cell contains a single value and all locations that corresponds to a cell. One set of cells and an associated value indicates a LAYER. Raster models are simple with which spatial analysis is easier and faster. But a raster data model requires a huge volume of data to be stored and the fitness of data is limited by the size of cell and the output is less beautiful [8]. A vector type data is defined by the vectorial representation of geographic data. In vector data, the basic units of spatial information are point, polyline and polygon. Each of these units is composed simply as a series of one or more coordinate points. For example, a polyline is a collection of related points, and a polygon is a collection of related lines. Figure 1 shows vector and raster data representation of the real world phenomena.

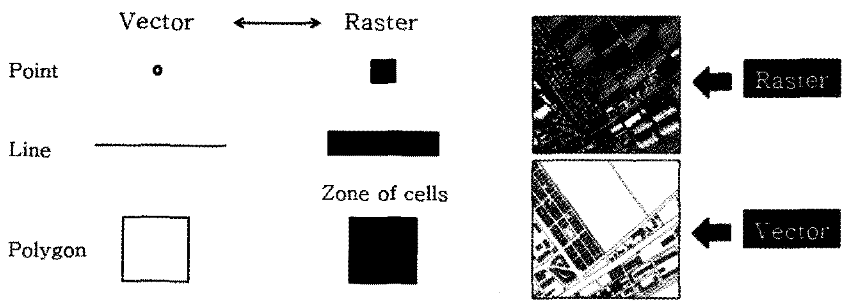


Fig. 1. Vector and Raster data that represent Real World Map.

2.2 Shapefile Format

The shapefile [9] is a popular geo-spatial vector data format for GIS software, which is developed and regulated Environmental Systems Research Institute (ESRI) as a open specification for data interoperability among ESRI and other software products. It consists of a main file, an index file, and a dBASE table. The main file is a direct access and variable record length file, in which each record describes a shape object with a list of its vectors. In the index file, each record contains the offset of the corresponding main file record from the beginning of the main file. The dBASE table contains feature attributes with on record per feature. The one-to-one relationship between geometry and attributes is based on record number. Attribute records in the dBASE file must be in the same order as records in the main file.

Because the shapfile does not have the processing overhead of a topological data structure, it has advantages over other data sources such as faster drawing speed and edit ability. The shapfile handles single features that overlap or that are noncontiguous. Also it typically requires less disk space and are easier to read and write. And there is so many softwares that support shapefile format, such as ARC/INFO, PC ARC/INFO, Spatial Database Engine (SDE), ArcViewGIS and Business Map. In this paper, we choose the shapefile format to handle the watermark embedding for digital vector map. We can directly create or modify shapefile by creating a program according to the shapefile specifications. GIS data structure can be easily converted to different formats. The proposed scheme is based on ESRI shape file which is a popular geospatial vector data format for GIS map. Here, we use the polyline/polygon type data of ESRI shape file.

3. PROPOSED WATERMARKING SCHEME

This paper presents a watermarking scheme for GIS vector map by using the mean length and perimeter of polylines and polygons in GIS vector map. The proposed scheme clusters all of polylines and polygons into N_W groups according to their lengths and perimeters and then embeds the binary watermark into the selected groups. The process of watermark embedding and extracting is shown in figure 2. The length and perimeter is robust to rotation and translation. But it can be changed by the scaling, of course. Therefore, we need to store the average of all lengths and perimeters for extracting the scaled map.

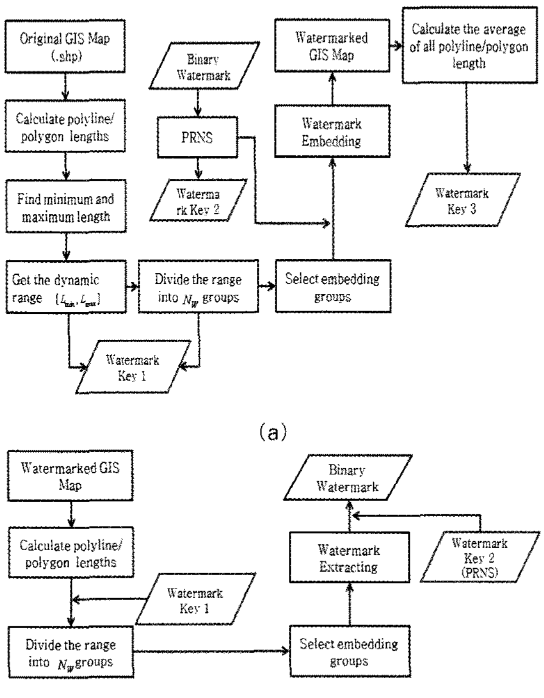


Fig. 2. The process of watermark (a) embedding and (b) extracting.

3.1 Watermark Embedding

A polyline consists of two or more vertices whose the first and last vertices are not equal. Whereas, a polygon consists of above four vertices whose the first and last vertices are equal, which is so-called as a closed polyline. Figure 3 shows examples of the polyline and polygon in a GIS data.

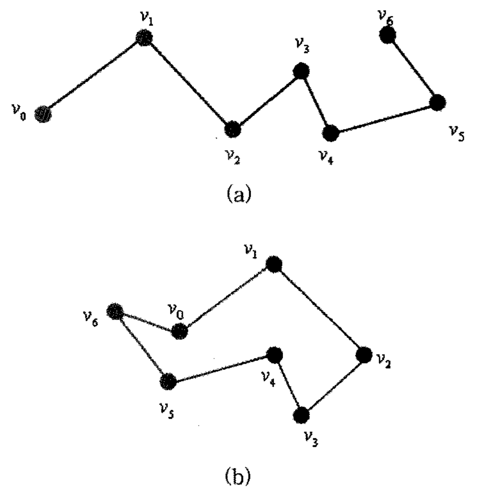


Fig. 3. Examples of (a) a polyline and (b) a polygon.

Firstly, we obtain lengths L_i of all polylines $PL_i = \{v_{ik} | k \in [1, N_i], v_{i1} \neq v_{iN_i}\}$ or perimeter L_i of all polygons $PG_i = \{v_{ik} | k \in [1, N_i], v_{i1} = v_{iN_i}\}$. The polyline length and the polygon perimeter are calculated by using the following simple equation.

$$L_i = \Sigma \| \overrightarrow{v_{ik} v_{ik+1}} \| \tag{1}$$

Then, we divide the dynamic range $[L_{\min}, L_{\max}]$ into N_W sections by using the uniform interval $\Delta = (L_{\max} - L_{\min})/N_W$. $L_{\min}$ and $L_{\max}$ are the minimum value and the maximum value among all of polyline lengths and polygon perimeters. All polylines and polygons are allocated to any section by using their lengths and perimeters. Figure 4 shows N_W sections that are divided by the uniform interval.

From this process, we get N_W groups R= $\{R_i | i \in [1, N_W]\}$ of polylines and polygons.

$$R_i = \left\{ \begin{matrix} PL_{i,j}, PG_{i,j} | \\ L_{\min} + (i-1)\Delta \le L_{ij} < L_{\min} + i\Delta, j \in [1, N_i] \end{matrix} \right\} \tag{2}$$

R_i is ith. group that includes polylines $PL_{i,j}$ and polygons $PG_{i,j}$ with the length and perimeter L_{ij} in the range $[L_{\min} + (i-1)\Delta, L_{\min} + i\Delta]$. N_i is the number of polylines and polygon that are allocated to this group. Some groups may not include polylines and polygons because of the clustering with the uniform step size. The watermark must not be embedded into groups that do not include polylines and polygons or include a few of polylines and polygons. For considering the safety and robustness, we select groups that include ten or more allocated polylines and polygons as the embedding target. The available bits of watermark is the same as the number of usable groups L_w. But the proposed scheme embed the watermark message of $M \le L_W$ bits repeatedly. The more repeat times, the more robustness but less watermark message. When the number of the repeat times is C, the length of watermark message is $M = L_W/(8 \times C)$. C is determined by considering both the length of watermark message and the robustness. We obtain the watermark message with the limit length M and convert it to bit-stream, $B = \{b_i \in \{0,1\} | i \in [1, L_w]\}$ and generate the final binary watermark $W = \{w_i \in \{0,1\} | i \in [1, L_w]\}$, $w_i = b_i \odot p_j$, ($i \in [1, L_w]$, $j = i \% L_{PRNS}$) from the bit-stream and pseudo-random number sequence (PRNS) $p_i (p_i \in \{0,1\}, i \in [1, L_{PRNS}])$. The PRNS length L_{PRNS} is within the range of [1, L_w].

Each of watermark bits $w_i \in \{0,1\} (i \in [1, L_w])$ is embedded by changing the mean length/perimeter

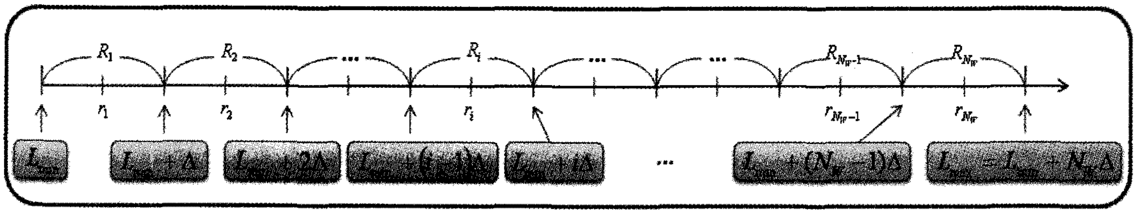


Fig. 4. N_W sections of the dynamic range for clustering polyline lengths and polygon perimeters.

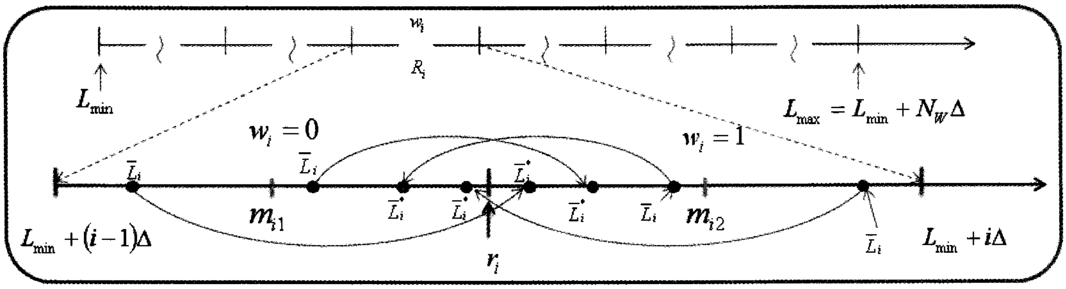


Fig. 5. Embedding a watermark bit w_i by changing the mean length $\overline{L_i}$ in a group R_i

$\overline{L_i} = \Sigma L_{ij}/N_i$ on the reference of the center value $r_i = L_{\min} + (i-1/2)\Delta$ of R_i group. If $w_i = 0$, then $\overline{L_i}$ will be moved to be less than the center value r_i. Otherwise, $\overline{L_i}$ will be moved to be greater than the center value r_i. Thus, we move $\overline{L_i}$ to $\overline{L_i}^*$ for satisfying the following embedding condition.

$$\overline{L_i}^* = \begin{cases} L_{\min} + (i-1)\Delta \le \overline{L_i}^* < r_i, & \text{if } w_i = 0 \\ r_i \le \overline{L_i}^* < L_{\min} + i\Delta, & \text{if } w_i = 1 \end{cases} \tag{3}$$

If $\overline{L_i}$ in a group R_i is within the specified range satisfying the embedding condition, it should be not changed. Otherwise, $\overline{L_i}$ should be changed for satisfying the above condition as well as the invisibility condition considering the distance between $\overline{L_i}$ and r_i, as shown in figure 5. The watermarked length $\overline{L_i}^*$ will be as follows.

If $w_i = 0$,

$$\overline{L_i}^* = \begin{cases} r_i - \dfrac{m_{i2} - \overline{L_i}}{2}, & \text{if } \overline{L_i} \in [r_i, m_{i2}) \\ r_i - \dfrac{(L_{\min} + i\Delta) - \overline{L_i}}{4}, & \text{if } \overline{L_i} \in [m_{i2}, L_{\min} + i\Delta) \end{cases} \tag{4}$$

If $w_i = 1$,

$$\overline{L_i}^* = \begin{cases} r_i + \dfrac{\overline{L_i} - (L_{\min} + (i-1)\Delta)}{4}, & \text{if } \overline{L_i} \in [L_{\min} + (i-1)\Delta, m_{i1}) \\ r_i + \dfrac{\overline{L_i} - m_{i1}}{2}, & \text{if } \overline{L_i} \in [m_{i1}, r_i) \end{cases} \tag{5}$$

In the above equation, m_{i1} and m_{i2} are the median of the range $[L_{\min} + (i-1)\Delta, r_i]$ and $[r_i, L_{\min} + i\Delta]$ respectively.

$$m_{i1} = L_{\min} + (i-3/4)\Delta \tag{6}$$
$$m_{i2} = L_{\min} + (i-1/4)\Delta \tag{7}$$

For calculating the watermarked length and perimeter $\overline{L_i}^*$ in equation (5), the vertex coordinates in polylines $PL_{i,j} = \{v_{ij,k} | k \in [1, N_{lij}]\}$ or polygon $PG_{i,j} = \{v_{ij,k} | k \in [1, N_{gij}]\}$ that are allocated in a group R_i. The watermarked vertices $v^*_{ij,k}$ can be obtained by controlling the change rate α_i as follows.

$$v^*_{ij,k} = \alpha_i v_{ij,k} + v_{ij,1}(1-\alpha_i), \quad \forall k \in [2, N_{lij}] \text{ or } \forall k \in [2, N_{gi,j}] \quad \text{where } \alpha_i = \overline{L_i}^* / \overline{L_i} \tag{8}$$

$v_{ij,1}$ is the first vertex in a polyline and polygon. By the above process, we change all vertices of polylines and polygons in each group according to the embedding condition. After embedding the watermarks, we calculate the mean length $\overline{L}^*$ of all polylines PL_i or the mean perimeter of all polygons PG_i in the watermarked map and store $\overline{L}^*$ for the watermark extracting in scaled map.

3.2 Watermark Extracting

The watermark extracting can be performed by using the keys stored in the embedding process, as shown in figure 2(b). The extracting process is similar as the embedding process. Firstly, we calculate the lengths and perimeters $\overline{L_i}'$ of all polylines and polygons in a watermarked map.

$$L_i' = \Sigma \| \overrightarrow{v_{ik}'v_{ik+1}'} \| \qquad (9)$$

Then we divide the range of $\overline{L_i}'$ by using the dynamic range $[L_{\min}, L_{\max}]$ and the group number N_W, which are stored in the embedding process, and cluster all polylines and polygons to N_W groups and obtain the mean length and perimeter $\overline{L_i}'$ of R_i usable groups in a watermarked map. Since the range $[L_{\min}, L_{\max}]$ and the group number N_W are not changed, the center value r_i' of R_i group in watermarked map should be r_i. A watermark bit w_i' can be extracted by comparing the mean length and perimeter $\overline{L_i}'$ and the center value r_i of any R_i usable group.

$$w_i' = \begin{cases} 0, \text{if } L_{\min} + (i-1)\Delta \le \overline{L_i}' < r_i \\ 1, \text{if } r_i \le \overline{L_i}' < L_{\min} + i\Delta \end{cases} \qquad (10)$$

After extracting watermark bits sequence $W' = \{w_i' | i \in [1, L_W]\}$, we decrypt it by using PRNS. Thus, the decrypted bits will be got by $b_i' = \overline{w_i' \oplus p_j}(i \in [1, L_w], j = i\%L_{PRNS})$. We can judge whether a pirated map is copied or not by BER(bit error rate) measure of W' and W.

4. EXPERIMENTAL RESULTS AND ANALYSIS

We evaluated the invisibility and robustness of the proposed watermarking technique by using 10 maps (5 polyline maps and 5 polygon maps) of Masan area that are ERSI shapefile format [9]. As stated on part III, we divided all polylines and polygons of test maps into a number of groups according to their lengths and selected usable groups that has ten or more polylines and polygons. Since numbers of polylines and polygons in test maps are all different, the number of groups and the watermark length are different on test maps. Table 1 shows the number of groups, the watermark length and vertex PSNR.

4.1 Invisibility

We used vertex PSNR (peak signal-to-noise ratio) similar as pixel-by-pixel PSNR of the image. The vertex PSNR is defined by

$$PSNR[dB] = 20\log_{10}\left(\frac{MAX(v_{x,y})}{RMSE}\right) \qquad (11)$$

where $RMSE = \sqrt{\Sigma(v_{x,y} - v_{x,y}^*)^2 / N_{total}}$.

$v_{x,y}$ and $v_{x,y}^*$ are the original vertex and the watermarked vertex, respectively. N_{total} is the number of all vertices of test map. Table 1 shows that all PSNRs in watermarked map are very high. It means that the change rate of watermarked vertices is very low as compared with the reduced scale of test map, dissimilar as general 2D image PSNR.

For evaluating the subjective invisibility, we checked the watermark imperceptibility from the

Table 1. The embedding object, the watermark length and PSNR in each test map

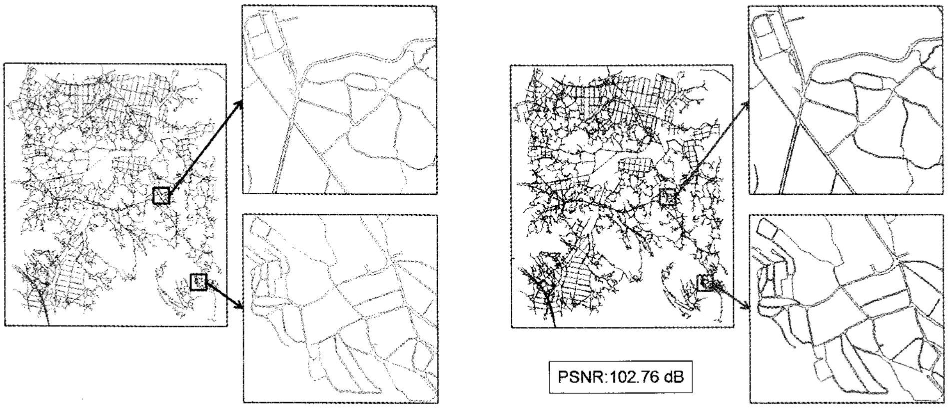
Type	Test map	Num. of Polyline/Polygon	Num. of Groups	Message Repeat Times	Watermark length	PSNR [dB]
Polyline	Masan #1	2831	150	3	70	103.67
	Masan #2	3563	150	5	105	102.76
	Masan #3	3734	300	5	107	100.32
	Masan #4	10622	200	5	94	101.28
	Masan #5	46911	1000	7	382	121.12
Polygon	Masan #6	10346	260	5	107	128.59
	Masan #7	13486	300	5	128	130.27
	Masan #8	15260	200	5	135	130.92
	Masan #9	8003	300	5	110	129.49
	Masan #10	46106	1000	7	434	128.93

original map and the watermarked map. Figure 6 shows an original polyline map and its watermarked map. And also, figure 7 an original polygon map and its watermarked map. We illustrate these maps together two magnified parts for looking over minutely. From these figures, we verified that the original map and its watermarked map in original reduced scale are much the same and also the visual difference between magnified parts of two maps are less.

4.2 Robustness

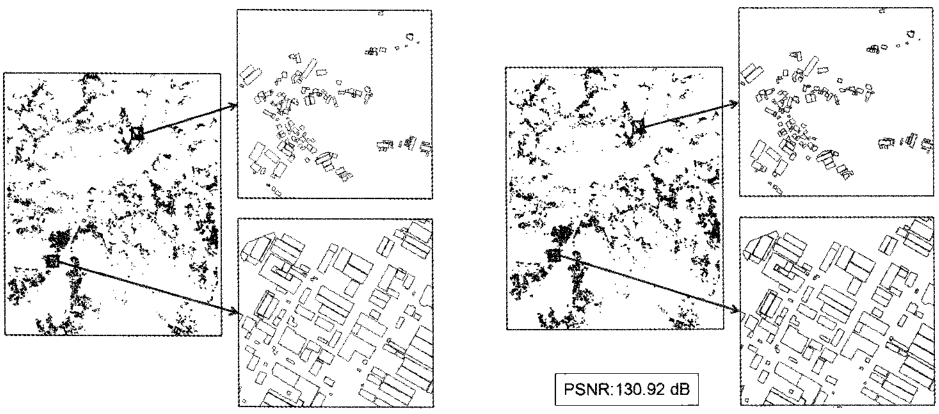
For evaluating the robustness, we used two editing tools in AutoCAD Map 3D 2009 software and Arcview software and computed BER. There are many kinds of attack that can be performed in the watermarked GIS map, such as RST(rotation, scaling, translation), object order scrambling (OOS), swapping, random noise, data inserting and deleting, cropping and so on. We compared our scheme with the conventional schemes of Ohbuchi [1], J.H. Kim [2] and H.J. Chang [3].

Figure 8 (a) and (b) show the watermarked maps rotated to 120° and 50°. Figure 8 (c) and (d) show the watermarked maps that the regions of top and bottom and the regions of left and right are swapped. Though the watermarked map is rotated to arbitrary angle and is swapped, the proposed scheme can extract all of watermark bits. Figure 9 shows BERs of extracted watermark in



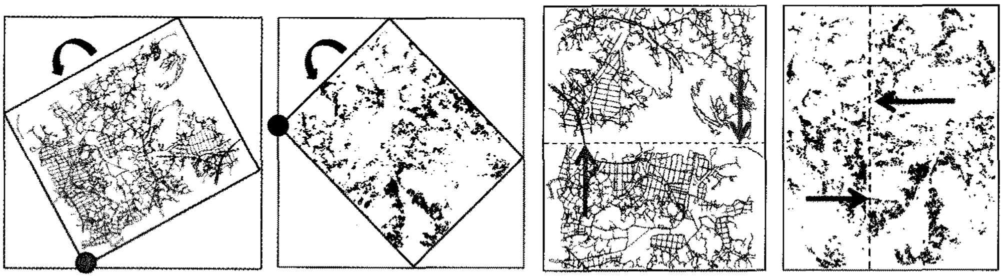
(a) (b)

Fig. 6. (a) Original polyline map and (b) watermarked polyline map.



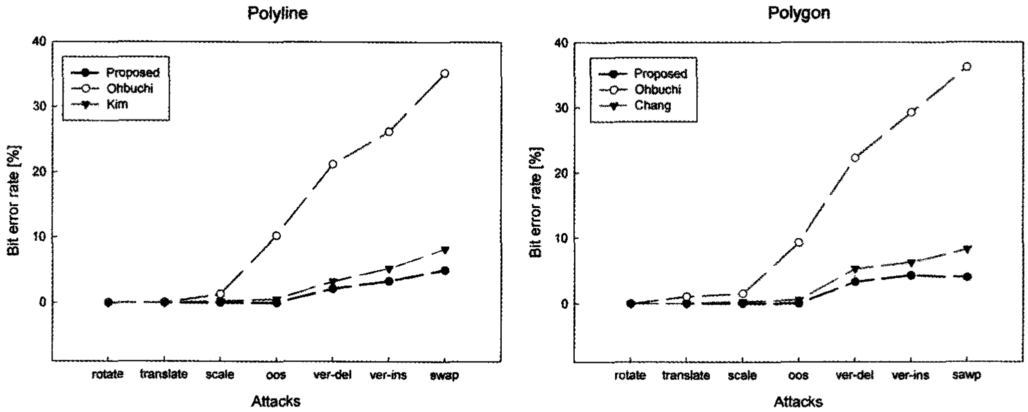
(a) (b)

Fig. 7. (a) Original polygon map and (b) watermarked polygon map.



(a) (b) (c) (d)

Fig. 8. Watermarked maps rotated to (a) 120° and (b) 50° and swapped (c) from top to bottom and (d) from left to right.



(a) (b)

Fig. 9. BERs of the extracted watermark in (a) polyline maps and (b) polygon maps that are attacked by RST, OOS, vertex deleting and adding, and swapping (OOS : object order scrambling, Ver-del : vertex deletion, Ver-ins: vertex insertion

polyline and polygon maps that are attacked by RST, OOS, vertex adding and deleting, and swapping. Our scheme use the length and perimeter for the embedding object that does not be affected by the rotation, translation and OOS. Therefore, the BERs of rotation, translation and OOS are 0, as shown in figure 9. But it can be easily changed by the scaling. In the scaling attack, we calculate firstly the mean length and perimeter $\bar{L}'^*$ of all polylines and polygons in attacked map and obtain the ratio of $\bar{L}^*$ and $\bar{L}'^*$ for estimating the scale factor. Then we re-scale all polylines and polygons by using the scale factor and extract the watermark in the re-scaled map. From the re-scaling process, we can extract all of watermark bits. The conventional schemes can extract all of watermark bits in RST. But Ohbuchi's scheme had BER of 0.1 in OOS. We added and deleted about 20-30% vertices in polylines and polygons. BERs of the proposed scheme are very low of 0.02-0.05. But BERs of chang's scheme and Ohbuchi's scheme are 0.04-0.07 and 0.21-0.26. In the swapping, BER of the proposed scheme is 0.06 but BERs of the conventional schemes are 0.08 and 0.38. Thus, we can extract above 94% of watermark bits in vertex deleting and adding and swapping.

In the cropping experiment, we cropped 1/2, 1/4, and 1/6 regions of test maps. Figure 10 show maps that different 40% regions are cropped. A number of polylines and polygons in the cropped region is deleted. The results of cropping experiment are shown in figure 11. From these figures, we know

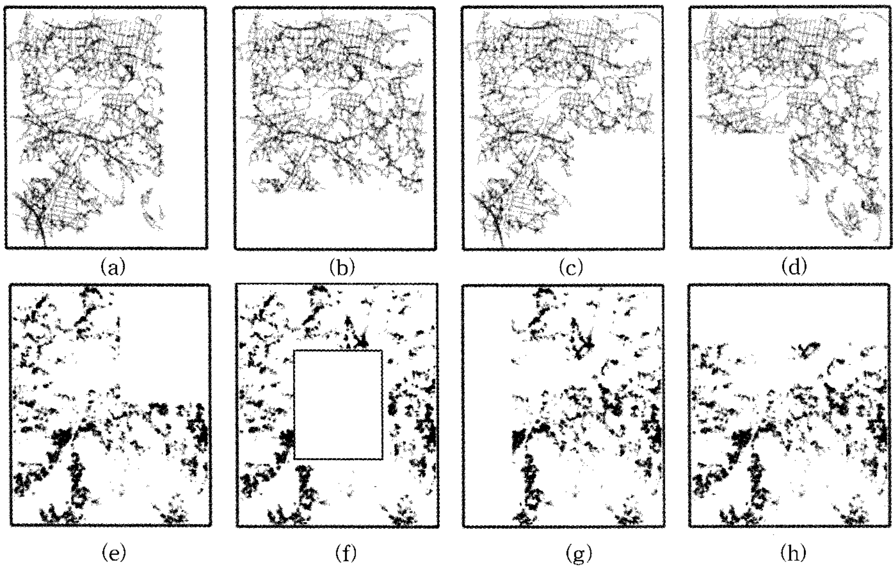


Fig. 10. (a)-(d) 25% cropped polylines maps and (e)-(h) 25% cropped polygons maps.

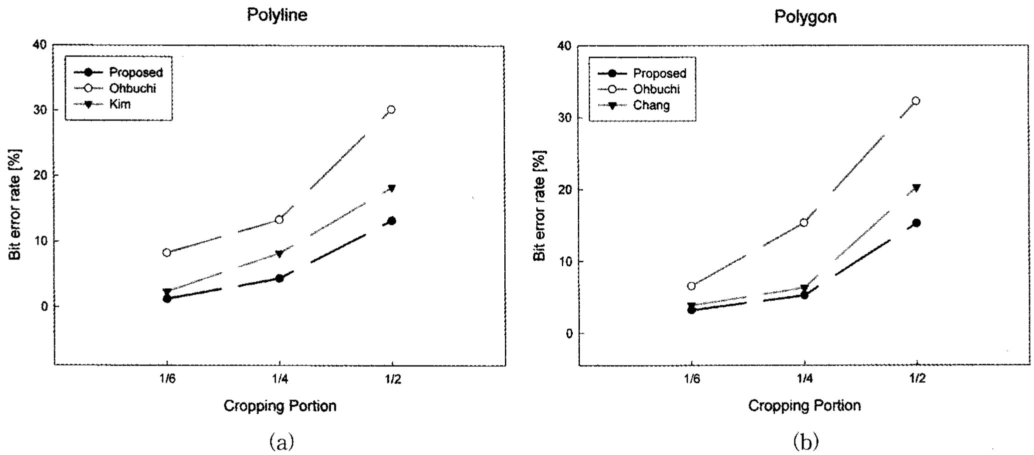


Fig. 11. BERs of the extracted watermark in the cropped (a) polyline maps and (b) polygon maps.

that BER of the proposed scheme is about 0.02-0.15 but BERs of the conventional schemes are about 0.04-0.18 and 0.07-0.34.

For the noising experiment, we used Gaussian random noise to disturb vertices of watermarked maps. Thus, we calculated the random signal z between 0 and 1 with Gaussian distribution and generated the noise signal n with the amplitude A.

$$n = A(2 \times z - 1) \tag{12}$$

We added the noise signal to all vertices as follows.

$$v' = v + n, n \in [-A, A] \tag{13}$$

The amplitude A was determined to be 5 cm and 25cm in the reduced scale. Figure 12 shows the watermarked polyline map and the noised polyline map. This figure illustrate that many polylines are perturbed by the noise. The results of noising experiment are shown in figure 13. From these figures, we know that BER of the proposed scheme is 0.01-0.08 but BERs of the conventional schemes are 0.01-0.10 and 0.01-0.18.

From these above results, we verified that the

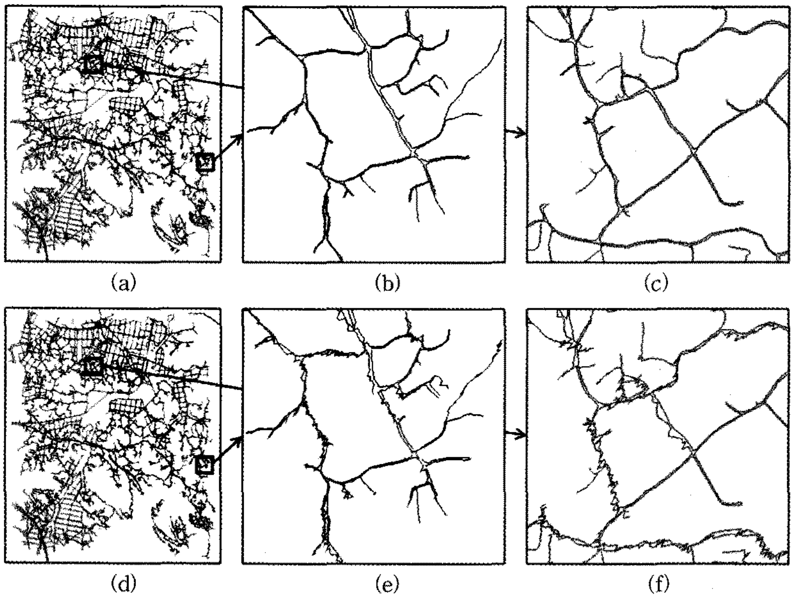


Fig. 12. (a) Watermarked polyline map, (b) and (c) magnified part in (a) and (d) noised polyline map, (e) and (f) magnified part in (d).

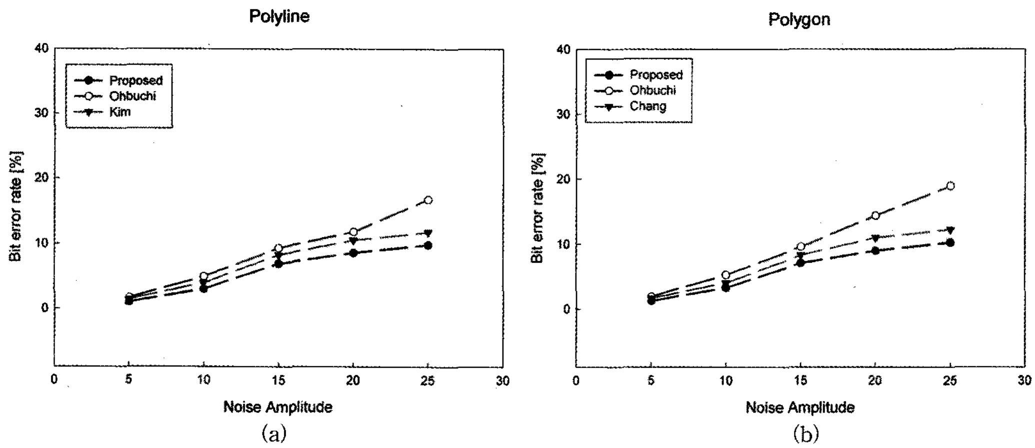


Fig. 13. BERs of the extracted watermark in the noised (a) polyline maps and (b) polygon maps.

proposed scheme has more the robustness against various attacks than the conventional schemes.

5. CONCLUSION

In this paper, we have developed an invisible blind and robust watermarking scheme for the copyright protection of GIS vector digital map by using the polyline and polygon geometric characteristics. In our scheme, we calculate the length and perimeter of all polylines and polygons in a map and cluster them to a number of groups by using uniform step size of the dynamic range of length and perimeter. We convert the watermark message to PRNS code for considering the safety and embed the watermark bit repeatedly by changing the mean length and perimeter of a suitable group. From experimental results, we know that the proposed scheme is a watermarking method that has good invisibility, safety, and robustness for vector digital map.

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