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Invariant Image Watermarking Based on Statistical Features in the Low-Frequency Domain

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Abstract:

We are living in the era of information where billions of bits of data is created in every fraction of a second and with the advent of internet, creation and delivery of digital data (images, video and audio files, digital repositories and libraries, web publishing) has grown many fold. Since copying a digital data is very easy and fast too so, issues like, protection of rights of the content and proving ownership, arises. The main reason is that in the existing watermarking algorithms, those exploited robust features are more or less related to the pixel position. In this paper, an image watermarking scheme by the use of two statistical features (the histogram shape and the mean) in the Gaussian filtered low-frequency component of images. The two features are: 1) mathematically invariant to scaling the size of images; 2) independent of the pixel position in the image plane; 3) statistically resistant to cropping; and 4) robust to interpolation errors during geometric transformations, and common image processing operations. As a result, the watermarking system provides a satisfactory performance for those content-preserving geometric deformations and image processing operations, including JPEG compression, low-pass filtering, cropping and RBAs.

Key Words:
Cropping, Gaussian filter, histogram, image watermarking, random bending attacks.

1. Introduction:

Watermarking has been considered for many copy prevention and copyright protection applications. In copy prevention, the watermark maybe used to inform software or hardware devices that copying should be restricted. In copyright protection applications, the watermark may be used to identify the copyright holder and ensure proper payment of royalties. Although copy prevention and copyright protection have been major driving forces behind research in the watermarking field, there is a number of other applications for which watermarking has been used or suggested.

In order to keep the image in its original form without changing of its parameters, embedding the watermark in original image using two statistical features considering as Histogram and Mean in Low frequency domain. The research described in this dissertation aims at providing the suitable yet efficient watermarking for the target application for which the capability is to be provided. Histogram and Mean based watermarking provides solutions to these problems.

Using invariant region representations:

By embedding the watermark (2) in those regions invariant to geometric attacks (6), the watermark synchronization errors can be avoided.These invariant representations may be the whole image, some invariant regions or invariant feature points. This class of synchronization techniques are also called second generation schemes [7].

The watermark was embedded into normalization-based moments against affine transforms. Moment-based approaches are highly vulnerable to cropping due to the fact that moments are extracted from all pixels. Once part of the pixels is discarded by an attacker, the moment values may be distorted seriously. In [8], the Harris detector was used to extract the feature points to group local invariant.

2. Watermark Insertion:

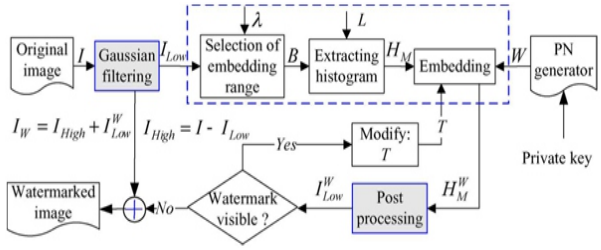

Fig 1: Watermark Insertion

As illustrated in Fig. 1, the watermark insertion consists ofthree main steps: Gaussian filtering, histogram-based embedding and post processing.

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1) Gaussian Filtering: The input image is filtered with a Gaussian kernel low-pass filter for removing the high-frequency information. The use of Gaussian filter-based preprocessing for extracting the robust feature is not new.

2) Histogram-Based Embedding: The histogram [HM] is extracted from the (ILOW) filtered image by referring to its mean value in such a way that the watermark is immune to the operation of scaling the value of all pixels, and the watermark recovery process can avoid exhaustive search (10).

The average value of the low-frequency component ILOW of an image I is calculated as Ā. By referring to Ā, an embedding range denoted by B=[(1-λ)Ā, (1+λ)Ā] is computed to generate the histogram with L equal-sized bins of width M, denoted by H={hM(i)|i= 1……L}. L should not be less than 2Lw in order to embed all bits (4).Let Bin_1 and Bin_2 be two consecutive bins in the extracted histogram. Suppose their population is and respectively. The embedding rules are formulated as

$$\begin{cases} \frac{a}{b} \geq T, & \text{if } w(i) = 1 \\ \frac{b}{a} \geq T, & \text{if } w(i) = 0 \end{cases}$$

Where T is a threshold controlling the number of modified samples. Imperceptibility of the watermark expressed with the PSNR value is ensured to be over 40 dB by adaptively modifying the T value. The PSNR is computed in the low-frequency component.3) Post Processing: The watermark energy is IW-I. SupposeG(.) is the Gaussian filtering function. In the extraction, for a marked image, the watermark energy computed from the low-frequency component isG(IW-I) (4) . According to the property of the Gaussian kernel filter, the extracted watermark energyis different from the embedded watermark energy IWLOW-ILOW. The difference reflects a loss of the watermark energy caused by the Gaussian filtering in the extraction (11). Considering the effect, a corresponding post processing step inthe watermark embedding phase by computing the maximum difference of the pixels between G(IW-I)andIWLOW-ILOW , formulated as

$$dGau = \max\left(\left|G(I_W - I) - (I_{\text{Low}}^W - I_{\text{Low}})\right|\right) - M.$$

Finally, the watermarked image (IW) is generated by combining the marked low-frequency componentIWLOWand the highfrequency component IHIGH.

3. Watermark Extraction:

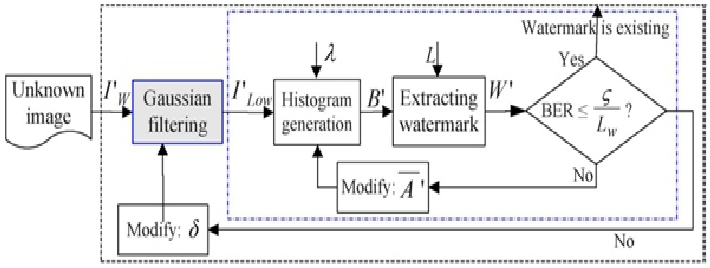

Fig 2: Watermark Extraction

The attacked image IW’, which has undergone some geometric attacks. The mean value Ā’ is computed from the filtered version of IW’ with the Gaussian filter of standard deviation σas the embedding process. A low bit error rate between W and W’ will indicate the presence of the watermark.

The mean value-based search:

In the extraction procedure, a searching space SM=[Ā’(1-Δ1), Ā’(1+Δ2)] is designed according to the percentages of the estimated maximum proportional deviation of the mean induced by various geometric attacks in such a manner that exhaustive search can be avoided. The percentage decreased by Δ1 and the percentage increased by Δ2. Respectively, the parameters and are assigned as -5% and 5%.

The σ-based search:

The Gaussian kernel filter is rotationally invariant (8), but is not invariant to the scaling. Considering the effect of some geometric attacks involving scaling,σ-based matching process is used. In the detection, the σ is in order assigned from the set of five elements.

nSigma= [σ, 2σ/3, 4σ/3, σ/2, 2σ].

The first element is the standard deviation used in the embedding process for coping with geometric attacks without involving scaling. The other elements are used for processingthose possible scaling modifications with factors ranging from 50% to 200%.

$$\text{PSNR} = 10\log_{10}\left(\frac{R \cdot C \cdot 255^2}{\sum_{i=1}^{R}\sum_{j=1}^{C} f(i,j) - f^w(i,j)}\right)$$

The above formula is very useful for reducing the computational cost in the embedding since T is used to control the embedding distortion.

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When the PSNR value is less than a predefined value, we need to decrease T to reduce the embedding distortion (2).In the watermarking scheme, the parameter is selected from the range [0.5, 0.7]. The mean value Ā'of a marked image is 128.

Effect of the Gaussian Filtering:

The input image (I) is filtered with aGaussian kernel low-pass filter for removing the high-frequency information (IHIGH) (3).To get the low-frequency component ILOW, the low pass filtering operation can be represented in the following way.

$$G(x,y,\sigma) = \frac{1}{2\pi\sigma^2} \exp^{-\frac{x^2+y^2}{2\sigma^2}} \quad \& \quad I_{\text{Low}}(x,y) = G(x,y,\sigma) * I(x,y)$$

Fig 3: Gaussian filtering

Gaussian Low-pass Filter:

Low-pass filtering has been shown to be an effective pre-processing step for enhancing robustness of the hash values to image processing operations, such as common compression and filtering operation (1). The low-pass filtering operation can be represented as the convolution of the Gaussian function and an image.

ILOW(x, y) = G(x, y, σ) * I(x, y)

Gaussian function has the form

$$G(x,y,\sigma) = \frac{1}{2\pi\sigma^2} \exp^{-\frac{x^2+y^2}{2\sigma^2}}$$

Invariance of Histogram Shape and Mean:

The histogram of an image can keep almost unchanged under some complicated geometric transforms (8). Here, we analyze the histogram shape invariance to geometric attacks from the image watermarking point of view. The histogram with equal-sized bins may be described by:

$$H_M = \{h_M(i)\ i = 1, \ldots, L\}$$

The mean of an image is computed as:

$$\bar{A} = \frac{1}{R \cdot C} \sum_{i=1}^{R} \sum_{j=1}^{C} I(i,j)$$

consider the effect of the scaling on the mean Ā

$$\begin{aligned}
\bar{A}' &= \frac{1}{R' \cdot C'} \int_{y=0}^{C'} \int_{x=0}^{R'} I'(x', y') dx dy \\
&= \frac{1}{\alpha R \cdot \beta C} \int_{y=0}^{\beta C} \int_{x=0}^{\alpha R} I\left(\frac{x}{\alpha}, \frac{y}{\beta}\right) dx dy \\
&= \frac{1}{R \cdot C} \int_{y=0}^{\beta C} \int_{x=0}^{\alpha R} I\left(\frac{x}{\alpha}, \frac{y}{\beta}\right) d\left(\frac{x}{\alpha}\right) d\left(\frac{y}{\beta}\right) \\
&= \frac{1}{R \cdot C} \int_{y_1=0}^{C} \int_{x_1=0}^{R} I(x_1, y_1) dx_1 dy_1 \\
&= \bar{A}
\end{aligned}$$

Where Ā' is the mean of the scaled image. Equation demonstrates that the mean is invariant to the scaling operation.Rotation is a common geometric operation. After rotation, some resulted pixels are placed in four homogeneous areas, which can be removed by using line detection techniques.Without consideration of the interpolation errors during rotation, the histogram shape and the mean will be exactly invariant due to their independence to the pixel position. Translation operation denotes the shifting of the pixels in the image plane. Under translation, the value of pixels remains unchanged in despite of the location of pixels being modified. Thus, the histogram shape and the mean are also invariant to translation.

4. Experimental Evaluation:

The example image Lenaof size 512 X 512 is adopted from the test data set (12). Thesimulation test results are similar for other images. The ratiosof population between groups of two neighbouring bins as a correlationscore are used to represent the histogram shape. In the following testing, the effect of RST, cropping and RBAs on the histogram shape is evaluated by observing the alteration of the ratios(10).

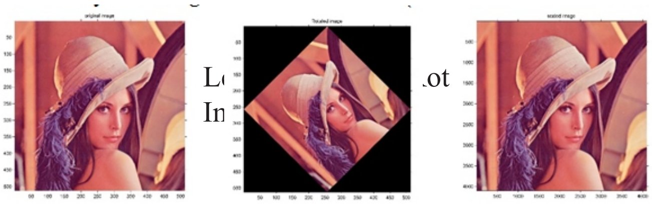

Fig 4: a) Original Lena b) Rotated Image c) Scaled Image

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In the previous histogram-based watermarking algorithms (9), the watermark robustness to geometric distortions, such as the watermark was resistant to JPEG compression with quality factor 20, linear filtering, and nonlinear filtering. The experimental results on colour images demonstrated that the watermark is robust to JPEG compression with PSNR of 35 dB, rotation of 25 degrees, scaling of 200%, etc. The multi-bit watermarking has a satisfactory performance to geometric distortions and common signal-processing operations, such as median filtering of 4 X 4, JPEG compression with quality factor 30, and rotation of 10 degrees, etc. The robustness principle of the histogram shape for various geometric distortions in both theoretical analysis and experimentalway, and then successfully incorporate the Gaussian filter and the histogram shape invariance for image watermarking (9). While keeping satisfactory imperceptibility, the watermark is resistant to geometric deformations and image processing operations, such as cropping of 50%, rotation of 30 degrees, scaling of 150%, median filtering of 5 X 5, JPEG compression with quality factor 40, JPEG2000 with 8 times compression ratio, etc.

5. Conclusion:

In this paper a robust image watermarking algorithm against different geometric attacks including challenging cropping operations and RBAs by using the property of the histogram shape to be independent of the pixel position, mathematically invariant to the scaling, statistically resistant to cropping (6). The watermark can be detected without knowledge of original images by sharing the exploited private key in the detector. The extensive experimental works have shown that the watermarking system has a satisfactory performance for different geometric attacks and common imageprocessing operations, including JPEG compression, wiener filtering, cropping, RBAs, etc. However, the histogram-based watermarking is suffering from its limitation for histogram equalization since this operation will distort the histogram shape much. Histogram equalization is a useful technique for improving image contrast,but its effect is too severe for many purposes. In addition,the watermark may suffer from a key estimation attack since the length of the exploited PN sequence is limited. In our future research, one consideration is to enhance the security of the watermarking scheme by introducing the colour information of colour images or seeking new ways to watermark the histogram shape so that a longer PN sequence can be embedded.

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