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A Novel Watermarking Algorithm based on SURF and SVD

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Abstract

Protection against geometric distortions and common image processing operations becomes a much challenging task in image watermarking. To achieve this, a novel watermarking algorithm based on Speeded Up Robust Features (SURF) and Singular Value Decomposition (SVD) was presented for digital image *copyright protection. By introducing the SURF's key points matching and geometric distortion estimation, the attacked watermarked image could be corrected and the watermark synchronization was realized. In this way, the feature regions of the host image, which were used for information hiding, could be correctly detected by the improved Harris-Laplace corner detector even after signal processing and geometric attacks. Finally, the watermark information were embedded into the U matrix of SVD of the host image. The application of the proposed scheme makes the watermark capable of transparent hiding. Extensive experimental results demonstrate that our technique performs better than traditional methods under different attacks.*

Keywords: *Speeded Up Robust Features; improved Harris corner detector; SVD*

1. Introduction

Digital watermarking is an efficient solution for copyright protection, which inserts copyright information, the watermark, into the host contents. The special application of digital watermarking technique requires that the embedded watermark should be not only transparent to observers, but also robust enough so that it cannot be easily destroyed or removed after some digital image processing or attacks. Various attacks have been reported to be effective against watermarking methods. Among them, geometric distortion is known as one of the most difficult attacks to resist. Geometric distortion desynchronizes the location of the watermark and hence causes incorrect watermark detection. In such cases, the watermark synchronization process is required to calculate the watermark location before watermark insertion and detection and is crucial for the robustness of the watermarking system.

Nowadays there are many existing watermarking algorithms [1-4]. In [2] the authors presented a watermarking approach which embedded the singular values (SVs) of the original image into the watermark one to attain the lossless objective. The scheme degraded the quality of the embedded watermark image by replacing SVs of the watermark image with those of the original one to some acceptable degree in advance. Bas et al. [3] proposed a content-based synchronization method, in which they first extracted salient feature points and then decomposed the image into a set of disjoint triangles through Delaunay tessellation. The sets of triangles (the patches) were used to insert and detect the watermark in the spatial domain.

In this paper a novel SURF and SVD based watermarking algorithm is proposed. The overview of our scheme is shown in Figure 1. First, the feature regions which are used for watermark insertion are extracted, and then the SVD are performed on each region and the watermark is embedded. Finally the SURF descriptors are extracted from the watermarked image and saved for future attack type estimation and attacked image correction. In this way, the watermark embedding positions are ensured to be stable and the watermark could be extracted accurately.

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The rest of this paper is organized as follows. Section 2 introduces SURF based image correction and Section 3 introduces the local feature region extraction in detail. In Section 4, we describe the watermark embedding algorithm and extraction algorithm respectively. Experimental results are exhibited in Section 5. Finally, conclusions are given in Section 6.

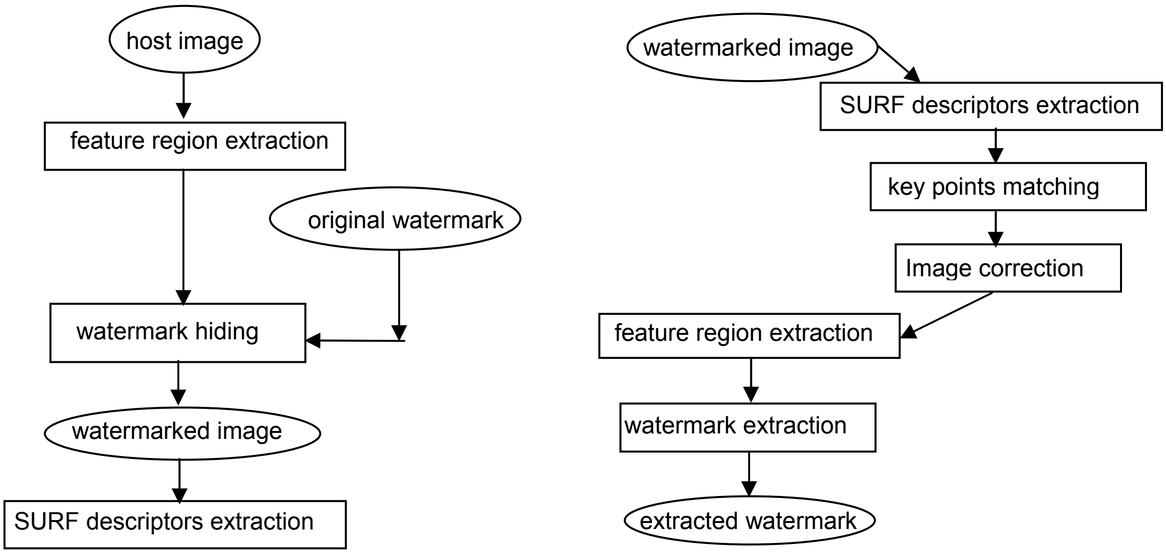

Figure 1. An overview of the proposed watermarking scheme. (a) embedding scheme. (b) extraction scheme.

2. Image Correction Based on SRUF

SURF (Speeded Up Robust Features) is a novel scale- and rotation-invariant interest point detector and descriptor proposed in [5]. It approximates or even outperforms previously proposed schemes with respect to repeatability, distinctiveness, and robustness, yet can be computed and compared much faster.

In this paper, the stable SRUF key points of watermarked image are used to estimate geometric distortion factors and correct the watermarked image, including image rotation distortion correction, scale distortion correction and translation distortion correction. After watermark embedding, the key points and their corresponding descriptors of the watermarked image are extracted and saved. In the process of watermark extraction, the attacked watermarked image's key points are firstly extracted, and then the key points matching are started. Finally, the matching points will be listed and the distortion factor will be calculated. As soon as we get the geometric distortion factor, the attacked image will be corrected. Compared with the SIFT method in our previous work [6], the SURF has same correction effect as SIFT but takes less time.

The detailed steps of SURF are as follows.

2.1. Constructing the Hessian Matrix

Given a point x = (x, y) in an image I, the Hessian matrix H(x, σ) in x at scale σ is defined as follows

$$H(x,\sigma)=\begin{bmatrix} L_{xx}(x,\sigma) & L_{xy}(x,\sigma) \\ L_{xy}(x,\sigma) & L_{yy}(x,\sigma) \end{bmatrix} \quad (1)$$

where $L_{xx}(x, \sigma)$ is the convolution of the Gaussian second order derivative $\frac{\partial^2}{\partial x^2} g(\sigma)$ with the image I in point x, and similarly for $L_{xy}(x, \sigma)$ and $L_{yy}(x, \sigma)$.

The Hessian determinant is calculated according to the Formula (2), where D_{xx}, D_{yy} and D_{xy} denote the weighted box filter approximations in the x, y and xy-directions.

$$\det(H_{approx}) = D_{xx}D_{yy} - (0.9D_{xy})^2 \quad (2)$$

The search for local maxima of this function over both space and scale yields the interest points for an image. The exact method for extracting interest points is explained in the following part.

2.2. Constructing the Scale-Space

The scale space is analyzed by up-scaling the filter size rather than iteratively reducing the image size. As the processing time of the kernels used in SURF is size invariant, the scale-space can be created by applying kernels of increasing size to the original image. This allows for multiple layers of the scale-space pyramid to be processed simultaneously and negates the need to sub sample the image hence providing performance increase.

2.3. Accurate Interest Point Localization

The task of localizing the scale and rotation invariant interest points in the image can be divided into three steps. First the responses are thresholded such that all values below the predetermined threshold are removed. Increasing the threshold lowers the number of detected interest points, leaving only the strongest while decreasing allows for many more to detect. Therefore the threshold can be adapted to tailor the detection to the application. After thresholding, a non-maximal suppression is performed to find a set of candidate points. The final step in localizing the points involves interpolating the nearby data to find the location in both space and scale to sub-pixel accuracy.

2.4. Orientation Assignment

To determine the orientation, Haar wavelet responses of size 4σ are calculated for a set of pixels within a radius of 6σ of the detected point, where σ refers to the scale at which the point was detected. The specific set of pixels is determined by sampling those from within the circle using a step size of σ.

The responses are weighted with a Gaussian centered at the interest point. In keeping with the rest the Gaussian is dependent on the scale of the point and chosen to have standard deviation 2.5σ. Once weighted the responses are represented as points in vector space, with the x-responses along the abscissa and the y-responses along the ordinate. The dominant orientation is selected by rotating a circle segment covering an angle of $\frac{\pi}{3}$ around the origin. At each position, the x and y-responses within the segment are summed and used to form a new vector. The longest vector lends its orientation the interest point.

3. Local Feature Region Extraction

The Harris-Laplace corner detector, which combines Harris detector with Laplace, computes a multi-scale representation for the Harris interest point detector and then selects points at which a local measure (the Laplace) is maximal over scales. This provides a set of distinctive points which are invariant to scale, rotation and translation as well as robust to illumination changes and limited changes of viewpoint. Unlike the key points of SURF, the feature points detected by the improved Harris corner detector are always the places which are suitable for hiding information. After image correction, the extracted feature points from the original image and corrected image could be well matched.

In this paper, we adopt an improved Harris-Laplace corner detector [7], which costs less computation time and uses the weighted average Harris response as shown in Formula (3), to detect the feature points.

$$H_n = \sum_{k=1}^{n} p(k)H(x, y, k) \quad (3)$$

Where p(k) denotes the weight function of the kth scale.
The improved Harris detection function is as Formula (4).

$$H(x,y,n)=(s\varepsilon^n\sigma)^2 g(x,y,\varepsilon^n\sigma) * \begin{vmatrix} L_x^2(x,y,s\varepsilon^n\sigma) & L_x(x,y,s\varepsilon^n\sigma)L_y(x,y,s\varepsilon^n\sigma) \\ L_x(x,y,s\varepsilon^n\sigma)L_y(x,y,s\varepsilon^n\sigma) & L_y^2(x,y,s\varepsilon^n\sigma) \end{vmatrix} \quad (4)$$

where ε, s, σ are constants, ε denotes the scale factor, the value of ε, s and σ are set to 1.4, 0.7 and 1 respectively, p(k) equals to k. $g(x,y,\varepsilon^n\sigma)$ is Gaussian circular window with variance σ, * means convolution, L_x and L_y respectively denotes the gradient magnitude at x direction and y direction.

In this paper, to help in achieving robustness towards attacks such as cropping, translation or localized image changes, feature points that found by the improved Harris-Laplace corner detector are used to locate the positions of watermark embedding.

3.1. Local Feature Region Detection

We set the feature points found by the improved Harris corner detector as the central points and carve up the host image into a serious of sub-images to hide the watermark information. Because not all the sub-images are suitable for embedding watermark with imperceptibility, the detailed method for choosing the regions to hide information is based on the following three steps.

Step 1：Select each feature point by the decreasing order of their magnitude of the response function, then set the feature point as the central point and construct a square region size of $L_{region} \times L_{region}$ pixel.

Step 2: In order to ensure the imperceptibility of the proposed watermarking scheme, the average luminance of the pixels in the square region must be smaller than $T_{lu\min ance}$.

Step 3: Make sure the square regions are non-overlapped. If the regions are overlapped, we only hold the region with large magnitude of the response function or with more feature points.

After the local feature region extraction, the sub-images which have complex texture and median luminance are obtained and used to hide the watermark.

4. Watermarking Algorithm

4.1. Embedding Algorithm

Singular Value Decomposition (SVD) is one of the most powerful numeric analysis techniques and its application in image compression and image watermarking field is also compelling [8-9].

Let A be a grayscale image with size of m×n. Every real matrix A can be decomposed into three matrices as $A = USV^T$ by SVD, where U and V are orthogonal matrices with size of m×m and n×n respectively, S is a diagonal matrix with the same size as A.

In this sub-section, we employ SVD to embed watermark into the selected local feature regions of host image. After studying the characteristics of U matrix in the result of SVD, we get the conclusion that not all the neighboring coefficients in the first column in U matrix follow the rule that the relationship were preserved when general image processing was performed. So we adopt a new method to embed watermark based on the algorithm of [8].

The SVD_based algorithm is described as follows:

Step 1: Select the local feature regions according to the magnitude of the response of improved Harris detector in decreasing order.

Step 2: Perform SVD on the $L_{region} \times L_{region}$ feature region and get the U component.

Step 3: Define |y| denotes the absolute value of the elements of y, N_{row} denotes the row number in the first column of U component, |d| denotes the difference between the neighboring coefficients, as shown in Formula (5). T_{block} denotes the threshold value which is used to select the feature regions which can keep the relationship unchanged. The algorithm is finished when all the watermark bits of $\mathrm{W}_{\mathrm{encoded}}$ have been embedded into the host image.

$$|d| = \| \mathrm{U}(N_{row}, 1)| - |\mathrm{U}(N_{row} + 1, 1)\| \quad (5)$$

Step 4: Insert one bit watermark signal into the selected feature region following the code below.

```
if(|d| <= T_block)
        if(|U(N_row,1)|-|U(N_row +1,1)|>0)
{
w1=1;  w2=0;
Result1=-||U(N_row,1)|+| T_global -|d||/2|;
Result2=-||U(N_row +1,1)|-|T_global -|d||/2|;
Result3=-||U(N_row,1)|-|T_global +|d||/2|;
Result4=-||U(N_row +1,1)|+|T_global +|d||/2|;
}
else
{
w1=0;  w2=1;
Result1=-||U(N_row,1)|-|T_global +|d||/2|;
Result2=-||U(N_row +1,1)|+|T_global l+|d||/2|;
Result3=-||U(N_row,1)|+|T_global -|d||/2|;
Result4=-||U(N_row +1,1)|-|T_global -|d||/2|;
}
end
          if   (W_encoded (i)= =w1)
                {
                 U_embed(N_row,1)=Result1;
                 U_embed(N_row +1,1)=Result2;
                 }
          elseif (W_encoded (i)= =w2)
                 {
                 U_embed(N_row,1)=Result3;
                 U_embed(N_row +1,1)=Result4;
                  }
          end
end
```

where $W_{encoded}$ denotes the watermark bit and U_{embed} denotes the modified U component while T_{global} denotes the threshold for all the sub-blocks.

Step 5: Perform the inverse SVD on each feature region to get the modified host image.

Step 6: The SURF is performed on the watermarked image, and the key points and their descriptors are extracted and saved.

4.2. Watermark Extraction Algorithm

Watermark extraction algorithm is the exact inverse process of embedding algorithm.

Step 1: The SURF is performed on the attacked watermarked image and the key points and their descriptors are extracted and saved.

Step 2: The key points matching are firstly performed, and then the geometric distortion factors are estimated, finally the watermarked image is corrected.

Step 3: The improved Harris corner detector is used to find the watermarked feature regions.

Step 4: The value of extracted watermark bit for a given feature region is calculated according to Formula (6) where $\mathrm{watermark}_{\mathrm{recover}}$ denotes the extracted watermark.

$$\begin{aligned} &if\ \|\ \mathrm{U}(N_{\mathrm{row}},1)\ | - |\ \mathrm{U}(N_{\mathrm{row}}+1,1)\ \| >= 0 \\ &\qquad watermark_{recover}(i) = 1 \\ &else\quad watermark_{recover}(i) = 0 \end{aligned} \tag{6}$$

5. Experimental results

Figure 2 are the result images of 'Lena' with size 512*512. The original watermark is a sequence of pseudo-random numbers, and here the 64 bits are embedded into the selected feature regions using our algorithm. Taking 'Lena' image for example, in the experiment we first detect the local feature regions according to the improved Harris corner detector. In the process of preprocessing and embedding, the value of L_{region} is set to 8 and $T_{luminance}$ is set to 230. The threshold values of T_{block} and T_{global} are 0.04 and 0.02. As far as the coefficients in U component are concerned, we make use of the relationship between the row 2 and row 3 in the first column.

(a) (b)

Figure 2. (a) Original host image 'Lena' and feature regions. (b) Watermarked image

Free of any attacks, the PSNR (peak signal noise ratio) of the watermarked image 'Lena' is 41.1856, which is capable to insure the fidelity of the watermarked host images. The correct ratio of the extracted watermark is 100%.

Figure 3 and 4 are the SURF key points matching results of 'Baboon' image with size of 200*200. In the process of image correction, 150 descriptors are found in Figure 3, and the matching points are shown in Figure 4, the estimated rotate angle is 30.0423 which almost equals to the real angle of 30. The image correction results are good as shown in Table 1.

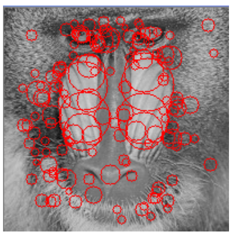

Figure 3. Key points of SURF result of 'Baboon' image

The correct ratio results of the extracted watermarks from 'Lena' and 'Baboon' under different attacks are showed in Table 2 and the correct ratio results are better than [10]. From Table 2, we can make the conclusion that our algorithm is robust to attacks usually encountered in image processing and transmission, especially to the attacks of rotating, translation and scaling.

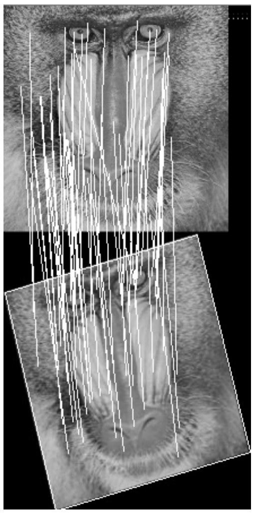

Figure 4. Key points matching of SURF result of 'Baboon' image

Table 1. The SURF correction results

	Ratation	Rotation corretion	Scaling	Scaling correction
Lena	-40	-40.0423	0.8	0.8000
Baboon	30	30.0120	0.8	0.7999

Table 2. The correct ratio results of extracted watermarks under different attacks by the proposed scheme.

Attack Type / Images	Lena	Baboon
JPEG 70%	0.8696	0.8964
Rotating 30 degrees	0.7763	0.7698
Scaling Size=0.8	0.7403	0.7125
Translation tx=-20 ty=-20	1	1

6. Conclusion

In this paper, a novel technique for digital image copyright protection based on robust watermarking has been presented. The SURF is used for image correction. The scheme takes advantage of the feature points of improved Harris detector to locate the watermark hiding positions and to improve the watermark detection ratio. The results show excellent performance on both robustness and transparency.

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