A Reversible Digital Watermarking Algorithm for Vector Maps

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Abstract

A reversible digital watermarking algorithm of 2D vector maps based on BP neural network is proposed in this paper. The watermarks were converted to binary bits, and were manipulated as the coefficients of neural network; for embedding the watermarks invisibly, the weights of the neurons would be adjusted to fitting to the neural coefficients, which picking the watermark information. In the phase of watermark extraction, those coefficients were extracted from vector maps; with above trained neural network, the watermark would be output by inputting the obtained coefficients of the neurons. Experimental results show that the maps could be recovered lossless. Compared with other classical algorithms of the kind on the tests, it is indicated that the algorithm has higher robustness, better invisibility. Especially, it can resist on the common map operations: rotation, translation.

Keywords: Lossless, reversibility, vector map, watermarking

1 Introduction

With the fast development of information processing technology and network techniques, digital vector map has becoming the necessary resource being widely used in GIS, intelligent transport system, digital city, digital national defense construction and so on. Digital vector map has great economical value and strategy significance for its accurate content. And its fabricating cost is huge. On the other hand, illegal copying and stealing of digital vector map are becoming increasingly rampant. A lower level security of it will cause enterprises' losses and even bring risks to national security. As a result, the security problem has attracted our government, military and science research institution's attention. Digital watermarking technology is a common scheme to secure the copyright of digital vector map.

There are several problems for the research of digital watermarking for vector maps: firstly, the map should be changed neither on precision nor on coordinates. Secondly, watermarks often can be broken by some common operations oriented the host map. E.g. format conversion, data fitting, and vector compression. The research on digital watermarking for digital vector map has lasted for about 20 years and many schemes have been proposed to solve some kinds of security problems of it. But these schemes have not fully considered the data characteristic of digital vector map and the particular operations on it.

In recent years, the research on digital watermarking of 2D vector map can be classified four kinds as follows:

1) The watermark is embedded into the spatial coefficients of the maps by moving the points or changing the coordinates [3, 9, 16, 18].

2) The watermarks also can be restored by the frequency of the maps by DWT (Discrete Wavelet Transformation), DCT (Discrete Cosine Transformation) or DFT (Discrete Fourier Transformation) [6, 13, 20].

3) As we know, above algorithms based on spatial or frequent domains both distort the precision of vector maps and this would be influence the usage. Therefore, the scholars [15] proposed the lossless watermarking technology. These kind algorithms can't change the content of maps when embedding or extracting [11], the watermarks have better invisibility, but the realization of the algorithm has large problem.

4) To keep normal using of the maps and the watermarks should be robust in the maps at same time. The reversible digital watermarking algorithm is proposed. It is realized easier than lossless algorithm. But its performance on robustness and invisibility is good as lossless algorithm [17]. As the watermarks being embedded into the map, the content would be changed, but it can be recovered to the origin after the watermarks being extracted from the host map. Therefore, the reversible algorithm is also lossless to the host map.

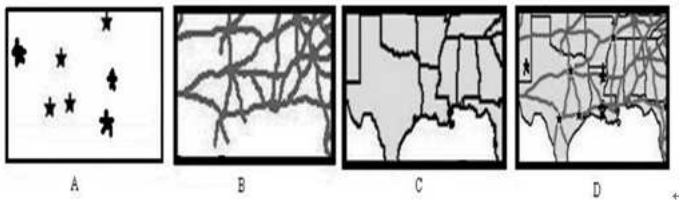


Figure 1: Composing of digital vector map

In sum, the reversible digital watermarking algorithm can be realized easier and keep better performance. A reversible digital watermarking algorithm based on BP neural network for vector maps is represented in this paper. With a designed neural network, through changing the coefficients, the relations between the watermarks and the neural coefficients can be stored into the input layer. The relations can be detected by the trained neural network, and the watermarks can be extracted by manipulating the coefficients again. Because the host maps can be recovered to the origin, there is no absolute loss on the host map.

2 Basic Theories

2.1 Structure of Vector Map

According to different sources and uses, digital maps can be divided into several kinds: digital vector maps, digital raster maps, remote sensing imagery maps, digital elevation maps and digital thematic maps. Currently, 2D vector maps are used widely.

A digital vector map usually consists of three parts: geometric information, attribute information and topological information.

Geometric information mainly contains the location, coordinates of the entities in the GIS space; the physical characteristics can be described by the attribute information, such as name, type, etc.

Topological information records all of the topological relations between spatial entities. Mostly, geometric information will be combined with topological information known as spatial information in the published papers.

For the vector maps, the geographic information can be managed by the sorts of layers. In China, the geographic information can be belonged to 14 layers. As shown in shown in Figure 1, a vector map is often composted of three basic layers, such as vertexes, lines and regions.

The entity in the vertex layer (Figure 1.A) can be indicated with the discrete space coordinates ; the entity in the line layer (Figure 1.B) is composed of the sequence of coordinates $< (x_1, y_1), (x_2, y_2), \ldots, (x_i, y_i) >$, in which, (x_1, y_1) is the starting point and (x_i, y_i) is the end of the line. An entity in the region layer (Figure 1.C) is a circle $< (x_0, y_0), (x_2, y_2), \ldots, (x_i, y_i), \ldots, (x_0, y_0) >$, starting the (x_0, y_0) along the fixed direction around and eventually returned the origin. By the vertexes, lines and regions overlaid, a complete digital vector map (Figure 1.D) is published.

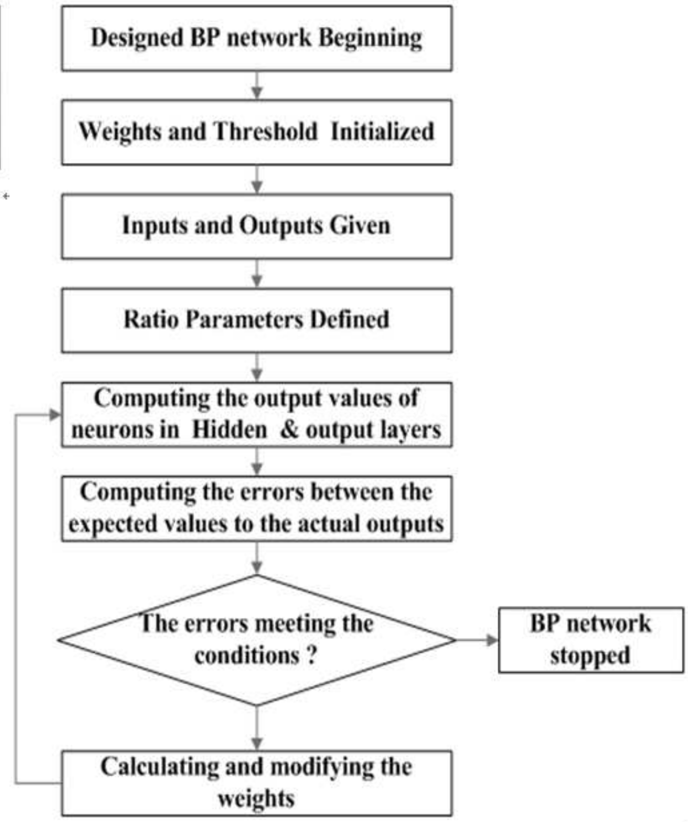


Figure 2: Studying process of a BP neural network

2.2 BP (Back Propagation) Neural Network

In the scheme, a designed back propagation network is trained to extract the watermark from the host vector map. It mainly contains 3 layers in the network: input layer, hidden layer and output layer.

The BP neural network is a type of supervised learning neural network; the output of a neuron is not only determined by the inputs and weights but also the previous outputs [12].

As shown in Figure 2, BP neural network is a back propagation algorithm using multilayer feed forward network to nonlinear mapping by least squares technique. It uses gradient search technique in order to achieve the minimum mean square error between the actual output and the desired value.

BP neural network has two stages in the learning process: the first stage is to input the known sample data. In the designed network, with the weights and threshold values of the previous iteration, the input data from input layers would be transmitted upon hidden layers, and eventually to the output layer. The value of a neuron in a layer can only determine the neuron in the neighbored layer. The second stage is to modify the value of weights and thresholds. If the output cannot be expected, then the error signal would be back propagated along the original connection path. The weights of the neurons referred in each layers would be changed until convergence to the smallest square error. By adjusting the weights and threshold of each neuron, the neural network can be trained. According to the rules of iterations, after meeting certain conditions, a neural network would be established. From the inputs to the outputs, there are nonlinear relations among the signals.

3 The Proposed Algorithm

3.1 Watermarks Embedding Procedure

Step 1. Watermark $W = \{w(i), 1 \leq i \leq l\}$, $w(i) \in \{0,1\}$. $V_{\{LH,HL\}}$ is the wavelet coefficients obtained from vector map V_0 by the first level discrete wavelet decomposition.

Step 2. The wavelet coefficients belonged to $V_{\{LH\}}$ or $V_{\{HL\}}$ would be rearranged by the value in descending order, from which, L elements would be firstly selected, and watermark W would be embedded into these elements:

$$V_{\{LH,HL\}}(i) = S_{\{LH,HL\}}(i) + (2w(i)-1) \times t, t \in (0,1)$$
$$S_{\{LH,HL\}}(i) = \sum_{x=-1}^{i} \sum_{y=-1}^{i} (V_{\{LH,HL\}}(i_x + x, i_y + y) - V_{\{LH,HL\}}(i_x, i_y))$$

t is the embedding intensity, of which, the value is bigger, the robustness of algorithm is better; otherwise, the transparency of the watermark is better. $V_{\{LH,HL\}}(i)$ is the new value of frequent band i from $\{V_{LH}\}$ or $\{V_{HL}\}$ after watermark being embedded.

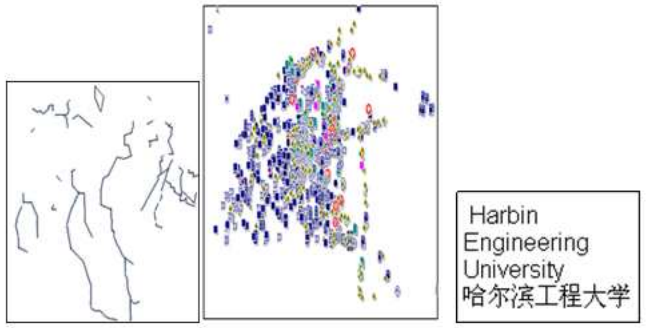
Step 3. When L selected coefficients $\{V_{\{LH,HL\}}(L)\}$ and other unchanged coefficients in $\{V_{\{LH,HL\}}\}$, a host vector map V' is reorganized, it is storing the watermark W.

3.2 Watermarks Extraction Procedure

Watermark is extracted from host map V' by wavelet decomposition. If content of map V' is not changed, then $V'_{\{LL,HH\}} = V_{\{LL,HH\}}$. L wavelet bands can be selected from $V'_{\{LL,HH\}}$ again, with which, we can organize the input layer having 9 neurons in the BP neural network. The extracting steps are as follows:

Step 1. For the vector map V', through wavelet decomposing, frequent bands $V'_{\{LL,LH,HL,HH\}}$ can be computed;

Step 2. Using the same method as embedding watermark, selecting L medium frequency coefficients $V'_{\{HL,LH\}}$ from $V'_{\{LL,LH,HL,HH\}}$;



a. vector map V_1 b. vector map V_2 c. Watermark W_0

Figure 3: Vector maps and watermark on robustness tests

Step 3. In accordance with the number of neurons in the input layer, choosing the coefficients from $V'_{\{HL,LH\}}$ and computing $S'_{LH,HL}(i)$. Comparing the difference value between $S'_{LH,HL}(i)$ and $S_{LH,HL}(i)$ according to the following equation:

$$\varepsilon(i) = V_{LH,HL}(i) - S'_{LH,HL}(i).$$

Thus, we can achieve the difference series, called the squares error $E = \{\varepsilon(i)\}$, via, $\varepsilon(k)$ is output of the k-sample in the BP neural network.

Step 4. Choosing $E_0 = \{\varepsilon(i)\}|_{i=1}^{L}$ as the training set of the BP neural network, if $w(i) = 0$, then $\varepsilon(i) = 0$; else, $\varepsilon(i) = 1$. With E_0, the BP neural network will be trained.

Step 5. Taking the $\{E - E_0\}$ as the input samples, and obtaining the series of $\varepsilon(t)$; according to Equation (1), the watermark W' can be extracted by the trained BP neural network.

$$W' = \{W_t\}, w_t = \begin{cases} 1, & \text{if } \varepsilon(t) \geq 0.5 \\ 0, & \text{else} \end{cases} \quad (1)$$

Step 6. After extracting the watermarking W' from the host map V', we need compute the similarity between the original watermarking W and W':

$$Sim(W, W') = 1 - \frac{\sum_{i=1}^{L} W_i - W'_i}{\sum_{i=1}^{L} W_i \times \sum_{i=1}^{L} W'_i}$$

4 Experimental Results and Discussion

We select actual Harbin urban related vector maps on the test [7]. As shown in Figure 3, V_1 is the map about Harbin urban water system and V_2 described the service pots in Harbin city. W_0 is the bmp-formatted watermark image, it can be converted into a 2112-bits binary string.

In [8], Professor Niu introduced many famous digital watermarking algorithms, of which, we select a reversible

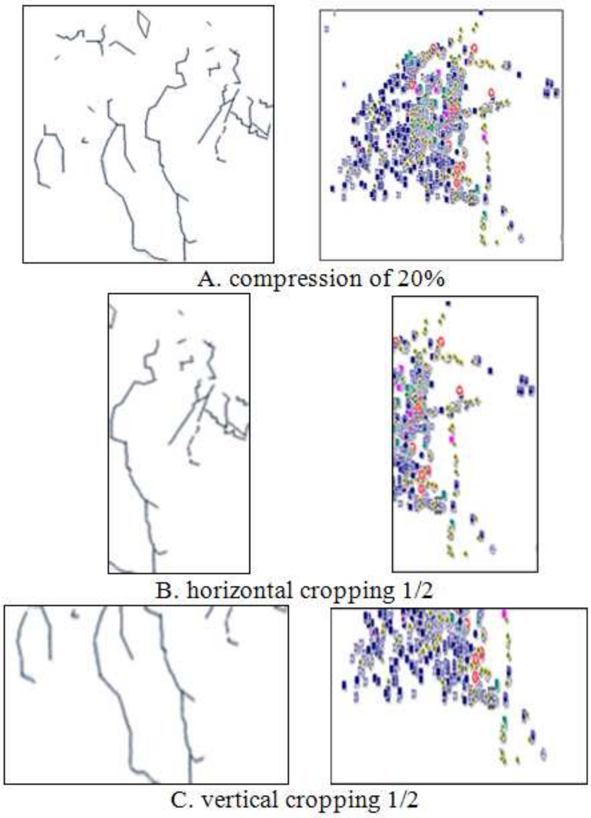


Figure 4: Robustness tests under some geometric transformations (Left: V_1. Right: V_2)

algorithm of the kind proposed by Michael [14]. In [14], the watermark is embedded into the vertexes series, and the modified map would be converted to the origin after the extraction operation finished. Therefore, it is a kind of spatial reversible watermarking algorithm.

For a vector map, the common attacks are geometric transformations. V_1 is embedded the watermark by our algorithm, and V_2 is used by Michael's method. Watermark W_0 used is as shown in Figure 3c, which is embedded into double vector maps under the same rate. The embedding rate is a ratio of the watermark bits to the number of vector objects.

As shown in Figure 4, we choose cropping and compression to test the performance of two watermarking algorithms. Besides, there are some more transformation operations, like format-converting, adding or removing vertexes, precision-adjusting, map scale changing, etc. the common feature of these operations is that the content of the vector map would be imperfect; it will influence the using of the map. Because the watermark embedded is scattering in the map, most bits of wa-termark can be extracted only if the map can be used.

The results are shown in Table 1. The indicator of performance evaluation [10] is error coding rate (ECR), viz. the ratio of the number of error extracted watermark bits to the entire length of the original watermark W_0.

Table 1: Results of the robustness experiment

Map	Attack	ECR
V_1	Compression	16.12%
	Horizontal cropping 1/2	19.84%
	Vertical cropping 1/2	14.49%
V_2	Compression	10.73%
	Horizontal cropping 1/2	18.06%
	Vertical cropping 1/2	27.40%

4.1 Precision Analysis

Deng et al. proposed an algorithm that a vector map would be divided into several girds, and watermark is embedded into each gird, this algorithm has a low-loss on precision and the capacity can be adjusted according to the scale of the map [2]. Because of the features of reversible algorithm, the realization our digital watermarking technology also has a distortion to the map.

Compared with [2], the results of precision loss tests are shown in Table 2. It can be clearly seen that our proposed algorithm has smaller loss on the accuracy than [2]. Especially, our algorithm is reversible [5], when the watermark is extracted from the host map, the loss of precision can be eliminated, and the map to the users is lossless. (x_i, y_i) is a single vertex in the vector map (Figure 3b).

4.2 Operations-Attack Analysis

Our discussed above is all about the robustness and other performances on the purposed attack tests [19], these attacks are completed by those attackers who want to remove the watermark information by some unauthorized methods. During the designing and research phrase of most algorithms, anti-purposed attacks must be an important factor, which determined the performance of the algorithm.

But there are some unpurposed attacks, like some common map operations [1, 4]: translation, rotation, scaling, and vertex reordering, etc. these operations will not degrade the quality of the vector map, and they can facilitate the using of the vector map. However, some so-called robust watermark can be removed by these unpurposed operations easily. To test the performance of our algorithm, some unpurposed operations are selected, such as translation, rotation, scaling. Because the frequent coefficients of the vector map cannot change by some operations like format-converting, vertexes/objects reordering, these operations are not mentioned any more.

From the test data above in Table 3, we say that our algorithm still has a stable robustness and keep a good performance, it can resist some common operations, and the watermark can be extracted after the map is processed by users. Our algorithm is practical in some sense.

Table 2: Results of loss on accuracy

Axis		Original value	After watermark embedded	
			Our algorithm	Ref. [2]
	x_1	86.1595613	86.1595701	86.1595631
x	x_2	102.4548891	102.4548879	102.4548762
	x_3	91.5684435	91.5684442	91.5684490
	y_1	89.5612862	89.5612819	89.5612722
y	y_2	56.5998432	56.5998418	56.5998592
	y_3	105.4568431	105.4568427	105.4568235

Table 3: Results of the operation attacks

Map	Operation	ECR
V_1	Translating to the top right on 2cm	20.73%
	Rotation (turning clockwise 15°)	23.69%
	Scaling up by 10%	17.07%
V_2	Translating to the left on 1cm	14.52%
	Rotation (turning clockwise 125°)	28.50%
	Scaling down 25%	18.75%

5 Conclusions

Through adjusting the wavelet coefficients transformed from a vector map, watermarks can be embedded into the map, and a designed BP neural network can be trained; the algorithm is reversible, with the trained neural network, the watermark can be blind extracted and the map can be turned to the origin. Experimental test demonstrates that the algorithm has the good overall performance to resist whether purposed attacks or unpurposed operations.

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