A Robust Integrated Watermarking Algorithm for Vector Geographic Data Copyright Protection

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Abstracts: Vector geographic data play an important role in the natural resources and environment sector as well as in other location information services. This is also one of the types of data where the cost to create it is relatively large because of the difficulty in surveying, collecting, and authorizing. The rapid development of the Internet has created many advantages in the distribution, exploitation, and use of vector geographic data, but it also gives rise to many problems such as duplication, redistribution, forgery, and illegal data use. The theft on the Internet is becoming more and more sophisticated and the number of violations is increasing, showing the urgent need to research and develop an effective solution to protect the copyright of vector geographic data and prevent them from being illegally collected and used. Among the major studies and solutions, digital watermarking emerges as an effective method and is an active research area for copyright protection. Towards a good solution for copyright protection of vector geographic data, our study proposes a new algorithm with three main contributions, including: (1) generating short, pseudo-random meaningful watermarks to in-crease robustness and to enable automated as well as visual manual verifying; (2) building a uniformly distributed mapping between the vertex coordinates and the watermark bit indexes to increase the robustness of the watermarks; and (3) integrating two types of watermarks, namely, spatial domain-based watermarking and zero-watermarking to be resistant to most common attacks on geographic vector data. The algorithm works on all types of vector geographic data, including points, polylines, and polygons.

Keywords: Vector Watermarking; Vector Copyright Protection; Vector Geographic Data; Copyright Protection; Digital Watermarking; Zero-Watermarking.

1. INTRODUCTION

Copyright protection is a very broad concept and therefore there are many solutions or techniques to implement. However, each technique usually only protects the author's rights against certain attacks. Copyright protection techniques can be divided into two groups: precaution techniques; and accountability techniques [1]. Preventive techniques implement defensive methods such as encrypting data or controlling user access to prevent unauthorized users from accessing the data. Alternatively if unauthorized users can access the data, these techniques ensure they cannot exploit or utilize it. Accountability techniques perform post-checks, meaning that when in doubt or periodically, data can be checked to verify its copyright.

Digital watermarking is an accountability technique whose process is: (1) embedding copyright information (called watermark) into the data; (2) distributing the data to the user and assuming that the data will be subject to certain types of attacks (or transformations); and (3) detecting and extracting copyright information (embedded watermark) from data to verify copyright. Watermarking techniques are highly dependent on the protected object due to the different characteristics of these objects.

Vector geographic data represents the spatial and non-spatial properties of features that are geographically located on Earth. Usually, vector geographic data is organized into one or more layers, wherein each layer typically representing a type of feature with spatial properties such as points, polylines, or polygons. Maps are usually built by superimposing these layers of data. The main formats of vector geographic data are shapefile (.shp), geojson (.json), GeoPackage (.gpkg), or GeoDatabase.

Although the number of studies on digital watermarking to protect the copyright of vector geographic data in recent years has been quite large, it is still much less than the number of studies on digital watermarking to protect the copyright of multimedia data. This may be due to the ubiquity of multimedia data and the complexities arising from the nature of the vector geographic data (such as data structures, data analysis purposes, etc.).

To serve the purpose of copyright protection, watermarking techniques are needed to ensure stability/robustness against attacks, accidental or intentional modification. However, each current watermarking technique is only resistant to certain types of attacks, so an integrated solution is needed to increase resistance to many types of attacks. This paper will present our research results to form an integrated algorithm between spatial domain-based watermarking (specifically, watermarking embedded in the coordinates of vertices) and zero-watermarking (specifically, is a zero-watermark based on statistical properties), to create a stable/robust watermarking technique for copyright protection of vector geographic data. The algorithm contains three advantages, including (1) a technique to generate short, pseudo-random, and meaningful watermarks to increase durability and also be able to verify the watermark automatically and intuitively; (2) a uniformly distributed map between vertex coordinates and watermark bit indexes to increase the durability of watermark; and (3) the integration of two watermarking techniques to be able to resist many types of attacks.

2. METHODOLOGY

2.1. Watermarking Process For Copyright Protection

Watermark-based data copyright protection is accomplished by performing some operations on the data before transferring the data to the user. This work is called watermark embedding which consists of two steps: (1) watermark generation and (2) watermark embedding. Watermarks are generated from copyright information and some other information (e.g., user information). In some cases (e.g., in zero-watermarking) the generated watermark based on the data itself will be protected copyright. To increase security by eliminating the ability to visually view as well as statistically the adjacent information of the watermark, the watermark is often shuffled and may be encrypted by a key-using encryption algorithm [2]. The watermark is stored and in the case of a zero-watermarking can be sent to a trusted authenticated party. The watermark is then embedded into the data to create a product ready to be delivered to the user (called watermarked data). The procedure of copyright protection watermark embedding is shown in **Figure 1**.

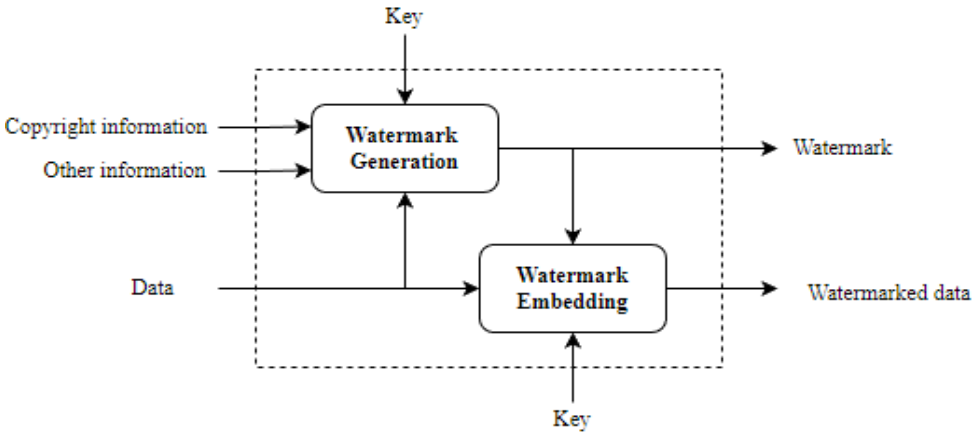


Figure 1. The procedure to embed watermark for copyright protection.

The watermarked data is transferred to the user and is assumed to be subject to some accidental or intentional transformations or attacks. When verifying copyright is required, the process of detecting and extracting watermarks to prove copyright is performed. This process typically involves detecting if the data contains a watermark and then extracting the watermark to prove copyright. The input to the process will be data, which is needed to verify the copyright, and in some cases may need both watermark and the original data. The extracted watermark also needs

the key to decrypt to get the copyright information. The watermark detection and extraction process are shown in **Figure 2**.

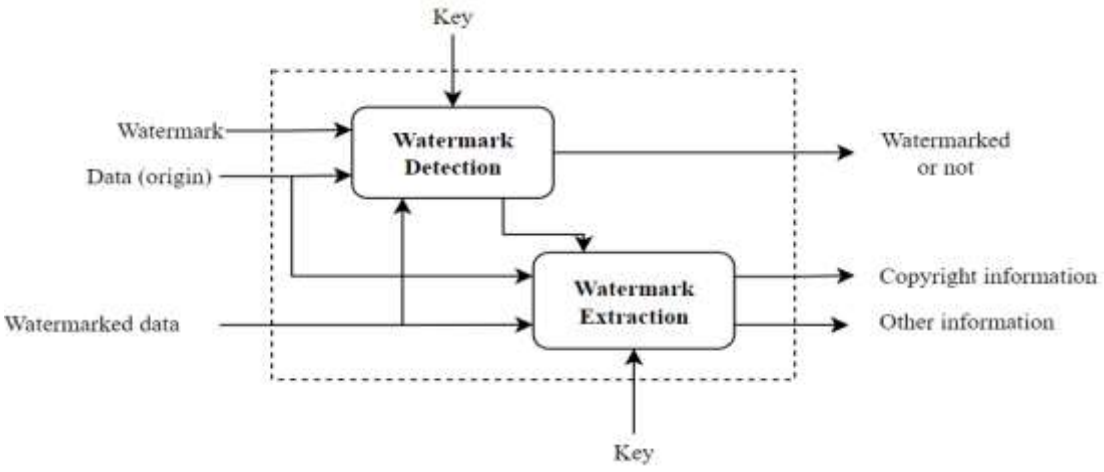


Figure 2. The procedure to verify the copyright.

2.2. Analysis Of Watermarking Techniques

Based on the embedding domains as well as the accuracy requirements of the watermarked data, watermarking techniques are divided into several categories such as spatial domain-based watermarking, frequency domain-based watermarking, reversible watermarking, lossless watermarking, and zero-watermarking. Research on watermarking using techniques of embedding information into the spatial domain (coordinates of objects) can be mentioned as [3-9], techniques of embedding information into the frequency domain such as [10-12]. Reversible watermarking techniques for vector geographic data are performed in [13-18]. In [19,20], the studies of watermarking without losing information based on the storage order are presented. Zero-watermarking techniques are studied in [21-26].

Watermarking algorithms often try to embed some information (watermark) into the data for the purpose of copyright protection by serving to detect and extract the watermark to prove the copyright of the owner. The embedding is based on the principle of finding redundant space in the data so that the watermark can be inserted without or with little effect on the data to be protected. The techniques for inserting or hiding this information into other information mainly used today include spectral modulation, least significant bit, or quantization index modulation techniques [27]. Note also that the watermark does not have to be embedded in the carrier data, and techniques of this kind are called zero-watermarking.

Based on the degree of stability of the watermark against attacks on the watermarked data, the watermarking algorithms can be classified into robust and fragile watermarking. Robust watermarking is useful for copyright protection while fragile watermarking is useful for integrity and authenticity issues. Based on the ability to see the watermark visually on the watermarked data, watermarking techniques are classified into visible and invisible watermarking. For multimedia data such as images or videos, visible watermarking is an effective way to explicitly identify data copyright. However, for vector geographic data, besides serving visual presentation, the data also serves many spatial analyses, therefore, the watermarking techniques on vector map data are mainly invisible watermarking, which is not seen by users. Based on the techniques of embedding watermarks into data, it is possible to divide watermarking algorithms into spatial domain-based watermarking and frequency domain-based watermarking. Spatial domain-based watermarking seeks to insert watermarks into the vertex coordinates or relations of geometric features, while frequency domain-based watermarking first, seeks to transfer geometric features from the spatial domain to the frequency domain using transformations such as Fourier transformation, Cosine transformation or wavelet transformation, then insert watermark into the coefficients, and finally convert back to the space domain using the corresponding inverse transformations. Based on whether original data is

needed to verify watermarked data, watermarking algorithms are divided into blind and non-blind watermarking. With blind watermarking, extracting watermark information only needs the watermarked data itself, while with non-blind watermarking, extracting watermark information requires both original data and watermarked data.

Based on the influence as well as the ability to recover the original data from the watermarked data, watermarking algorithms are classified into lossy watermarking and lossless watermarking. Conventional watermarking techniques distort the original data and, in some cases, may be unacceptable (e.g., in geodesy, cartographic, military fields). Lossless watermarking attempts to preserve the original data and as such is suitable for copyright protection applications of highly accurate vector geographic data.

As analyzed in [19], the current studies of lossless watermarking for vector geographic data can be divided into three main categories. The first type is reversible watermarking which protects copyright by embedding watermark in the original data and it is possible to recover the original data from the watermarked data through watermark extraction. Unfortunately, the reversible watermarking technique has obvious defects that the watermark can only be used once because the reversible watermark information must be discarded after the watermark extraction. Therefore, this technique does not satisfy the requirement of copyright protection.

The second lossless watermarking technique is zero-watermarking, where the watermark is generated from the characteristics of the data without any modification to the original data. The generated watermark will be stored in an IPR (Intellectual Property Rights) repository for future proof of copyright. The main point of the method is to extract stable characteristics of the original data that are resistant to various types of attacks. There are two popular methods of extracting features that are based on statistical and geometrical features, respectively. For example, the map is divided into rings using concentric circles. The number of vertices in each belt is then counted to be used as information on statistical feature. These characteristics are further combined with copyright information to form zero-watermarks. Compared with reversible watermarking, zero-watermark achieves complete lossless information. However, the technique does not actually embed the watermark in the data, so there may be issues of trust in third parties in the proof of copyright.

The third technique is watermarking based on storage features. This method embeds the watermark by transforming the storage order of the vector data without changing the coordinate values, thus avoiding the defect of single-use limitation in reversible watermarking and avoiding the limitation of replying on a third-party in zero-watermarking. With this technique, the storage direction of a polyline is quantized by 0 or 1 corresponding to the storage characteristic of that polyline. To embed watermark, the watermark bit is considered whether consistent with the quantum value of the storage direction. If they are the same, the storage order of that polyline does not change. Otherwise, the storage order of that polyline is reversed. Compared with zero-watermarking, this technique actually embeds the watermark in the data.

The watermark itself can be classified into two groups as meaningful watermark and meaningless watermark. Meaningful watermarks are usually logo images that are easily visually inspected when extracted, while meaningless watermarks are often represented as a pseudo-random sequence of bits. Detecting the presence of meaningless watermarks often uses statistical correlations (e.g., the Pearson correlation coefficient). In addition, meaningless watermarks are usually much shorter than meaningful watermarks, so meaningless watermarks increase the robustness of watermarking techniques and are often used for small data sets. To improve the robustness of watermarking techniques and to ensure the security of the watermark, the watermark is often scrambled and can be encrypted by a cryptosystem before being embedded in the data. A contribution of this study is proposing a technique to generate a meaningful watermark with characteristics of a meaningless watermark, so can be detected and verified automatically with high accuracy. The generated watermark is also meaningful watermark, so can be verified visually by humans.

2.2.1. Spatial Domain-Based Techniques

The techniques use the spatial domain to embed watermark bits into the coordinates of vertices or other features such as distances, angles, or even the storage order of vector geographic data. To get a robust watermarking

algorithm against common attacks such as feature deletion/addition, feature compression (simplification), vertex deletion/addition, algorithms try to embed watermark bits multiple times on the data and thus it is necessary to establish a one-to-many mapping of watermark bits to the vertices. For example, when we want to embed a watermark bit, the algorithm needs to establish a mapping that maps this bit to multiple vertices. This mapping needs to ensure that the watermark bits are embedded "*uniformly*" over the entire data set to prevent attacks such as data clipping. One contribution of this study is the construction of such a mapping.

Embedding watermark bits into vertices in vector geographic data can be done by one of the techniques such as least significant bit, quantization index modulation, or storage order.

2.2.2. Frequency Domain-Based Techniques

The frequency domain-based techniques organize the whole data or each feature (polyline or polygon) as a sequence of coordinates. Coordinate sequences are then converted to the frequency domain using one of the numerical transformations such as Fourier, Cosine, or Wavelet. The watermark bits will be embedded in the frequency domain coefficient values and then converted back into the space domain by the corresponding inverse digital transformations. In this way, the watermark bit is embedded and propagated into the coordinate sequence.

To ensure robustness, techniques using the frequency domain also use one-to-many mappings from the watermark bits into coordinate sequences as in the spatial domain-based technique. In general, techniques using frequency domain have higher stability than spatial domain techniques, but the accuracy of data after embedding watermark is lower.

2.2.3. Lossless Watermarking Techniques

Lossless watermarking techniques cannot embed watermark bits directly into the values of geometric objects in the data (whether directly or using frequency transformation) because this would reduce the accuracy of the data. Instead, these techniques seek to utilize the special characteristics of vector geographic data. A typical example is using the ordering of the vertices of a polyline or polygon to store a bit of information; for example, if the order is clockwise then the information bit is 1 and vice versa if the order is anti-clockwise then the information bit is 0.

2.2.4. Zero-Watermarking Technique

Zero-watermarking techniques actually do not embed watermarks in the data but are watermark generating techniques. Watermarks are generated based on the immutable characteristics of the data to ensure against attacks such as projection and CRS transformation. The generated watermark is a meaningless watermark that tries to characterize the data. This meaningless watermark may be saved by a trusted third party for future reference purposes. Some watermarking techniques also add the step of combining this meaningless watermark derived from data with copyright information to form a meaningful watermark.

3. INTEGRATED WATERMARKING ALGORITHM

The proposed vector geographic data copyright protection integrated watermarking algorithm includes spatial domain watermarking, embedding watermarks in the coordinates of the vertices and zero-watermarking based on statistical characteristics. With the selection of embedded features as vertices, this watermarking is capable of embedding watermark on all types of vector geographic data including types of points, polylines, and polygons data. Moreover, in vector geographic data, the number of vertices is often more than the number of features, so in this watermarking technique, each bit of the watermark is embedded in the data more times and that means the watermark will be more stable.

3.1. Short, Pseudo-Random, And Meaningful Watermark Generation

By using the big character representation of a string as a meaningful watermark, the watermark can be verified by humans directly and its size remains small. For example, the watermark “CEID” and the watermark “HA NOI” as shown in **Figure 3** have the size of only 114 and 168 bits, respectively.

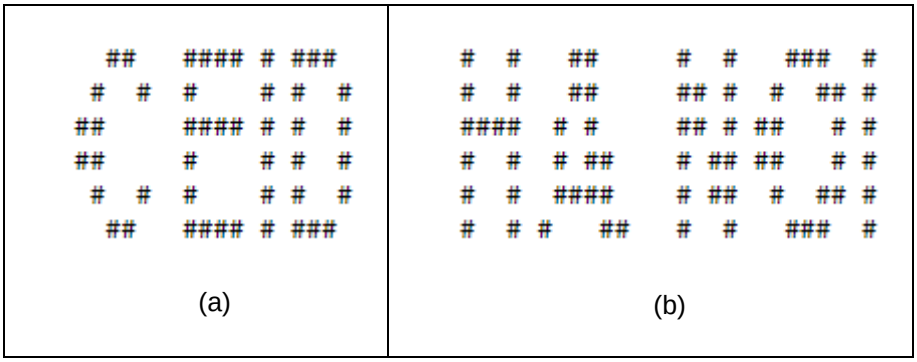


Figure 3. Watermark "CEID" and "HA NOI".

The big character representation of watermarks is generated using Pillow library. Without loss of generality, the bits representing the character are assigned the value 1 and the remaining bits are assigned the value -1. Thus, the watermark is represented by an array of bit values 1 and -1. Usually, the number of bits 1 and -1 of a watermark is not equal and therefore does not reflect randomness as if the watermark is randomly generated from bits 1 and -1. Our algorithm tries to make the number of bits 1 and -1 equal by padding bits 1 or -1 to the water as shown in **Figure 4**.

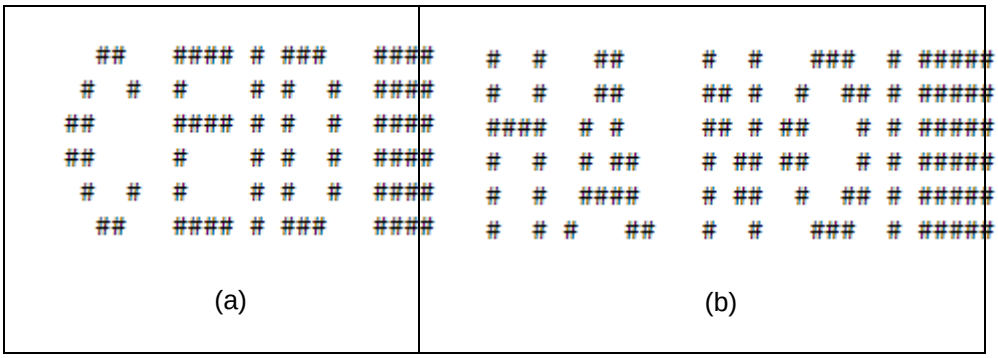


Figure 4. Watermark "CEID" and "HA NOI" with roughly equal number of bits 1 and -1.

An Arnold’s transformation is applied to the watermark to generate a pseudo-random, watermark as shown in **Figure 5**.

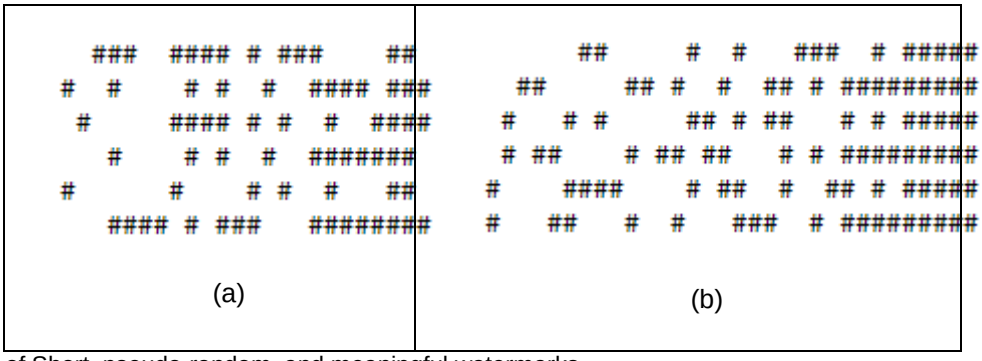


Figure 5. Example of Short, pseudo-random, and meaningful watermarks.

The use of these watermarks makes automatic watermark detection and verification (using statistical indicators) unbiased and also allows intuitive manual verification.

Flatten the watermark into a vector and assume that the watermark is $W = \{w[i],0 \le i < N\}$, where $w[i]$ is the watermark bit, i is the watermark bit index, N is the length of the watermark, and $w[\,i] \in \{-1,1\}$. The algorithm will embed each bit of this W watermark in the vertices of the vector geographic data.

3.2. Watermark Embedded In The Vertices

Our procedure for embedding watermark's bits in the coordinates of vertices is heavily based on the technique proposed by Wang et al [3] but improves upon the determination of which watermark bit should be embedded in a vertex and then embeds that bit in the vertex coordinates based on the quantization technique.

3.2.1. Watermark Embedding

Vector geographic data contains vertices with coordinates. The vertex coordinates are the basis of the points, polylines, and polygons that are the basic feature classes in the vector geographic data. To obtain a strong watermarking algorithm against common attacks such as data slicing, data inversion, data simplification (compression), vertex addition, vertex deletion, we need to establish a mapping between the vertex coordinates and the watermark bit index such that the watermark bits are distributed "uniformly" over the vertex coordinate, and then watermark bits will be embedded in the corresponding vertex coordinates according to this mapping.

Assume that the vertex coordinates of the vector geographic data are the set $VC = \{vc_i\,|(x_i, y_i\,),0 \le i < M\}$, where vc_i is the i-th vertex, (x_i, y_i) is the coordinates of the i-th vertex, and M is the number of vertices. The mapping between (x_i, y_i) and two watermark bit indexes (ix, iy) is established using the following equations:

$$\begin{cases} ix = \mathrm{Hash}(\mathrm{x_i}) \,\%\, N \\ iy = \mathrm{Hash}(\mathrm{y_i}) \,\%\, N \end{cases}$$

Thanks to the uniform distribution of a hash function, this map is also uniform distribution. It is a many-to-one mapping between the vertex coordinates and the watermark bit index. The watermark bits are embedded in the corresponding vertex coordinates using a quantization technique to ensure blind detection of the watermark bits. In the vast majority of cases, the number of vertex coordinates is much more than the length of the watermark. This leads to a many-to-one relationship mapping between the vertex coordinates and the watermark bit index, resulting in a watermark bit entry corresponds to multiple extracted watermark bits.

3.2.2. Watermark Detection

The watermark is extracted according to the reverse process of the watermark embedding process. The main steps to extract watermark are as follows: for certain vertex coordinates (x_i, y_i), the watermark bit is extracted from (x_i, y_i) using a quantization algorithm, and the index for the watermark bit is calculated based on the mapping function.

Suppose the extracted watermark bits are the set $W' = \{w'\,[i][j],0 \le i < N, 0 \le j < L_i\}$ and $w[i][j] \in \{-1, 1\}$ where $w[i][j]$ is the j^{th} extracted watermark bit of the i^{th} watermark bit index, N is the length of the watermark, L_i represents the number of extracted watermark bits corresponding to the i^{th} watermark bit index, and M is the number of vertices. Also $L_i \ge 0$ and $\sum_{i=0}^{N-1} L_i = 2 * M$.

The basic principle of the watermark detection algorithm is first calculating the watermark W'' with fixed length N based on the extracted watermark bits W', then calculate the correlation coefficient between W'' and the original watermark W to judge whether the watermark is contained in the data. Watermark $W'' = \{w''\,[i],0 \le i < N\}, w''[i] \in \{-1,1\}$ is determined by calculating $t_i = \sum_{j=0}^{L_i-1} w'\,[i][j]$ and then calculating $w''[i]$ according to the equation.

$$w''[i] = \begin{cases} 1 \; if \; t_i > 0 \\ -1 \; if \; t_i < 0 \\ 1 \; or \; -1 \; randomly \; if \; t_i = 0 \end{cases}$$

The normalized correlation coefficient c_1 is calculated using the equation.

$$c_1 = \frac{\sum_{i=0}^{N-1} w[i] * w''[i]}{N}$$

According to Wang et al [3], threshold $\mu_1 = 4 * \sqrt{1/N}$ can be used to detect watermark with the FPE is less than 0.0001. The watermark detection rule is as shown in the following expression.

$$\begin{cases} non - watermarked \; data & c_1 \leq \mu_1 \\ watermarked \; data & c_1 > \mu_1 \end{cases}$$

Wang et al [3] also proposed other coefficient using extracted watermark bits W' directly instead of derivate watermark W'' (called the Adaptive Watermark Detection). This normalized correlation coefficient c_2 is calculated using the following equation.

$$c_2 = \frac{\sum_{i=0}^{N-1} \sum_{j=0}^{L_i-1} w[i] * w'[i][j]}{2 * M}$$

When a watermark is not contained in the detected data, for watermark bit index i , the extracted watermark bit $w'[i][j]$ is randomly equal to 1 and -1, and because the watermark W is pseudo-random, the mean and variance of $w[i] * w'[i][j]$ can be expressed as $E(w[i] * w'[i][j]) = 0$ and $V(w[i] * w'[i][j]) = 1$. According to the central limit theorem, correlation coefficient c_2 can be approximated by the normal distribution with a mean of 0 and a variance of $\frac{1}{2*M}$ as shown in the expression.

$$C_2 \sim N(0, \frac{1}{2 * M})$$

The threshold $\mu_2 = 4 * \sqrt{\frac{1}{2*M}}$ is used to detect watermark with the FPE, $e_1 = 1 - \phi(4) = 0.000031671 < 0.0001$.

Our algorithm using both c_1 and c_2 and thresholds μ_1, and μ_2 respectively, to state whether a detected data is watermarked or not. Moreover, manual visual inspection is also performed before concluding watermarked data for copyright protection purposes. The rule is shown in the following expression.

$$\begin{cases} watermarked \; data & c_1 > \mu_1 \; and \; c_2 > \mu_2 \; and \; manual \; visual \; inspection \\ non - watermarked \; data & others \end{cases}$$

3.3. Zero-watermark based on statistical properties

Zero-watermarking does not embed the watermark in vector geographic data but computes the stable features of the data which can then be used to prove the copyright of the data. Our algorithm uses the zero-watermarking technique based on statistical characteristics proposed by Xun et al [25]. The algorithm divides the map into rings and counts the number of vertices in each round. Also, because it is based on vertices, the algorithm can work on all types of vector geographic data including point, polyline, and polygon data. In addition, when working with vertex data, the number of vertices in the vector geographic data is often much larger than the number of features of them, so the statistical properties are often more stable.

3.3.1. Zero-Watermark Embedding

Embedding zero-watermark is actually the process of generating watermark. First compute the coordinates of the center point, $AvePoint(\bar{x}, \bar{y})$, and the average distance, $AveDistance$, of all the vertices of the vector map dataset to the center point.

$$\bar{x} = \sum_{i=1}^{M} x_i$$

$$\bar{y} = \sum_{i=1}^{M} y_i$$

$$AveDistance = \frac{\sum_{i=1}^{M} \sqrt{(x_i - \bar{x})^2 + (y_i - \bar{y})^2}}{M}$$

where M is the number of vertices of the vector geographic data.

Next, we design a circle. The center of the circle is $AvePoint$ and the radius of the circle is twice $AveDistance$. Divide this circle into N (the size of the watermark) rings by concentric circles.

Finally, we count the number of vertices in each ring and consider it a statistical property of the vector geographic data. This data is stored in a vector Z of length N.

Let $AveNums$ is the average number of vertices for all rings. Vector Z^* is calculated using the formula.

$$Z_i^* = \begin{cases} 0, Z_i < AveNums \\ 1, Z_i \geq AveNums \end{cases}$$

Zero-watermark I is computed by XOR between Z^* and copyright information W

$$I = Z^* \oplus W$$

3.3.2. Zero-watermark extraction

To extract the zero-watermark, first, based on the protected vector geographic data, we obtain the zero-watermark I from the third-party authoritative verifier. Next, based on the length of I, the vector map data is divided into rings and then counts the number of vertices in each ring to calculate Z^* as in the zero-watermark embedding procedure. copyright information is calculated according to the formula:

$$W' = Z^* \oplus I$$

3.4. Integrate watermarking algorithm to protect copyright

The algorithm consists of two processes, the embedding watermarking process and the watermark extraction process from the vector geographic data that need to be authenticated.

3.4.1. Watermark embedding steps

Step 1. Generate pseudo-random watermark from a string.

Step 2. Embedding copyrighted images into data using watermarking algorithm embedded in vertex coordinates.

Step 3. Create zero-watermark according to zero-watermark algorithm based on statistical characteristics and send it to a trusted third-party (authoritative verifier).

3.4.2. Steps to extract watermark to prove copyright.

Step 1. Extract the watermark according to the watermarking algorithm embedded in the vertex coordinates. If the copyright information is enough to prove copyright, the process is over.

Step 2. Extract the watermark according to the zero-watermark algorithm based on the statistical features, if the copyright information is enough to prove the copyright, the process is over.

On the contrary, the conclusion is that there is not enough evidence to determine copyright.

4. EXPERIMENTS

4.1. Generate Pseudo-Random Meaningful Watermark

Using the string “CEID” as copyright information, we convert it into the big character representation as shown in **Figure 1**.

Figure 6. Big character representation of CEID.

This big character representation is encoded in a matrix with 6 rows and 19 columns, Number -1 encodes the space and number 1 encodes the # character. The matrix is stored as a two-dimensional binary matrix 6×19. The matrix contains 47 bits value 1 and 67 bits value -1. To let the appearance of bits 1 and bits -1 be nearly the same, the padding technique is applied to this copyright image to let it have the nearly equal frequency of both 1 and -1 bits.

Figure 7. Padding copyright image of CEID.

The size of the new copyright image is 6×24 and the frequencies of 1 and -1 bits in the padding copyright image now are $71/144$ and $73/144$ respectively. Using Arnold’s transformation with 2 shuffled rounds, the shuffled copyright image or watermark seems to be a meaningless watermark. The watermark is shown in **Figure 8**.

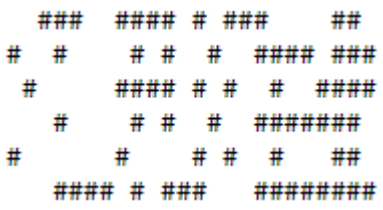


Figure 8. The watermark contains copyright information of CEID.

4.2. Embedding And Detecting Watermark

We tested the algorithm on a number of vector geographic data belonging to twenty-five northern provinces of Vietnam including provincial administrative boundaries, main road network and population concentration points. The selection of data of all three types of points, polylines, and polygons is to test the algorithm's ability to work with vector geographic data. We embedded the copyright information (called watermark) into the testing data to create layers of vector geographic data that have been embedded with copyright information with an error of 10^{-9} units (i.e., degree or meter depends on the map projection).

4.2.1. Experiment With A Polygon Vector Geographic Data

The polygon vector geographic data is the provincial administrative boundary data as shown in **Figure 9**.

Figure 9. The provincial administrative boundaries of twenty-five northern provinces of Vietnam.

This polygon data has 25 features (multi-polygons) with 39,797 vertices. So, the data has 79,594 coordinates, i.e., x and y coordinates. The copyright information is flattened into a 144-dimentional vector. Using our pseudo-uniformly distributed map, i.e., SipHash function, 79,594 coordinates are uniformly distributed into the watermark bit indexes, i.e., the set of $\{1, 2, \ldots, 144\}$. The number of coordinates embedding each watermark bit are shown in **Table 1**.

Table 1. The number of coordinates embedding each watermark bit

Bit index	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
No	559	569	568	516	550	533	570	560	531	559	522	508
Bit index	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
No	525	542	564	555	551	539	551	543	564	530	546	503
Bit index	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
No	528	585	503	584	521	553	552	547	603	561	566	513
Bit index	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**
No	530	545	546	537	601	570	551	536	556	574	567	577
Bit index	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**
No	548	547	578	490	535	545	518	582	584	577	577	510
Bit index	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**
No	546	581	554	533	635	524	553	536	540	618	574	571
Bit index	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**
No	540	486	588	541	538	548	612	585	588	598	557	563
Bit index	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**
No	548	507	597	580	520	527	573	549	577	553	595	593
Bit index	**96**	**97**	**98**	**99**	**100**	**101**	**102**	**103**	**104**	**105**	**106**	**107**
No	511	551	562	585	551	588	569	527	528	532	544	527
Bit index	**108**	**109**	**110**	**111**	**112**	**113**	**114**	**115**	**116**	**117**	**118**	**119**
No	515	620	519	553	569	580	529	533	554	525	505	520
Bit index	**120**	**121**	**122**	**123**	**124**	**125**	**126**	**127**	**128**	**129**	**130**	**131**
No	541	558	534	564	545	609	595	519	543	503	555	560
Bit index	**132**	**133**	**134**	**135**	**136**	**137**	**138**	**139**	**140**	**141**	**142**	**143**
No	580	549	512	537	591	583	551	544	520	591	540	590

The distribution of coordinates for each watermark bit index is shown in **Figure 10**.

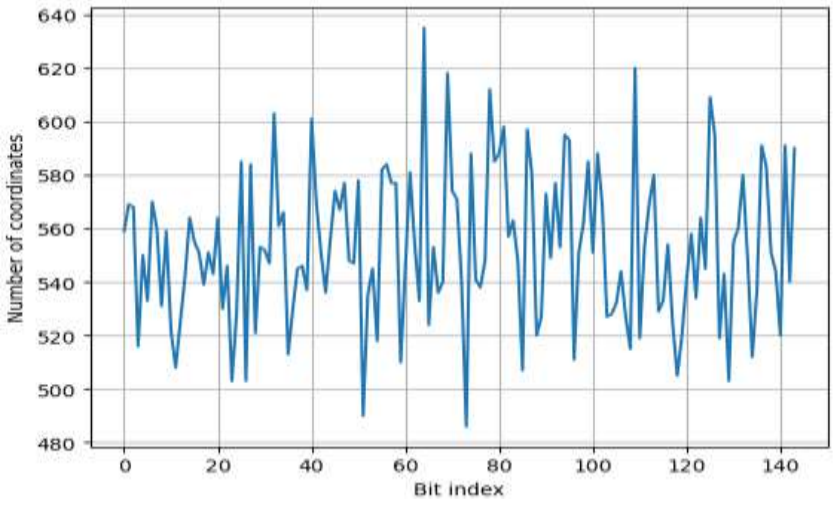


Figure 10. The distribution of coordinates for each watermark bit index.

The watermark bits seem to be uniformly distributed into spatial vertices. **Figure 11** shows a small area of the polygon data with vertices symbolized by the watermark bit index embedding in their x coordinates.

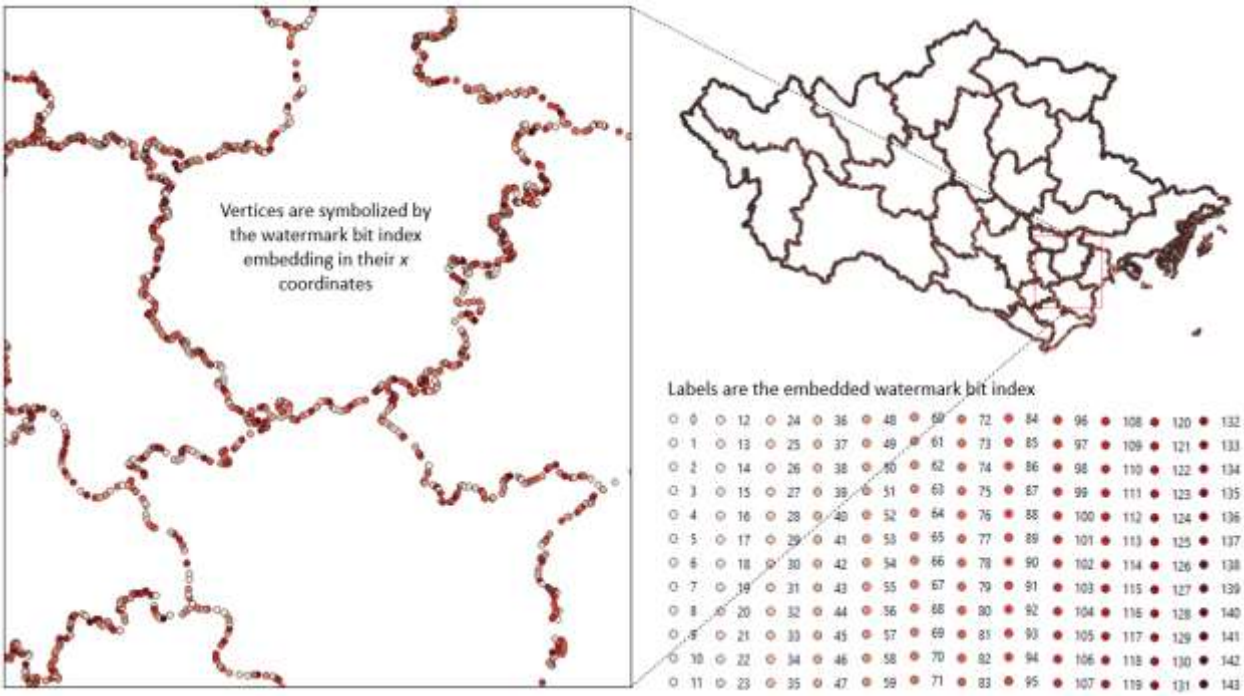


Figure 11. Uniform spatial distribution of watermark bits to coordinates.

We tested the stability of the watermark against vertex deletion, feature deletion, and feature modification attacks by clipping the watermarked polygon data to keep a small area as shown in **Figure 12**.

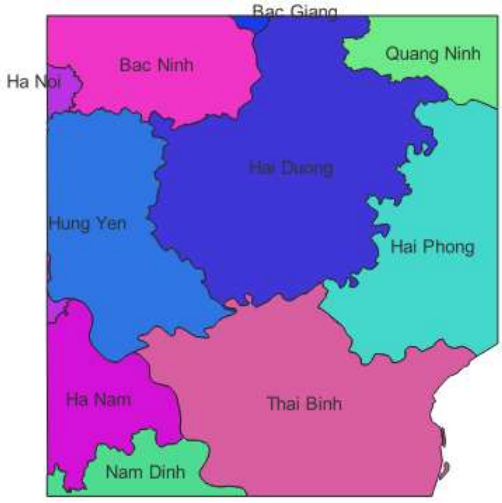


Figure 12. A clipped area of watermarked polygon data.

Extracted watermark W' is extracted from clipped polygon data and then watermark W'', normalized correlation coefficients (c_1, c_2) and thresholds (μ_1, μ_2) are calculated. The coefficient $c_1 = 1.0$ and the threshold $\mu_1 = 0.33333$; the coefficient $c_2 = 0.99210$ and the threshold $\mu_2 = 0.04078$. The automatic watermark detection concludes that the data contains a watermark or copyright information. The watermark W'' and the original watermark are applied to Arnold's inverse transformation and shown side by side to verify visually (see **Figure 13**).

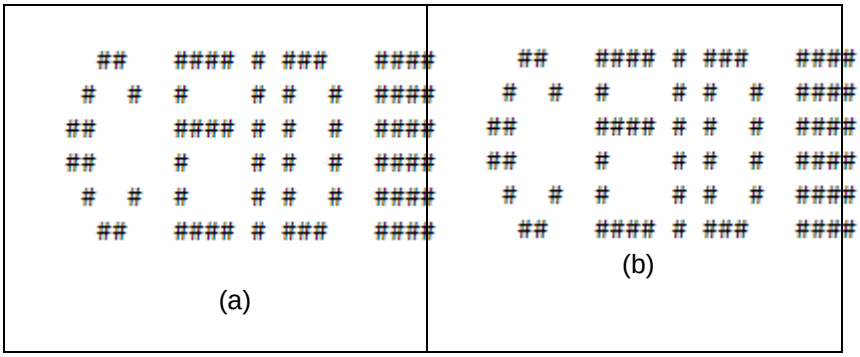


Figure 13. (a) original watermark, and (b) watermark W'' extracted from the data.

4.2.2. Experiment with polyline vector geographic data

The polyline vector geographic data is the major road network in twenty-five northern provinces of Vietnam as shown in **Figure 14**.

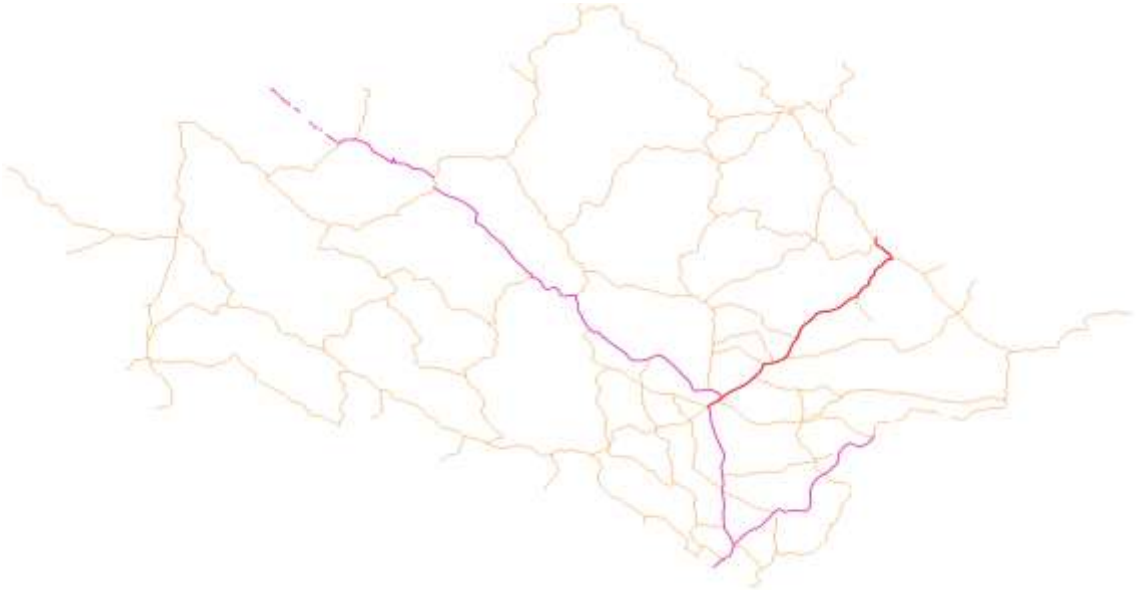


Figure 14. The major road network of twenty-five northern provinces of Vietnam.

This polyline data has 241 features (multi-polylines) with 2,111 vertices. So, the data has 4,222 coordinates, i.e., x and y coordinates. The watermark is a 144-dimensional vector. Using our pseudo-uniformly distributed map, i.e., SipHash function, 4,222 coordinates are uniformly distributed into the watermark bit indexes, i.e., the set of $\{1, 2, \ldots, 144\}$. The number of coordinates embedding each watermark bit is shown in

Table 2.

Table 2. The number of coordinates of polyline data embedding each watermark bit

Bit index	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
No	35	28	31	30	33	26	46	22	27	25	29	38
Bit index	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
No	26	31	41	13	21	32	26	32	42	18	23	39
Bit index	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
No	42	28	28	35	18	39	48	53	48	22	33	21

Bit index	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**
No	29	29	34	23	16	33	20	36	36	27	31	21
Bit index	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**
No	32	40	30	29	36	17	39	19	27	29	31	28
Bit index	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**
No	32	42	15	27	30	25	28	20	37	41	34	43
Bit index	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**
No	44	28	30	17	21	49	29	24	37	22	27	31
Bit index	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**
No	38	27	32	26	19	39	31	37	20	24	25	20
Bit index	**96**	**97**	**98**	**99**	**100**	**101**	**102**	**103**	**104**	**105**	**106**	**107**
No	34	26	25	26	17	20	41	27	35	17	31	27
Bit index	**108**	**109**	**110**	**111**	**112**	**113**	**114**	**115**	**116**	**117**	**118**	**119**
No	53	24	30	32	38	16	33	22	30	34	39	15
Bit index	**120**	**121**	**122**	**123**	**124**	**125**	**126**	**127**	**128**	**129**	**130**	**131**
No	16	27	29	24	18	13	22	26	34	30	38	29
Bit index	**132**	**133**	**134**	**135**	**136**	**137**	**138**	**139**	**140**	**141**	**142**	**143**
No	26	24	13	25	22	40	34	30	32	26	25	35

The distribution of coordinates for each watermark bit index is shown in **Figure 15**.

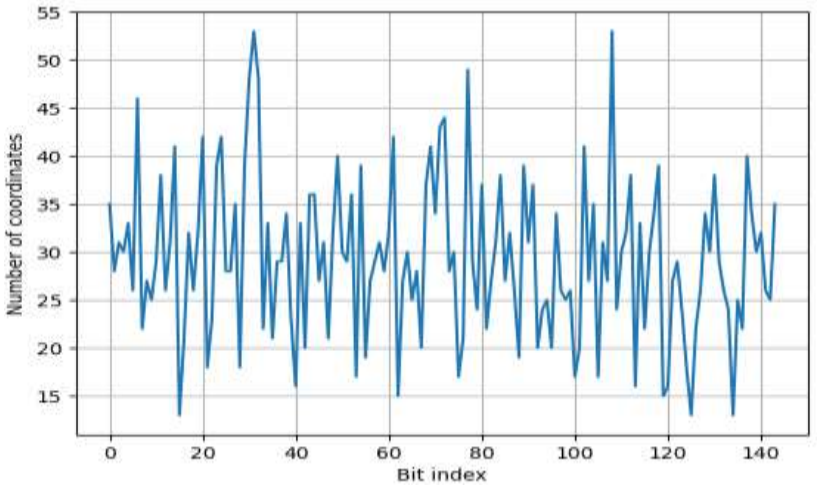


Figure 15. The distribution of coordinates of polyline data for each watermark bit index.

The watermark bits seem to be uniformly distributed into spatial vertices. **Figure 16** shows a small area of the polygon data with vertices symbolized by the watermark bit index embedding in their x coordinates.

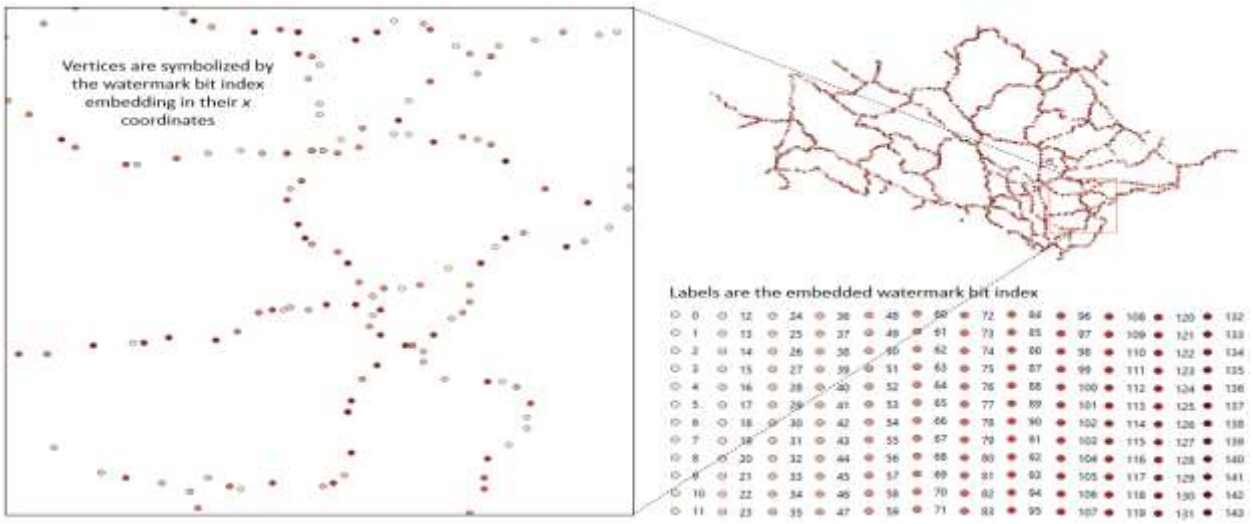


Figure 16. Uniform spatial distribution of watermark bits to coordinates of the polyline data.

We tested the stability of the watermark against vertex deletion, feature deletion, and feature modification attacks by clipping the watermarked polyline data to keep a small area as shown in **Figure 17**.

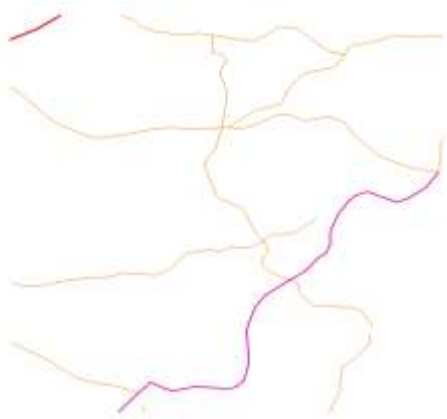


Figure 17. A clipped area of watermarked polyline data.

Extracted watermark W' is extracted from clipped polygon data and then watermark W'', normalized correlation coefficients (c_1, c_2) and thresholds (μ_1, μ_2) are calculated. The coefficient $c_1 = 0.75$ and the threshold $\mu_1 = 0.33333$; the coefficient $c_2 = 0.96648$ and the threshold $\mu_2 = 0.14949$. The automatic watermark detection concludes that the data contains a watermark or copyright information. The watermark W'' and the original watermark are applied to Arnold's inverse transformation and shown side by side to verify visually (see **Figure 18**).

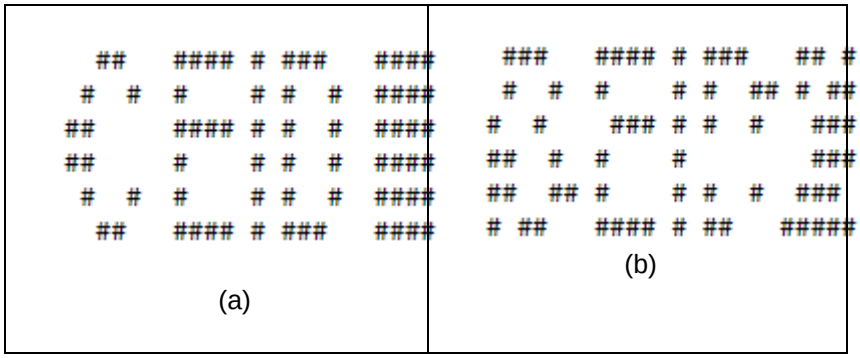


Figure 18. (a) original watermark, and (b) watermark W'' extracted from the polyline data.

4.2.3. Experiment With Point Vector Geographic Data

The point vector geographic data is the population concentration places in twenty-five northern provinces of Vietnam as shown in **Figure 19**.

Figure 19. The population concentration places of twenty-five northern provinces of Vietnam.

This point data has 341 features (points) and also 341 vertices. So, the data has 682 coordinates, i.e., x and y coordinates. The watermark is a 144-dimensional vector. Using our pseudo-uniformly distributed map, i.e., SipHash function, 682 coordinates are uniformly distributed into the watermark bit indexes, i.e., the set of $\{1, 2, \ldots, 144\}$. The number of coordinates embedding each watermark bit is shown in

Table 3.

Table 3. The number of coordinates of point data embedding each watermark bit

Bit index	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
No	3	4	2	9	2	6	2	4	3	8	1	1
Bit index	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
No	3	6	6	6	11	7	2	3	6	6	4	3
Bit index	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
No	7	4	3	5	7	5	5	3	3	5	2	9
Bit index	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**
No	3	7	2	8	6	5	4	3	6	6	7	3
Bit index	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**
No	3	3	5	5	2	4	5	4	4	4	5	10
Bit index	**60**	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**
No	2	5	5	4	6	4	6	5	8	6	4	3
Bit index	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**
No	3	4	3	3	8	5	6	3	3	5	9	3
Bit index	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**
No	6	5	3	9	9	9	7	4	3	7	3	5
Bit index	**96**	**97**	**98**	**99**	**100**	**101**	**102**	**103**	**104**	**105**	**106**	**107**
No	3	4	8	2	2	4	2	5	2	1	3	1

Bit index	**108**	**109**	**110**	**111**	**112**	**113**	**114**	**115**	**116**	**117**	**118**	**119**
No	4	9	4	8	3	12	4	5	5	4	4	5
Bit index	**120**	**121**	**122**	**123**	**124**	**125**	**126**	**127**	**128**	**129**	**130**	**131**
No	1	7	2	5	5	8	6	4	2	5	6	6
Bit index	**132**	**133**	**134**	**135**	**136**	**137**	**138**	**139**	**140**	**141**	**142**	**143**
No	3	6	4	6	7	6	5	4	5	4	5	3

The distribution of coordinates for each watermark bit index is shown in **Figure 20**.

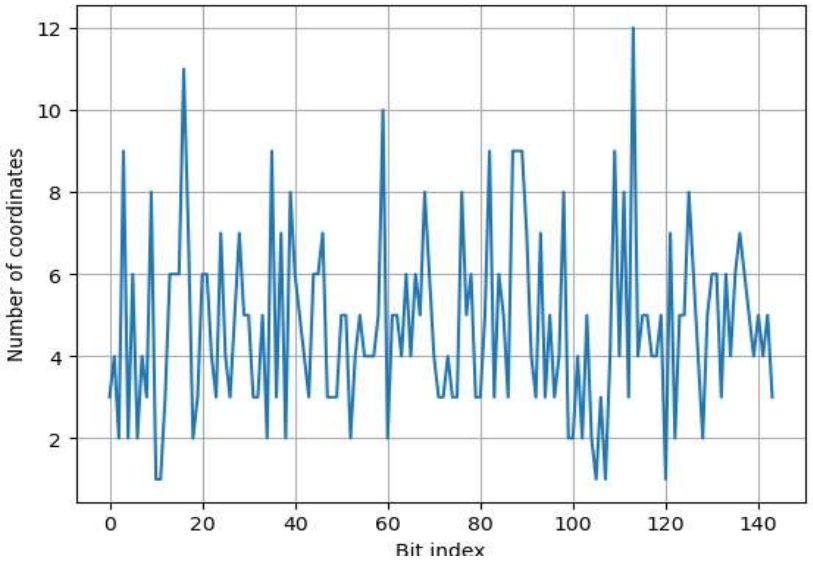


Figure 20. The distribution of coordinates of point data for each watermark bit index.

The watermark bits seem to be uniformly distributed into spatial vertices. **Figure 21** shows a small area of the polygon data with vertices symbolized by the watermark bit index embedding in their x coordinates.

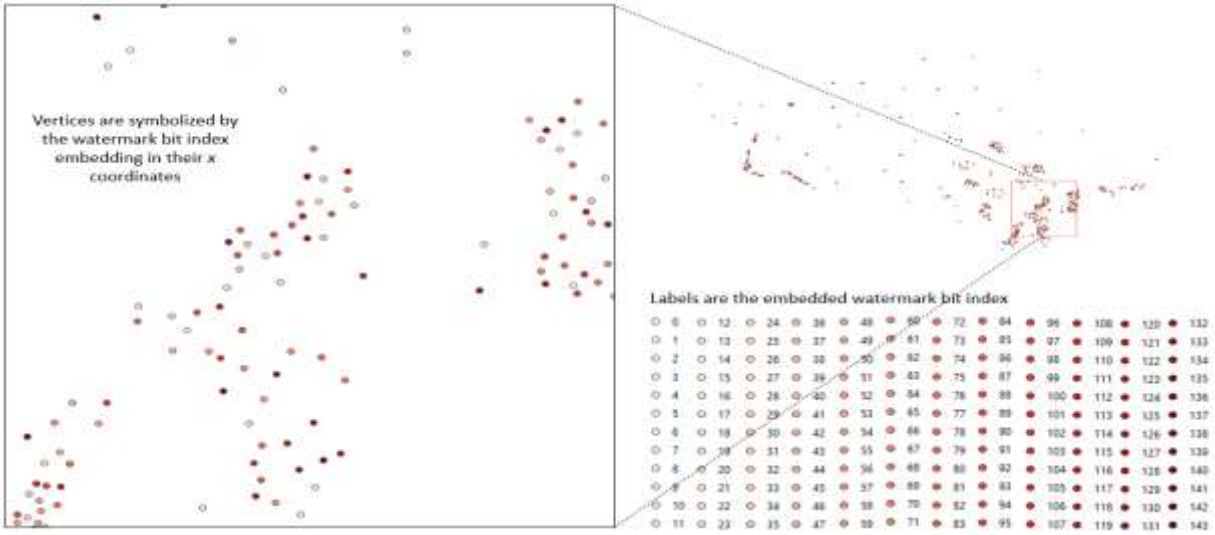


Figure 21. Uniform spatial distribution of watermark bits to coordinates of the point data.

We tested the stability of the watermark against vertex deletion, feature deletion, and feature modification attacks by clipping the watermarked polyline data to keep a small area as shown in **Figure 22**.

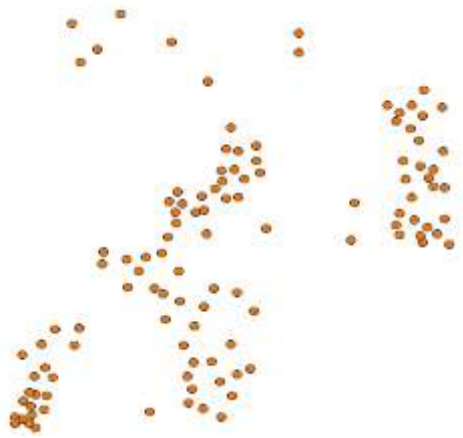


Figure 22. A clipped area of watermarked point data.

Extracted watermark W' is extracted from clipped polygon data and then watermark W'', normalized correlation coefficients (c_1, c_2) and thresholds (μ_1, μ_2) are calculated. The coefficient $c_1 = 0.77778$ and the threshold $\mu_1 = 0.33333$; the coefficient $c_2 = 1.0$ and the threshold $\mu_2 = 0.18814$. The automatic watermark detection concludes that the data contains a watermark or copyright information. The watermark W'' and the original watermark are applied to Arnold's inverse transformation and shown side by side to verify visually (see **Figure 23**).

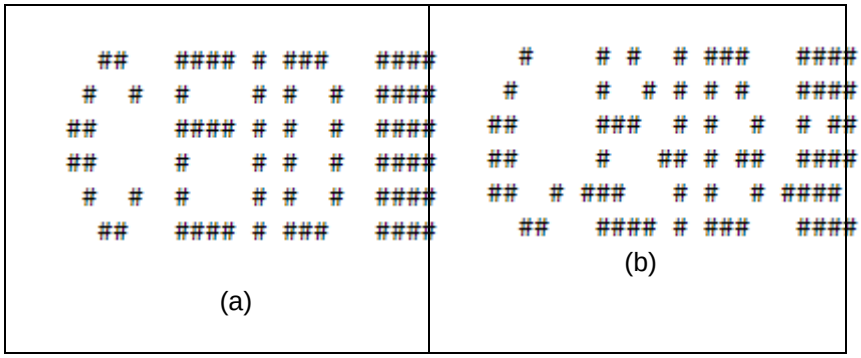
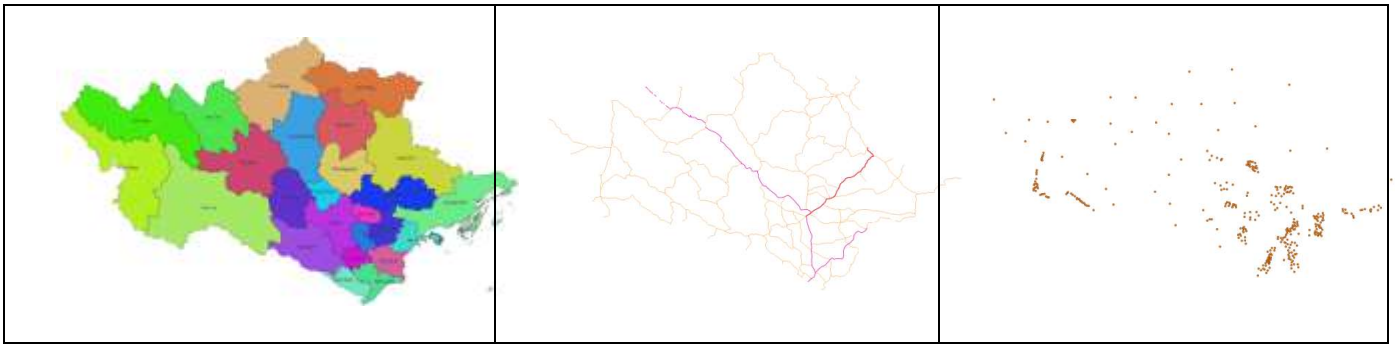


Figure 23. (a) original watermark, and (b) watermark W'' extracted from the point data.

4.3. Embedding And Detecting Zero-Watermark

We also tested the algorithm's resistance to coordinate system transformation attacks by embedding the watermark in all three data types (i.e., generating the zero-watermark) to generate the watermarked data. These watermarked data are then converted from the WGS-84 geographic coordinate system to the VN-2000 projected coordinate system. Applying the zero-watermark extraction procedure to these projected data, we get the results as shown in **Figure 24**.



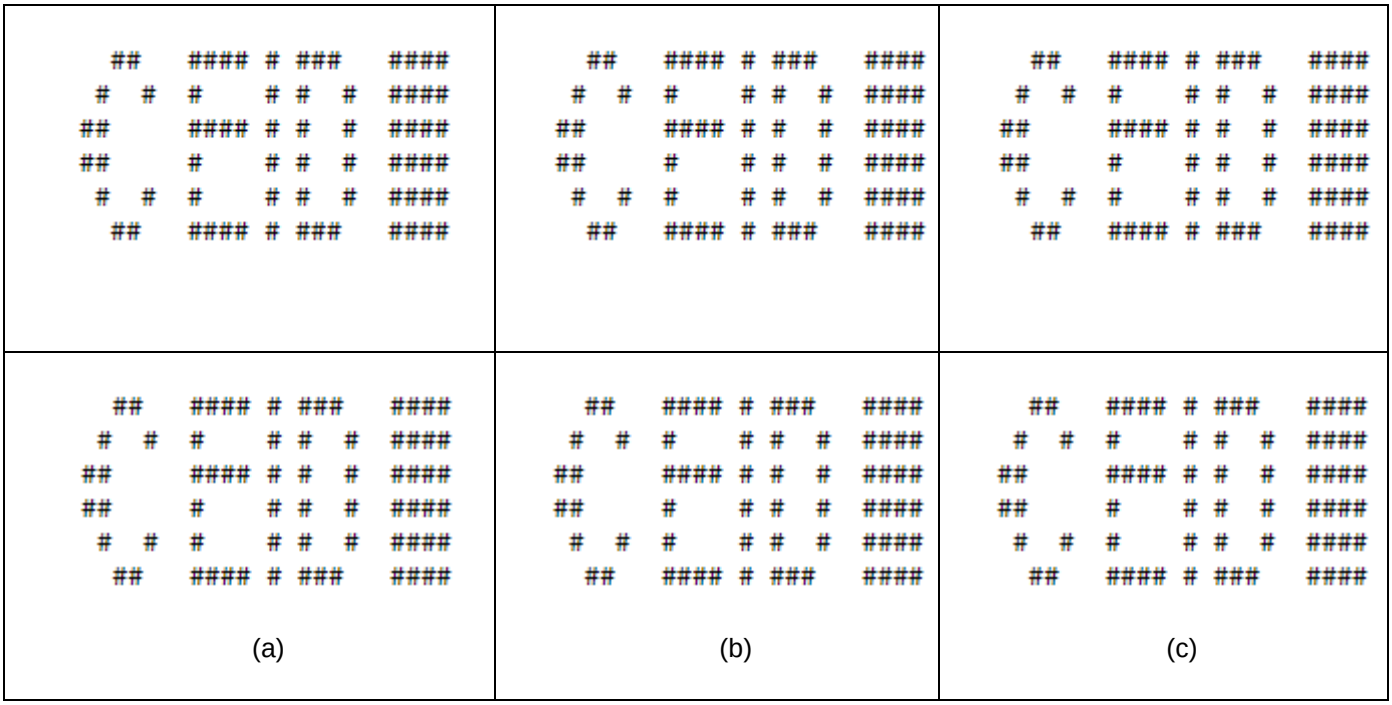


Figure 24. The rows in columns (a), (b), (c) are projected data, original copyright information, and information extracted from the data.

CONCLUSIONS

The algorithm integrates two types of watermarks, including spatial domain watermark and zero-watermark, allowing the watermark to be more resistant to common attacks. By using meaningful watermarks and visual representation in the form of copyright images, the algorithm allows visual copyright identification from which there is more evidence for copyright verification than using only statistical characteristics.

The algorithm has been expressed into program code using Python language that can be easily implemented into real applications.

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