A Robust Watermarking Scheme based on Delaunay Image Reconstruction Robust to Affine Transformation

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Abstract. This paper proposes a sub-channel image reconstruction algorithm based on Delaunay triangle. First, according to the different sensitivity of the human eye to the three color channels, different channels are used to avoid the influence of watermark embedding on pixels around the feature points. Then, feature points should be selected on the selected channel to make them have sufficient robustness. At this time, the location of the feature points extracted on the corresponding channel can be used as the watermark embedding position. Finally, considering the influence of geometric attacks such as affine transformation, this paper proposes a reconstruction algorithm based on Delaunay triangle, which uses feature point information to reconstruct the image before the watermark extraction, and extract the watermark on the reconstructed image. The effect of watermark extraction has been improved.

1. Introduction

Digital watermarking is a common method to protect information security and copyright, and it is an important direction in the research field of information hiding technology. Robust watermarking is also a hot research direction, and the synchronization of geometric robust watermarking is one of the difficult points of research. When the image is rotated, scaled, translated, sheared, etc., the position of the watermark information is also changed due to the geometric deformation, and the watermark information cannot be synchronized and cannot be extracted correctly. Among them, because affine deformation is not a single geometric deformation, the extraction of affine invariant features against affine deformation has always been the biggest difficulty facing image watermarking [1].

In recent years, the research on watermarking against geometric attacks has mainly focused on the use of invariant feature points [2-4], templates [5-7], normalization [8-10], histograms [11-12] and so on. Research using feature points generally uses the matching of feature points to reconstruct an image. This type of method generally does not consider the influence of interpolation and sampling on the watermark in the process of reconstructing the image. The method of using the template is to embed the template information along with the watermark information into the carrier image to recover the attacked image. The detection and deletion of template information is very fatal to watermark extraction. The normalization method is generally to find a normalization method that resists geometric attacks, and embed the watermark in the normalized image to achieve the purpose of resisting the attack. Watermarking technology based on histogram is also a common method of resisting geometric attacks.
Most of them use the histogram shape of the low frequency subband in the frequency domain to describe the watermark position. However, the limitation of the watermark based on the global histogram is that the number of embedded watermarks is relatively limited. This kind of method considers the increase and decrease of pixels appearing in the process of affine transformation systematically.

According to the characteristics of the color image can be divided into channels, this paper proposes image reconstruction and watermark embedding schemes based on different channels. Using feature points to estimate the affine matrix parameters for image reconstruction, the digital watermark can be embedded in the embedding area corresponding to the carrier image. The watermarking algorithm in this paper can effectively synchronize the watermark embedding area while resisting the attack of affine transformation, and then extract the watermark correctly.

2. Image reconstruction algorithm based on Delaunay triangle

In the anti-affine transformation watermarking scheme, image reconstruction is a very effective method to solve the watermark synchronization problem.

2.1. Image reconstruction algorithm idea

The affine matrix \(A\) contains scale, translation, and rotation attacks. We hope that the affine matrix \(A\) can be directly estimated, rather than the parameters of a single attack. Then the geometric distortion can be corrected by inverse affine transformation. The affine matrix can be constructed by the mapping relationship between three pairs of feature points and least square method to calculation. For a given affine matrix, match the point \((x_i, y_i)\) of the original image and the point \((x'_i, y'_i)\) of the image after being attacked, where \(i = 1, 2, \cdots, n\) the relationship can be described as:

\[
\begin{bmatrix}
  x'_1 \\
  x'_2 \\
  x'_3 \\
  \vdots \\
  x'_n \\
\end{bmatrix} = \begin{bmatrix}
  x_1 & y_1 & 1 \\
  x_2 & y_2 & 1 \\
  x_3 & y_3 & 1 \\
  \vdots & \vdots & \vdots \\
  x_n & y_n & 1 \\
\end{bmatrix} \begin{bmatrix}
  a \\
  b \\
  c \\
  d \\
\end{bmatrix}
\]

which is \(x' = GA_{abe}\) and

\[
\begin{bmatrix}
  y'_1 \\
  y'_2 \\
  y'_3 \\
  \vdots \\
  y'_n \\
\end{bmatrix} = \begin{bmatrix}
  x_1 & y_1 & 1 \\
  x_2 & y_2 & 1 \\
  x_3 & y_3 & 1 \\
  \vdots & \vdots & \vdots \\
  x_n & y_n & 1 \\
\end{bmatrix} \begin{bmatrix}
  e \\
  f \\
\end{bmatrix}
\]

which is \(y' = GA_{df}\).  

(1)

The elements in \(A_{abe}\) and \(A_{df}\) are the coefficients in affine matrix respectively. The best solution of the overdetermined equation is to find the vectors \(A_{abe}\) and \(A_{df}\) so that \(GA_{abe}\) and \(GA_{df}\) form the projection of the vector \(x'\) and \(y'\) on the vector space. The least squares solution of an overdetermined equation is the solution of the equation. In fact, the above least squares solution is equivalent to finding an affine matrix that minimizes the following objective function \(f_A\):

\[
f(A_a) = \sum_{i=1}^{n} \left( \begin{bmatrix} x'_i \\ y'_i \end{bmatrix} - \begin{bmatrix} x_i \\ y_i \end{bmatrix} \right)^2
\]

(2)

The process can be expressed as find the most suitable \(A_{a}\) to minimize the value of the objective function \(f(A_a)\). Where \(a = 1, 2, \cdots, n\), is expressed as the \(a\) th affine matrix.

The grid structure constructed by the Delaunay triangular grid algorithm is composed of multiple non-overlapping triangles. Using the least square method to estimate the affine transformation matrix of the corresponding sub-triangle in the Delaunay triangle grid, several affine matrices \(A_a\) can be obtained. However, due to the fact that different sub-triangles share the same feature point or share the same triangle edge in the grid structure, when traversing all triangles in the grid to estimate the affine matrix, it is necessary to record the triangle information \(Dots\) that has been calculated. If all three points in the
triangle to be calculated have been calculated, the next one will not be calculated, so as to improve the
calculation efficiency.

After estimating all the sub-triangles in the full grid, several affine matrices $A_n$ can be obtained, and
the coefficients of the same position in all affine matrices are averaged to obtain the final affine matrix
$A_{last}$, and the attacked image is corrected by inverse affine transformation. And restore the geometric
deformation of the attacked image.

2.2. Image reconstruction algorithm
Before extracting watermarks, we use ASIFT algorithm to extract feature points and construct a
corresponding feature point set $U'$ from the attacked image. Here, we use the highest threshold that can
filter enough feature points $F_k(x', y')$, where $k = 1, 2, \ldots, M$ for matching. Match it with the feature point
set $U$ used during embedding, and the feature point set can be used for image reconstruction is obtained.
The similarity between feature point set $U$ and feature point set $U'$ can be evaluated by calculating the
inner product between the vectors and negating the $\cos$ value of the obtained number. Then check
whether the point set $U''$ has a null value, if so it means that there is a feature point has not been matched.
The corresponding feature points should be delete to obtain a new feature point set $U_{del}$. Next we use
the point set $U''$ to generate the Delaunay triangulation structure $TRI_{af}$, if there is a feature point set
$U_{del}$, use it to generate the Delaunay triangulation structure $TRI_{be}$. Select three points of a triangle in the
structure $TRI_{af}$, calculate the affine matrix $A_a$ by matching the three points of the triangle in the
structure $TRI_{be}$, and count the three points of the triangle into the point set $Dots$. Then choose another
triangle three points that are not repeated in the structure $TRI_{af}$. Judge whether the three points of the
triangle are not in the point set $Dots$, if so, do not use them to calculate the affine matrix and re-select,
if not, match the three points of the triangle in the subdivision structure $TRI_{be}$ to calculate the affine
matrix $A_a$ and count the three points of the triangle into the point set $Dots$. Finally, after all triangles in the
structure $TRI_{af}$ have been executed, a number of sets of affine matrices $A_a$ are obtained, and the
final image reconstruction matrix is obtained by averaging. Where $I_{all}$ is the number of affine matrices.

$$A_{last} = \frac{1}{I_{all}} \sum_{i=1}^{I_{all}} A_a$$

(3)

3. The scheme of watermark
This section introduces the methods of embedding and extracting watermarks.

3.1. Embed watermark
Suppose the carrier image is $I$, the watermark sequence is a set $w$ of "0" and "1" bits of length $N$. The
ASIFT algorithm is used to extract feature points $F_i(x, y)$, where $k = 1, 2, \ldots, N$ on the G channel. The
center point $C(x, y)$ is used as the reference point, the Euclidean distance $\text{Dist } F_i$ between $C(x, y)$
and each feature point is calculated separately, and the feature point $F(x_{be}, y_{be})$ with largest distance is
selected as the location point. Calculate the slope of the line formed by $C(x, y)$ with $F(x_{be}, y_{be})$ and
record it as $FC-\text{Begin}$. $F(x_{be}, y_{be})$ will be used as the starting point for embedding watermark, then
the feature points will be arranged in the order from left to right and top to bottom. After the image is
scanned, it will continue to scan from the point \((0,0)\) until the point \(F(x_{be},y_{be})\) is scanned. The slope of the line between the last feature point and \(C(x,y)\) is \(FC – End\). The points \(F(x_{be},y_{be})\) and \(FC – Begin\), \(FC – End\) are used as keys.

The steps of the watermark embedding algorithm are as follows:
Step1: Extracted area of \(S \times S\) size, where \(S = 2r + 1, r\) is the radius. Sort the pixels with gray level;
Step2: After sorting, use lowest level \(IL_l\), highest level \(IL_h\) and middle level \(IL_m\) to calculate the two intervals \(IL_l\) and \(IL_h\) to get the moving range;
\[
\begin{align*}
IL_l &= IL_m - \gamma(II_m - IL_l) \\
IL_h &= IL_m + \gamma(II_h - IL_m)
\end{align*}
\]
\(\gamma, 0 < \gamma < 1\) is used to control the variables of the pixel interval.
Step3: The number of pixels to be moved is \(N_{MP} = S \times S \times \alpha\), \(\alpha\) represents the variable of the ratio of the number of pixels to be moved to the total number of pixels in the corresponding area,
\[
\begin{align*}
index(MP1) &= index(IL_m) - N_{MP} / 2 \\
index(MP2) &= index(IL_m) + N_{MP} / 2
\end{align*}
\]
where index represents the index of the gray level in the corresponding sorting matrix.
Step4: If watermark data bit is 1, changing the intensity level value of the moving pixel to \(IL_l\), move the pixel to the "1 area"; if the watermark data bit is 0, move the pixel to the "0 area". Therefore, a special intensity level histogram distribution is generated, indicating the watermark data bits.

3.2. Extract location watermark
Before watermark is extracted, the key is first decoded to retrieve the information it carries. If there is any affine transformation attack, use decoded feature point information to estimate inverse affine matrix, and reconstruct the attacked image to original position. Then extract and match the feature points on the restored image again, and find the center point \(C'(x',y')\) of the reconstructed image, use it as a reference point and calculate the Euclidean distance between \(C'(x',y')\) and the extracted feature points. The feature point \(F'(x'_{be},y'_{be})\) with largest Euclidean distance seen as anchor point, calculates its slope with the center point, and compares it with \(FC – Begin\). If they are consistent, \(F'(x'_{be},y'_{be})\) will be used as the starting point of the watermark sequence extraction, then the feature points will be arranged in order from left to right and top to bottom. After the image is scanned, continue scanning from the point \((0,0)\) until the point \(F'(x'_{be},y'_{be})\) is scanned. If it is inconsistent, calculate all slope of the straight line formed between the feature point and the center point, find the feature point match with \(FC – End\), then arrange the feature points in the order from right to left and bottom to top. After the image is scanned, continue scanning from the point \((0,0)\) until the starting point, the sequence must be reversed before use.

When extracting the watermark, in each area the pixel intensity level is compared with the corresponding \(IL_m\) value. The number of pixels with an intensity level greater than \(IL_m\) is calculated as \(C0\), and the number of pixels with intensity level less than \(IL_m\) is calculated as \(C1\). For each area, compare \(C0\) with \(C1\), if \(C0>C1\), the watermark bit is "0"; otherwise, the watermark bit is "1".

4. Experimental results and analysis
The simulation experiment is implemented in the MatlabR2014a environment of the Windows 7 operating system. A total of 50 test images are used in the experiment, all of which are \(512 \times 512\) color images, with pixel values between \([0,255]\). The PSNR values of ‘Barbara’, ‘Boat’, ‘Lena’, ‘Man’ are 43.49, 40.87, 43.16, and 41.97 dB, and the SSIM values are 0.996, 0.997, 0.998, and 0.996, respectively.
On the selected test images, experiments were carried out on the following 7 attack types: rotation, scaling, JPEG compression, median filtering, low-pass filtering, noise pollution and affine transformation. In the case of embedded 16-bit watermark, the results show the effectiveness of the proposed watermarking scheme.

We use different affine matrices in affine transformation attack experiment. They are respectively (a) \[
\begin{bmatrix}
1.15 & 0.1 & 0 \\
0.15 & 1.13 & 0 \\
0 & 0 & 1
\end{bmatrix},
\]
(b) \[
\begin{bmatrix}
1 & 0.1 & 0 \\
-0.15 & 1.1 & 0 \\
0 & 0 & 1
\end{bmatrix},
\]
(c) \[
\begin{bmatrix}
0.9 & -0.12 & 3 \\
-0.1 & 1.09 & 5 \\
0 & 0 & 1
\end{bmatrix},
\]
corresponding images are in Figure 1.

Since feature points can be better reconstructed according to the constructed Delaunay triangulation structure after matching, and feature points are not in the same channel of watermark embedding positions, the watermark embedding has less impact on the feature points, and the reconstructed image can easily extract the feature points corresponding to the location. Therefore, the reconstructed image can effectively extract the corresponding watermark, and the effect is shown in table 1.

| Affine Attack | Baboon | Pepper | Lena | Sailboat on lake |
|---------------|--------|--------|------|------------------|
| (a)           | 14/16(87.5%) | 13/16(81.25%) | 13/16(81.25%) | 13/16(81.25%) |
| (b)           | 14/16(87.5%) | 14/16(87.5%) | 15/16(93.75%) | 14/16(87.5%) |
| (c)           | 13/16(81.25%) | 13/16(81.25%) | 14/16(87.5%) | 14/16(81.25%) |

Table 2 mainly compares the experimental results of different methods under common image processing attacks. The results show that the method in this paper is robust against noise, filtering and JPEG compression attacks. Compared with other algorithms, this method can perform better in filtering and JPEG compression attacks at the same time.

| Attacks                | Thanh[2] | Pun[3] | Lyu[4] | Ours |
|------------------------|----------|--------|--------|------|
| Gaussian noise 0.03    | 0.984    | 0.825  | 0.654  | 0.823|
| Salt and pepper noise 0.5 | 0.925    | 0.948  | 0.773  | 0.953|
| Median filter 4×4      | 0.851    | 1      | 0.675  | 1    |
| JPEG 80                | 0.965    | 1      | 0.821  | 1    |

Table 3. The correct rate of watermark extraction under common geometric attacks

| Attacks            | Thanh[2] | Pun[3] | Lyu[4] | Ours |
|--------------------|----------|--------|--------|------|
| Rotation 10°       | 0.917    | 0.950  | 0.886  | 0.969|
| Rotation 30°       | 0.823    | 0.850  | *      | 0.906|
| Scaling 1.5        | 0.947    | 1      | 0.982  | 1    |
| Scaling 0.8        | 0.943    | 1      | 0.943  | 1    |

Table 3 mainly compares the experimental results of different methods under different parameter rotation and scaling attacks. It can be seen that as the rotation angle increases, the accuracy of different schemes has shown different degrees of decline, but the method in this paper not only has the highest
accuracy rate, but also has a relatively slow decrease in accuracy rate, showing robustness to rotation. The experiments related to zooming attacks include zooming in and zooming out. Since the pixels increased by zooming follow the interpolation rules, the original pixels will not be greatly affected when the image is restored, so the effect is better; the restoration of the image after the zooming attack is related to the surrounding pixel values, and Because the method in this paper is a histogram scheme attached to feature points, it shows very strong robustness.

5. Conclusion
This paper draws on the uniqueness and closestness of the Delaunay triangulation structure, and proposes an image reconstruction algorithm based on the Delaunay triangle. Then, in view of the problem that watermark embedding will affect the extraction of corresponding location feature points, different channels are used to extract and embed feature points. It not only ensures that the extraction of feature points conforms to the human visual effect, but also ensures that the embedding of the watermark does not affect the extraction of feature points. The image reconstruction algorithm based on Delaunay triangle reduces the impact on the reconstruction matrix when individual feature points are offset, and avoids the problem of inability to match when the feature points are lost.

The results show that the method in this paper has a good performance in computing the inverse affine matrix image reconstruction, and at the same time has good robustness under a considerable range of different attacks. Comparing the various methods of, the method in this paper not only performs well in general single attacks such as rotation and scaling, but also performs well when combined attacks of rotation and scaling occur.

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