A Robust Blind Image Watermarking Scheme Based on Feature Points and RS-invariant Domain

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Abstract

A robust blind image watermarking scheme based on feature points and RS-invariant domain is proposed. Our goal is to detect the watermark without any prior knowledge about the original image and the suffered distortions. We address the robustness against both geometric distortions and signal processing attacks. To resist the cropping and the translation, the idea of the localized watermarking is introduced and the disks centered at the feature points by using the Harris detector are used to embed the watermark. To resist the rotation and the scaling, the watermark is embedded into the RS-invariant domain obtained by taking the magnitude of the 1-dimension DFT along the angular axis of the log-polar mapping (LPM) image repeatedly for each disk. Simulation results show that the proposed scheme is robust against both geometric distortions and signal processing attacks.

1. Introduction

Until now, there has been much emphasis on the robustness of the watermark to common signal processing attack, such as compression and signal filtering. However, even very small geometric distortions can defeat most of the existing robust watermarking methods [1-2]. Further, the detection of the watermark may be performed without any prior knowledge about the original host image and the suffered distortions. In this paper, we address the situation in which a watermarked image undergoes unknown geometrical distortions prior to the detection of the watermark.

Ruanaidh et al. [3] firstly proposed to embed the Watermark in the RST-invariant domain of the image by Fourier-Mellin transform (FMT). But the method involves a high computation cost and may cause severe loss of quality to the watermarked image. Lin et al. [4] proposed an improved scheme. This scheme can solve the implementation difficulty of FMT. However it can not solve other problems such as the frequency localization problem. Kim [5] proposed a scheme based on the improved FMT to overcome above problems. First, it takes LPM of an original image with the invariant centroid (IC) as the origin of LPM to guarantee scaling and translation invariance. Second, the LPM image is transformed by 2-D DFT, and the magnitude is used as the RST-invariant domain. Also the calculation cost is reduced as only one 2-D DFT is performed. Furthermore, to prevent the watermarked image from degrading due to the coordinate system conversion, only LPM image of the watermark is inverse mapped to Cartesian coordinates and add to the original image. However, the proposed scheme in [5] may reduce the validity of the watermark detection after the image is rotated with padding or cropping to remain the size of the image unchanged, because it used the 2-D DFT magnitude of LPM of the overall original image as the RST-invariant domain. Also, it is difficult to resist the cropping, because the embedding location is unknown when the size of the original image and the location of the part image in the original image are unknown, resulting in the synchronization destroyed.

In this paper, we develop a robust blind image watermarking scheme based on feature points and RS-invariant domain. To resist the cropping and the translation, we introduce the idea of the localized watermarking. Concretely, the disks centered at the feature points by using the Harris detector are used to embed the watermark. Furthermore, to resist the rotation and the scaling, the watermark is embedded into the RS-invariant domain of each disk repeatedly, where the RS-invariant domain of each disk is the magnitude spectrum of 1-D DFT along the angular axis of the log-polar mapping (LPM) image of the according disk. Especially, the watermark is embedded into the RS-invariant domain of each disk based on regional differential energy rather than individual differential energy to improve the robustness. Furthermore, to prevent the watermarked image degrading due to the coordinate system conversation, the watermark is not embedded in the RS-domain for each disk directly but rather the modification after embedding the watermark in the RS-invariant domain for each disk is inverse mapped to Cartesian coordinates and added to the original image.

2. The related work

2.1 The extraction of feature points

To resist to the cropping effectively, it is necessary to select stable feature points to locate the watermark-embedding region. The feature points should be satisfied with certain conditions [6], such as the perceptual significance, resistance to common signal processing and geometric distortions et al. Here, we use Harris detector [7] to extract the feature points. Assuming that the disks are centered at the extracted feature points on the original image, then each disk as the watermark-embedding region is translation invariant.

2.2. RS-invariant domain

The LPM performed on each disk centered at the extracted feature points has the properties including scaling invariance and the conversion of a rotation on Cartesian coordinates into a cyclic shift on log-polar coordinates when the sampling rates of the LPM are constant and the origin of the LPM is the center of the according disk. Meanwhile, the 1-D DFT magnitude is translation invariant. As a result, the magnitude spectrum of 1-D DFT along the angular axis of the log-polar mapping (LPM) of each disk is rotation invariant and it can be used as the RS-invariant domain.

3. Proposed watermarking scheme

3.1 Watermark embedding

The watermark is a sequence taking value 1 or -1. The number of 1s is the same with the number of -1s, so that the watermark sequence has zero mean value. The watermark W is denoted as $\{w_i | \mathbf{1} \le i \le l\}$. To improve the robustness, the watermark is modulated based on the spread spectrum [8] before embedding.

Select the disks centered at the feature points extracted by Harris detector [7] and embed the watermark into each disk repeatedly to resist the cropping and the translation. For each disk, the watermark embedding scheme is illustrated in Fig.1.

Let $i(x,y)$ be a certain disk where $D_{\min} \le \sqrt{(x-x_{\mathbf{0}})^2+(y-y_{\mathbf{0}})^2} \le D_{\max}$ and $(x_{\mathbf{0}}, y_{\mathbf{0}})$ is the extracted feature point and also the center of the disk. The LPM performed on the disk $i(x,y)$ with $(x_{\mathbf{0}}, y_{\mathbf{0}})$ as the origin of log-polar coordinates is denoted as $i(\rho,\theta)$. Then perform the 1-D DFT on $i(\rho,\theta)$ along the angular axis to obtain magnitude $|I(\rho, f_\theta)|$ as the RS-invariant domain and phase $I_\angle(\rho, f_\theta)$. As mentioned in the previous section, the watermark should be embedded into the RS-invariant domain $|I(\rho, f_\theta)|$ to resist geometrical attacks.

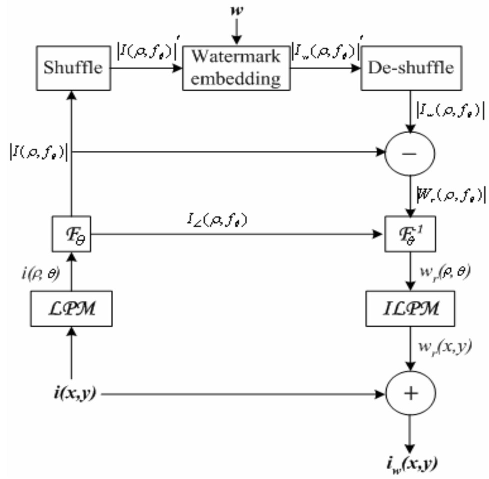

Figure 1. The watermark embedding scheme

Considering the robustness and imperceptibility of the watermark, the watermark should be embedded into the middle frequency band of $|I(\rho, f_\theta)|$. Assuming that the zero frequency term, namely DC, $|I(\rho,\mathbf{0})|$ is the center of the 1-D DFT magnitude, the watermark should be embedded into the rectangle $\{|I(\rho, f_\theta)| \, | R_{\mathbf{1}} \le f_\theta \le R_{\mathbf{2}}\}$.

Furthermore, to assure the watermark security and to improve the imperceptibility of the watermark, $|I(\rho, f_\theta)|$ in the middle frequency band should be shuffled to $|I(\rho, f_\theta)|'$ with a seed K before embedding the watermark so that the distribution of the 1-D DFT magnitude on $i(\rho,\theta)$ along the angular axis is more uniformly.

Considering the difference between the sub-region energy is more stable than the individual energy, each watermark bit can be embedded by adjusting the difference between the two sub-region energy in a certain group. In the implementation, considering the magnitude of 1-D DFT is symmetric to DC, firstly only the left half part of the middle frequency band is shuffled, embedded the watermark, shuffled inversely, then the right half part of the middle frequency band is symmetrically modified. Assuming there are m magnitude coefficients in the left half part of the middle frequency band, divide these m coefficients into l groups. Each group $G_n(\mathbf{1} \le n \le l)$ has $\lfloor m/l \rfloor$ magnitude coefficients and it is further divided into two size-same sub-region denoted as G_n^A and G_n^B, and one watermark bit w_n can be accordingly embed into the group G_n by adjusting the difference between the energy, Sum_n^A and Sum_n^B, of the two sub-region G_n^A and G_n^B, where Sum_n^A and Sum_n^B can be computed as:

$$\begin{aligned} Sum_n^A &= \sum_{(u,v)\in G_n^A} \left| I(\rho, f_\theta) \right|' \\ Sum_n^B &= \sum_{(u,v)\in G_n^B} \left| I(\rho, f_\theta) \right|' \end{aligned} \quad (1)$$

To embed the watermark bit w_n into the group $G_n(\mathbf{1} \le n \le l)$, the energy of the two sub-regions G_n^A and G_n^B in the watermarked group G_n can be adjusted to $Sum_n^{A'}$ and $Sum_n^{B'}$ respectively as follows:

If $|\Delta| \prec \sigma$ then

$$Sum_n^{A'} = Sum_n^A + sign(w_n) \bullet (\frac{\sigma}{\mathbf{2}} - \frac{\Delta_n}{\mathbf{2}} \bullet sign(w_n))$$

$$Sum_n^{B'} = Sum_n^B - sign(w_n) \bullet (\frac{\sigma}{\mathbf{2}} - \frac{\Delta_n}{\mathbf{2}} \bullet sign(w_n))$$

Else

$$\begin{aligned} Sum_n^{A'} &= Sum_n^A \\ Sum_n^{B'} &= Sum_n^B \end{aligned} \quad (2)$$

where $\Delta_n = Sum_n^A - Sum_n^B$ and $sign(\bullet)$ is sign function. To make the watermark bit adaptively embedded, σ can be determined as follows:

$$\sigma = alpha \bullet (Sum_n^A + Sum_n^B) \quad (3)$$

where $alpha$ is the embedding strength and $\mathbf{0} \le alpha \le \mathbf{1}$. To make the energy of the two sub-regions G_n^A and G_n^B in the watermarked group G_n satisfy (2), we modify each magnitude coefficient in G_n^A and G_n^B accordingly as follows:

$$\left| I_w(\rho, f_\theta) \right|' = \begin{cases} \left| I(\rho, f_\theta) \right|' + sign(w_n) \bullet (\frac{\sigma}{\mathbf{2}} - \frac{\Delta_n}{\mathbf{2}} \bullet sign(w_n)) \frac{\left| I(\rho, f_\theta) \right|'}{Sum_n^A} & (\rho, f_\theta) \in G_n^A \\ \left| I(\rho, f_\theta) \right|' - sign(w_n) \bullet (\frac{\sigma}{\mathbf{2}} - \frac{\Delta_n}{\mathbf{2}} \bullet sign(w_n)) \frac{\left| I(\rho, f_\theta) \right|'}{Sum_n^B} & (\rho, f_\theta) \in G_n^B \end{cases}$$

After attaining the watermarked coefficients $\left| I_w(\rho, f_\theta) \right|'$, shuffle $\left| I_w(\rho, f_\theta) \right|'$ back to their original locations with the seed K, denote as $\left| I_w(\rho, f_\theta) \right|$, and accordingly modify the right half part of the middle frequency band to remain the symmetry to DC. The watermark reference, $\left| W_r(\rho, f_\theta) \right|$ can be computed by subtracting $\left| I(\rho, f_\theta) \right|$ from $\left| I_w(\rho, f_\theta) \right|$. Then perform the 1-D IDFT on $\left| W_r(\rho, f_\theta) \right|$ with $I_\angle(\rho, f_\theta)$ to obtain the LPM image of the watermark reference $W_r(\rho, \theta)$, and then perform the inverse LPM of $W_r(\rho, \theta)$ to form the watermark reference in spatial domain, $W_r(x, y)$. In the end, the watermark is embedded into the RST-invariant domain of the disk $i(x, y)$ by add the watermark reference $W_r(x, y)$ to $i(x, y)$ in the spatial domain.

Repeat above procedures for each disk until the watermark is repeatedly embedded into all disks in the original host image.

3.2 Watermark detection

In the proposed watermark detection scheme, watermark detection can be accomplished without the original host image and any knowledge about the suffered distortions. Figure 2 illustrates the watermark detection scheme for a certain disk $i'(x, y)$, which is outlined as follows:

1) Determine the disks centered at the feature points.

2) Transform a certain disk $i'(x, y)$ into the RS-invariant data $\left| I'(\rho, f_\theta) \right|$.

3) Shuffle the middle frequency band of $\left| I'(\rho, f_\theta) \right|$, denoted as $\left\{ \left| I'(\rho, f_\theta) \right|' \;\middle|\; R_1 \le f_\theta \le R_2 \right\}$

4) Extract the watermark from $\left| I'(\rho, f_\theta) \right|'$. The detailed steps can be described as:

- Divide the shuffled left half of the middle frequency band into l groups where each group is denoted as $\tilde{G}_n(\mathbf{1} \le n \le l)$.
- Divide each group $\tilde{G}_n$ into two size-same sub-region denoted as $\tilde{G}_n^A$ and $\tilde{G}_n^B$ and compute the difference $\tilde{\Delta}$ between the two sub-region energy $\tilde{\Delta}_n = Sum_n^A - Sum_n^B$.
- Attain the watermark bit w_n' embedded into the group $\tilde{G}_n$ as:

$$w_n' = \begin{cases} \mathbf{1}, & if\ \tilde{\Delta}_n \ge \mathbf{0} \\ -\mathbf{1}, & if\ \tilde{\Delta}_n \prec \mathbf{0} \end{cases}$$

5) Compute the bits error rate BER between the extracted the watermark W' compared with the original watermark W .

6) Repeat the steps (2-5) for each disk and select the lowest BER as the resulting BER.

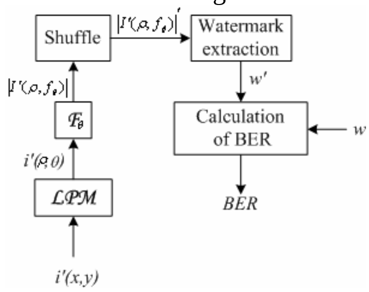

Figure 2. The watermark detection scheme

4. Experimental results

To evaluate the performance of the proposed scheme, the simulations are conducted. In the simulation, the 256×256 gray level image ''Lena'' is used as the original host image.

Fig.3 shows the original, watermarked images. The watermarked image has the PSNR of 42.1534 dB, which indicates that imperceptibility of the watermark is very good.

The robustness of the proposed scheme is measured by bit error rate (BER). Table 1 shows that the robustness of the proposed scheme against RST distortion and common image processing attacks.

(a) (b)

Figure 3. (a) Original image (b) Watermarked image

Table 1. Simulation results for attacks

Attack type	Parameter	BER
Rotation	1°	0
	5°	0
	10°	0
Scaling	0.5	0.20135
	0.9	0.13512
	1.3	0
	2	0
Translation	(100,100)	0
JPEG compression	60	0
	50	0
	40	0.06235
Median filter	2×2	0
	3×3	0
	4×4	0.03218

5. Conclusion

In this paper, we develop a robust blind image watermarking scheme based on feature points and RS-invariant domain. Experimental results show that our proposed scheme is robust against both geometric distortions and signal processing attacks while remaining good imperceptibility. Further work is to deduce the calculation cost to satisfy the real-time requirement in our video watermarking project.

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