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Reversible Fragile Watermarking Based on Difference Expansion Using Manhattan Distances for 2D Vector Map

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Abstract

The need for publishing maps in secure digital format, especially guarantees data integrity which motivated us to propose a scheme that detects and locates modification data with high accuracy while ensuring exact recovery of the original content. In particular, using fragile watermarking algorithm based on reversible manner to embed hidden data in 2D vector map for each spatial features. In this paper, a reversible data-hiding scheme is explored based on the idea of difference expansion with Manhattan distances. A set of invertible integer mappings is defined to extract Manhattan distances from coordinates and the hidden data are embedded by modifying the differences between the adjacent distances. Experiments results show that the proposed scheme has good performance in term invisibility and tamper modification ability. The scheme could detect modification data such addition and deletion some features, and exactly recovery the original content of the 2D vector map.

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Keyword : Reversible Watermarking; Fragile Watermarking; Difference Expansion; Manhattan Distances; Vector Map;

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1. Introduction

The digital map has the advantage of high precision, automated processes and lossless scaling compared to map in paper form. Ease of storage and distribution for the digital map brings other consequences, namely ease of data manipulation. It raises the needs of the producer maps that a publication map scheme that has security services to ensure integrity of the map. It also includes the need to eliminate distortions caused by the security services are applied to the map.

The integrity of the data refers to the authenticity of the data, that is, whether the data has been manipulated with a common or malicious data processing. A digital watermarking technology is used to embed hidden information in a digital map in order to indicate the author of the content [1][2][3][4], and authenticate the integrity of the content [5][6]. To remove the distortions introduced by authentication and tamper detection ability, fragile watermarking for digital maps can be integrated with reversible watermarking [7][8]. In reversible watermarking, the watermark is embedded into the host signal in an invertible manner so that after the hidden information are extracted, the signal can be restored to its original form before the embedding started. Fragile watermark is mainly used to protect the integrity and authenticity content of the data [9]. Once tampered with, the watermark will be damaged, the integrity of the data will be meaningless, it cannot represent the data is authentic Therefore, a fragile watermarking that exploits reversible watermarking schemes to embed the authentication data cannot only locate malicious attacks, but also recover the original content [6].

In this paper, a reversible scheme for fragile watermarking in 2D vector map are proposed based on modified difference expansion [7],[10] using Manhattan Distances. This approach has never been used before on previous researches. We use the Manhattan distances between adjacent vertices as the cover data to implement a distance-based scheme [7] to improve the capacity and invisibility in the result maps. The proposed scheme can be exactly detect and locate tampered features after manipulation data. The original 2D vector map can be precisely recovered after the extraction of the hidden data if no attack has occurred.

Outcomes of this research is a method of guaranteeing the integrity of the geospatial data more effectively and efficiently than what has been developed in several studies at this time. It is expected to increase confidence in the digital map transactions on a computerized environment.

We arrange the remaining part of this paper as follows : in Section 2 explain our reversible fragile watermarking scheme in detail. We present our experimental results and analysis of the algorithm in Section 3. Conclusions are summarized in Section 4.

2. The proposed watermarking scheme

In this section, we introduce a watermarking scheme in two stages. First, how watermarks were embeded into a vector map for each spatial features, as shown in Fig. 1. Second, how we extract the watermarks and recover the original vector map, as shown in Fig. 2.

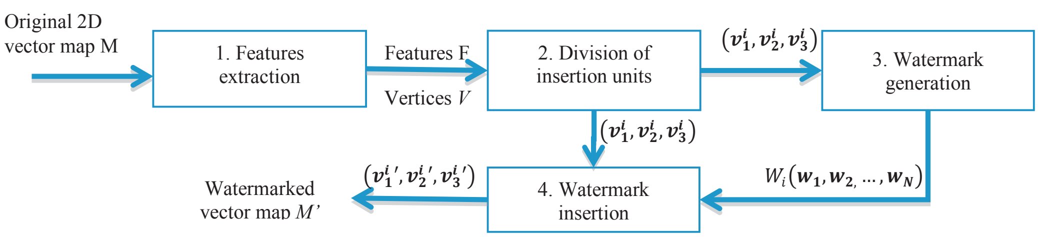


Fig. 1. Watermark insertion procedure.

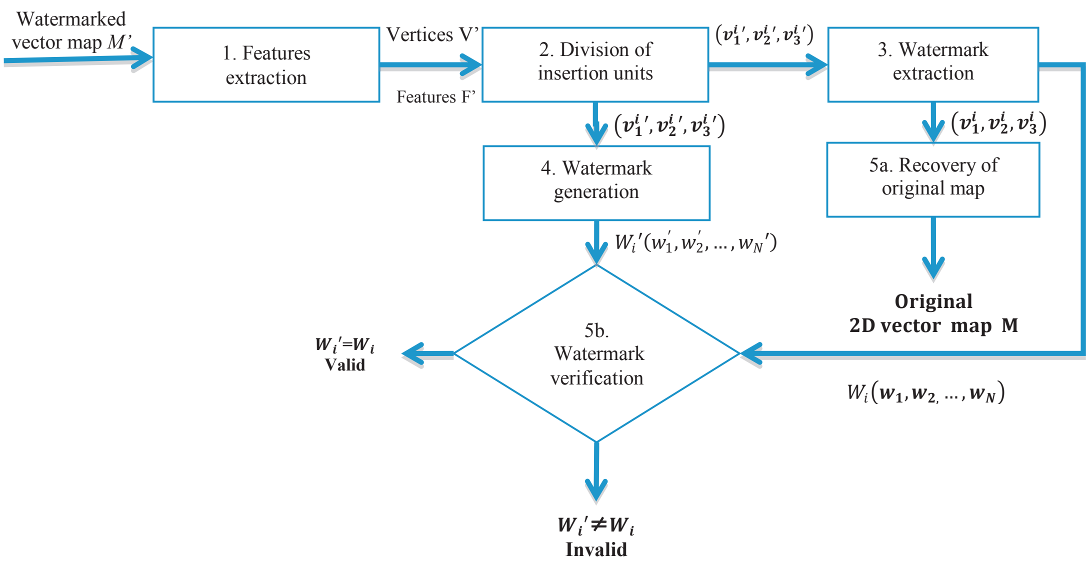


Fig. 2. Watermark verification procedure.

2.1. Watermark embedded procedure

A polyline feature is defined as a ordered set of vertices that forms one or more line segments, such thateach segment endpoint (called a vertex) $v(x, y)$is shared by exactly two segments. A polyline is closed if the endpoints are identical, called polygon. In general, the coordinates of vertices on a 2D vector map are floating-point numbers. Let d_{max} be the maximum number of digits after the decimal point and (x, y) be the original coordinates. For the purpose of restoring the original coordinates (x, y), the integer coordinates (x^i, y^i)can be extracted as Eq. (1).

$$(x^i, y^i) = \lfloor (x, y) \times 10^d \rfloor, d \leq d_{max} \tag{1}$$

For each features $F = \{vi|i \in [0, N]\}$, we group every three consecutive vertices as a insertion unit. Fig. 3 exhibits the structure of an insertion unit. Representation of N units in F are : $(v_1^i, v_2^i, v_3^i) = \{(x_1^i, y_1^i), (x_2^i, y_2^i), (x_3^i, y_3^i)\}, i \in \{1,2, \ldots\ldots, N\}$.

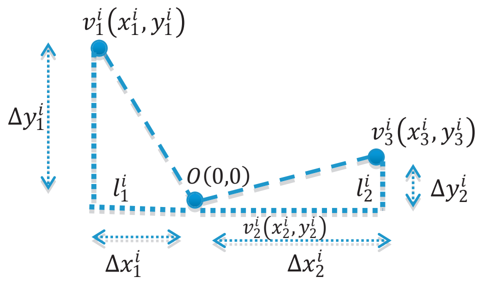


Fig. 3. An insertion unit.

The relative coordinates (Δx, Δy) for each insertion unit, with v_2^i as the center point$O(0,0)$) formed by Eq. (2).

$$\begin{cases} \Delta x_1^i = x_1^i - x_2^i \\ \Delta y_1^i = y_1^i - y_2^i \end{cases} \begin{cases} \Delta x_2^i = x_3^i - x_2^i \\ \Delta y_2^i = y_3^i - y_2^i \end{cases} \tag{2}$$

$$\begin{cases} l_1^i = |\Delta x_1^i| + |\Delta y_1^i| \\ l_2^i = |\Delta x_2^i| + |\Delta y_2^i| \end{cases} \quad \begin{cases} r_1^i = \left\lfloor \dfrac{|\Delta x_1^i| - |\Delta y_1^i|}{2} \right\rfloor \\ r_2^i = \left\lfloor \dfrac{|\Delta x_2^i| - |\Delta y_2^i|}{2} \right\rfloor \end{cases} \tag{3}$$

In Fig. 3 and Eq. (3), the Manhattan distances l_1^i and l_2^i denote the distances from the center point to its two neighbor vertices, respectively and r is an integer mean difference value which will not be modified during the embedded procedure. Within a pair, the difference d^i and integer-mean m^i of two manhattan distances are calculated as shown Eq. (4).

$$\begin{cases} d^i = l_1^i - l_2^i \\ m^i = \left\lfloor \dfrac{l_1^i + l_2^i}{2} \right\rfloor \end{cases} \tag{4}$$

$$d_i' = 2 \times d^i + w_k \tag{5}$$

We use the Manhattan distances for embedding watermark bits $w_k \in W(k = 1,2,\dots,N_W)$ by modifying the difference d^i as shown Eq. (5), if the insertion unit satisfy two conditions for embedded data. W is the embedded data, it could be cryptographic hash value of the original 2D vector map for verify data integrity or the secret data for secret communication. For the success of the proposed scheme, there are two conditions that must be met.

Condition 1. To ensure the original 2D vector map can be recovered, every watermarked vertices must stay at the same region with its original vertices. In other words, the relative coordinates of original vertices (Δx, Δy) must have the same sign of numbers with its watermarked vertices ($\Delta x'$, $\Delta y'$).

Condition 2. For ensuring the quality of watermarked 2D vector map, the distortion induced by embedded procedure should be constrained by the map's precision tolerance τ[7]. We use euclidean distances to calculate the distortions (Eq. (6)).

$$\sqrt{\left(x_1^{i\prime} - x_1^i\right)^2}, \sqrt{\left(x_3^{i\prime} - x_3^i\right)^2} \le \tau \tag{6}$$

If w_k has been finished embedded, the modified manhattan distances $l_1^{i\prime}$ and $l_2^{i\prime}$ are the obtained from d_i' and m^i by Eq. (7). And the coordinates vertices of the watermarked unit $(v_1^{i\prime}, v_2^{i\prime}, v_3^{i\prime})$ can be calculated by $l_1^{i\prime}$ and $l_2^{i\prime}$ using Eq. (8) and Eq. (9) which is selected according values of Δx_1^i dan Δy_1^i.

$$\begin{cases} l_1^{i\prime} = m_i + \left\lfloor \frac{d_i'+1}{2} \right\rfloor \\ l_2^{i\prime} = m_i - \left\lfloor \frac{d_i'}{2} \right\rfloor \end{cases} \tag{7}$$

$$\Delta x_1^{i\prime} = \begin{cases} r_1^i + \left\lfloor \frac{l_1^{i\prime}+1}{2} \right\rfloor, if\ \Delta x_1^i \ge 0 \\ -r_1^i - \left\lfloor \frac{l_1^{i\prime}+1}{2} \right\rfloor, if\ \Delta x_1^i < 0 \end{cases} \qquad \Delta x_2^{i\prime} = \begin{cases} r_2^i + \left\lfloor \frac{l_2^{i\prime}+1}{2} \right\rfloor, if\ \Delta x_2^i \ge 0 \\ -r_2^i - \left\lfloor \frac{l_2^{i\prime}+1}{2} \right\rfloor, if\ \Delta x_2^i < 0 \end{cases} \tag{8}$$

$$\Delta y_1^{i'} = \begin{cases} -r_1^i + \left\lfloor \frac{l_1^{i'}}{2} \right\rfloor, if\ \Delta y_1^{i'} \geq 0 \\ r - \left\lfloor \frac{l_1^{i'}}{2} \right\rfloor, if\ \Delta y_1^{i'} < 0 \end{cases} \qquad \Delta y_2^{i'} = \begin{cases} -r_2^i + \left\lfloor \frac{l_2^{i'}}{2} \right\rfloor, if\ \Delta y_2^{i'} \geq 0 \\ r - \left\lfloor \frac{l_2^{i'}}{2} \right\rfloor, if\ \Delta y_2^{i'} < 0 \end{cases}$$

$$\begin{cases} x_1^{i'} = x_2^i + \Delta x_1^{i'} \\ y_1^{i'} = y_2^i + \Delta y_1^{i'} \end{cases} \begin{cases} x_3^{i'} = x_2^i + \Delta x_2^{i'} \\ y_3^{i'} = y_2^i + \Delta y_2^{i'} \end{cases} \tag{9}$$

2.2. Watermark verification procedure

The watermark verification procedure consists of three basic processes: extraction of watermarks, verification of the watermarks, and recovery original map. Given the watermarked vector map M', the watermark can be extracted as follows :

1. Extract the watermarked map M' into $F_1', F'_2, \ldots \ldots, F'_D$ featuregroups which are in integers. For each group F'_i , we divide every three consecutive vertices as a watermarked insertion unit $(v_1^{i\prime}, v_2^{i\prime}, v_3^{i\prime}) = \{(x_1^{i\prime}, y_1^{i\prime}), (x_2^{i\prime}, y_2^{i\prime}), (x_3^{i\prime}, y_3^{i\prime})\}, i \in \{1,2, \ldots \ldots, N\}$. The following step 2) to 4) should be performed for every watermarked unit insertions.
2. Calculate the Manhattan distances $l_1^{i'}$ and $l_2^{i\prime}$ of the unit by Eq. (2) and (3).
3. Calculate the difference d_i' dan the integer-mean m^i of l_1^i and $l_2^{i\prime}$ using Eq. (4).
4. Collect the LSB of difference d_i' for all units, to obtain the extracted watermark W, after that calculate the original difference d_i using Eq. (10).

$$d_i = \left\lfloor \frac{d_i'}{2} \right\rfloor \tag{10}$$

After the procedure just shown, the original difference $d_i$of every unit is obtained. Combining with the integer-mean m^i, the original coordinates of every unit then can be calculated by Eq. (7) to (9). Then, for each unit. we calculate the watermark W'using the method described in section 2.1. A group F_i is deemed authentic if the two watermarks Wdan W' are equal; otherwisw it seen as tampered.

3. Results and analysis

The shape file format (.shp) of Environmental Systems Research Institute, Inc. (ESRI) is exploited for the scheme. In the experiment a simple shape file (.shp) format 2D vector map "Bogor road map" is used as the original map to test the performance of our scheme. The former vector map contains polyline features with 356 features and 2170 vertices. Because the geometric data structures of a polygon feature and polyline feature are identical, we show the result for polyline features in details.

In the first test case, we demonstrate the quality of our watermarking scheme. For evaluating the embedded vector map subjective quality, we compared the original 2D vector map and the watermarked ones. From Fig. 5a and 5b, we know the invisibility of the watermarkedvector map.

Root mean square error (RMSE) is exploited to measure the watermarked vector map objective quality by Eq. (11).

$$RMSE = \sqrt{\frac{\sum (V_{M'} - V_M)^2}{N}} \tag{11}$$

$V_{M'}$ and V_M are the corresponding vertices in the original map $(M)$and the watermarked map (M') and N denotes the total number of vertices in the maps. The RMSE of watermarked vector map in our experiment is 1.973. According to the watermark embedding procedure mentioned in section 2, a factor influencing the watermarked vector map quality is characteristics of the 2D vector map itself. In order to enhance the invisibility, the original vector map with higher correlation should be selected.

Fig 4 shown relationship among insertion distortion by Euclidean distances and watermarked vector map quality by RMSEs. If we want to increase the quality of watermarked vector map that we have to lower distortion by increasing limit of the map's precision tolerance. It causes the total number of insertion unit is decreased which means decrease the capacity of watermark can be inserted.

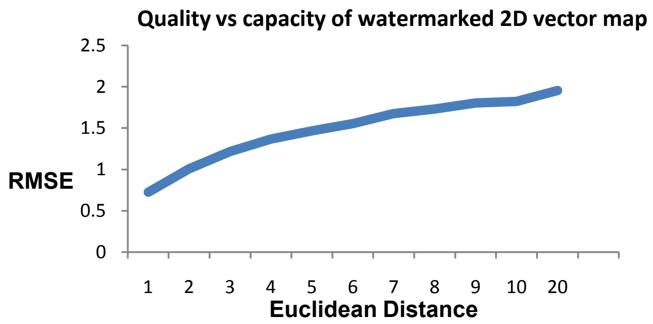


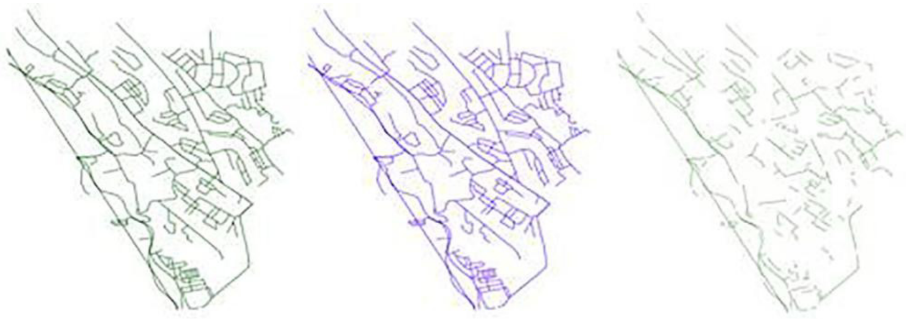
Fig. 4. Relationship between quality and capacity of watermarked 2D vector map

Fig. 5 is the experiment result. The vector map in Fig. 5a is watermarked by the scheme proposed in section 2 yielding the watermarked version seen in Fig. 5b. For evaluating the embedded vector subjective quality by human visual system (HVS), we compared the original vector maps and the watermarked ones. From Figs. 5a. and 5b, we know the invisibility of the watermarked vector maps. Fig. 5c illustrates subset of the watermarked vector map overlays with the original vector map to show differences between the two maps. These differences indicate shifts in the position coordinates of the original map features due to the insertion process. As long as the watermarked map has not been modified, the original map could be recovered accurately and two watermarks are exactly matched.

The tamper detection and localization ability of the proposed scheme has been demonstrated in the second test case. we modify some specific area purposely (modify the coordinates of some vertices, add some vertices, deletesome vertices). Fig. 6a. illustrates the vector map after watermark embedding which is manipulated using QGIS by one of example modification is deleted features operation. Later, integrity of the manipulated vector maps are tested using watermark verification procedure. Output of the watermark verification procedure is seen in Fig. 6(b). dashed line indicate the location where the tampering happened.

4. Conclusions

The proposed reversible fragile watermarking scheme was based on Manhattan distances to take features as computation unit, and embed watermark into 2D vector map. This scheme cannot only verify the integrity of the vector map, but also accurately locate the modification to certain features. In addition, the embedding of watermark information has taken into account the map's error tolerance. The vector map still has practical value after embedding the watermark. In occasions where high accuracy of data is required, the original vector map could be recovered through integrity verification, which better meets some specific application requirement. The experiment result show that the original vector map can be exactly recovered after the extraction of the watermark if no modification data process has occurred. From the result of test case of invisibility in the experiments, the important factor which determines the performance of the schemes is the quality of the selected cover data. Highly correlated cover data could result in high capacity and invisibility. One of our future works is exploring the scheme to be applied to point features. Another one is to enhance capacity of the scheme by iterative embedding on highly correlated data set.



(a) (b) (c)

Fig. 5. Experiments on the road map : (a) original vector map; (b) watermarked vector map; (c) the difference of them

(a) (b)

Fig. 6. Tamper detection and localization ability for the road map : (a) features deleted; (b) detected tampered features

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