PAPER

A Robust Registration Method for a Periodic Watermark Using Radon Transform

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SUMMARY Based on Radon transform, a novel method for registering a periodic (self-referencing) watermark is presented. Although the periodic watermark is widely used as a countermeasure for affine transformation, there is no known efficient method to register it. Experimental results show that the proposed method is effective for registering the watermark from an image that had undergone both affine transformations and severe lossy compression.
key words: *watermarking, affine transformation, Radon transform, registration*

1. Introduction

The watermark should be perceptually transparent, secure against unauthorized users and robust against various attacks. While the attacks such as lossy compression, denoising, noise addition, and lowpass filtering, reduce the watermark-to-cover (image) energy ratio, affine transformations render the watermark undetectable by desynchronizing the watermark [1]. As a remedy, special synchronization techniques, involving invariant domain, additional template, and self-reference (based on a periodic watermark), have been studied. Among theses, the current trend in the commercial circle is to use self-reference based technique [2]; it is generally understood that those techniques involving transform invariant domain suffer from implementation issues and those involving additional template additional distortion.

The synchronization recovery using the periodic watermark was first proposed by M. Kutter [3] and later studied by many others [4][5]. A periodic watermark is created by tiling the entire image with a single watermark pattern of smaller size than the cover image as shown in Fig. 1. In the autocorrelation domain, it appears as a lattice of peaks, and a careful analysis of both the orientation of the lattice and the distance between the peaks can reveal necessary information for synchronization recovery that the watermarked image has experienced. The analysis process is called registration. Conventional methods for registering periodic watermark rely on peak detection [4][5] for estimating the rotation angle and scaling factor, and this is computationally expensive and vulnerable to image interference. Under lossy compression, the registration is particularly difficult since the peaks of the watermark cannot be distinguished from the peaks of the cover. To reduce this vulnerability, a reliable registration method for the periodic (self-referencing) watermark is proposed based on Radon transform (RT). The RT has some useful properties for estimation of periodicity of a signal by accumulation and has proved to be robust against many image processing steps such as sharpening, blurring and compression. Watermark registration methods based on RT were first proposed by us [9] and Deguillaume et al. [10], where the peak detection is performed prior to RT. Since peak detection in the autocorrelation domain often suffers from the image (cover) signal, that results in many fake peaks, and intentional deletion [8] or lossy compression, the proposed reliable registration method without peak detection is preferable.

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2. Proposed Registration Method

The Hough transform (HT), which has been used in line detection [6][7], is a promising tool since the lattice of peaks can be thought of as parallel lines. The HT is a special case of the RT [6] since it can be applied only to binary image. In line detection, the equation of a line can be expressed as

$$\rho = x\cos\theta + y\sin\theta \quad (1)$$

where θ and ρ are the angle of line's normal and the distance from the origin to the line respectively. The RT maps each pixel of a line from image space (x, y) to a parameter space (ρ, θ) where the quantization of parameter (ρ, θ) is determined by the required precision of the parameter estimation. Each image point votes for all parameter combinations that could have produced it. The contributions from all image points are accumulated in each of the corresponding parameter and the final totals indicate the relative likelihood of the orientation and the distance [6]. Due to this accumulation property, the RT is conducive in estimating the rotation angle and scaling factor from the lattice of peaks. The autocorrelation of the extracted watermark using generalized Wiener filter [5][9] without any geometrical attacks is shown in Fig. 2(a). The autocorrelation of the extracted watermark after rotation is shown in

Fig. 2(b). It is clear that the lattice of peaks can reveal the affine transformations that the image has undergone. Since some of peaks may not be detected due to various reasons such as image interference, lossy compression and intentional deletion [1], reliable parameter estimation is important. Fig. 2(c) and (d) respectively represent RTs of Fig. 2(a) and (b). From Fig 2(d), it is evident that the image has been rotated by 15 degree.

In order to reverse the affine transformations, the angle of rotation and scaling factor that the watermarked image has undergone must be estimated from the watermarked image. The rotation angle can be estimated from the direction of a lattice of peaks, and the scaling factors from the periods of the peaks in both horizontal and vertical directions. To estimate the rotation angle and periods, the RT $H(\rho,\theta)$ of the autocorrelation of the extracted watermark is evaluated. We note that the autocorrelation values around the center are zeroed before RT since the peaks in this region may be caused by the image structure itself instead of the watermark. First, we find the set of positions $D = \{(\rho,\theta)\}$ where $H(\rho,\theta)$ has largest M values (typically $M = 64$). Since the RT accumulates the peaks aligned in the direction of the rotation, the rotation angle $\hat{\theta}$ is estimated as follows:

$$\hat{\theta} = \arg\max_{\theta} N(\theta) = \arg\max_{\theta} \sum_{(\rho,\theta)\in D} H(\rho,\theta). \quad (2)$$

For the determined angle $\hat{\theta}$, the period $\hat{T}$ is estimated as follows:

$$\begin{aligned}\hat{T} &= \arg\max_{T} A_{\hat{\theta}}(T) \\ &= \arg\max_{T} \int_{-\infty}^{\infty} H(\rho,\hat{\theta})H(\rho-T,\hat{\theta})d\rho. \quad (3)\end{aligned}$$

From the determined period, the scaling factor can be estimated. As in all other methods, the reliability of the proposed method is dependent on the energy of the extracted watermark. This energy is inversely proportional to the compression ratio. Thus the angle $\hat{\theta}$ and the period $\hat{T}$ can be inaccurate under the severe compression. For such a case, rather than determining a single candidate $\hat{\theta}$ and $\hat{T}$ as shown in equations (2) and (3), a number of possible candidates θ and T should be investigated in the order of maximizing $N(\theta)$ and $A_\theta(T)$ respectively. The reliability of the proposed method can be controlled by the number of candidates. It must be noted that there is a trade-off between the complexity (range of search space) and the performance of the watermark detector.

3. Experimental Results

The performance of the proposed registration method was tested on five popular test images: 512 by 512 Lena, Bridge, Boat, Goldhill and Peppers. Watermark is prepared as a 64 by 64 zero-mean pseudo-random pattern. To make the embedded watermark imperceptible, the watermark pattern is multiplied by the local masking function calculated from the human visual system [11] as in Fig. 1. By using the human visual system, maximal robustness can be obtained subject to the imperceptibility constraint. The resulting peak signal-to-noise ratio (PSNR) of the watermarked images was above 40 dB. For the test, the five test images were watermarked with twenty different watermark patterns (in total, a hundred watermarked images were used for evaluation). Each watermarked image was first rotated and cropped to its original size, and then scaled. The rotation angles of 1, 5, 10, 15, 30, 45 degree and the scaling factors of 0.75, 0.95, 1.05, 1.25, 1.5 were used. After extracting watermark using a generalized Wiener filter [5], the RT of the autocorrelation of the extracted watermark was obtained. From the RT, the rotation angle and the scaling factor were estimated using $N(\theta)$ and $A_\theta(T)$ as stated in Section 2. The precision of the estimation was chosen to be 0.25 degree of rotation angle and 0.0156 of scaling factor. The required precision of the estimation depends on the robustness of the watermark pattern against small amount of geometric distortions. The watermark used in the experiments is designed to have robustness against scaling-up to 1.0078 (scaling-down to 0.9922) and rotation to 0.125 degree by an appropriate shaping filter. The details of the watermark pattern design can be found in [9] and [12]. Table 1 and 2 show the estimation accuracy of the rotation angle and the scaling factor respectively using the proposed method for various JPEG quality factors. Nine candidates of θ are selected in the order of maximizing $N(\theta)$, and nine candidates of T are selected in the order of maximizing $A_\theta(T)$ for the determined rotation angle θ. As we compress more, the accuracy of the estimation is reduced, and thus in order to increase the reliability more candidates must be used in the detector. The results in Table 1 and 2 show that estimating scaling factor is more difficult than estimating rotation angle especially under the severe compression. Thus we can conclude that the overall performance of watermark detector is affected by scaling rather than rotation. Besides the JPEG compression, the proposed method was tested when some of peaks were deleted or embedded intentionally [8]. The estimation results were sufficiently accurate if the intentional deletion or embedding does not degrade the image quality severely.

4. Conclusion

This paper proposes a novel watermark registration method for the periodic watermark based on RT. By incorporating RT rather than explicit peak detection in the autocorrelation domain, the watermark-registration resilience against both affine transformations and lossy compression can be significantly improved. By the experiments, we showed that the proposed method can estimate correct rotation angle and scaling factor with a small number of candidates. This clearly shows that the proposed registration method improves the detection performance of the periodic watermark.

Acknowledgments

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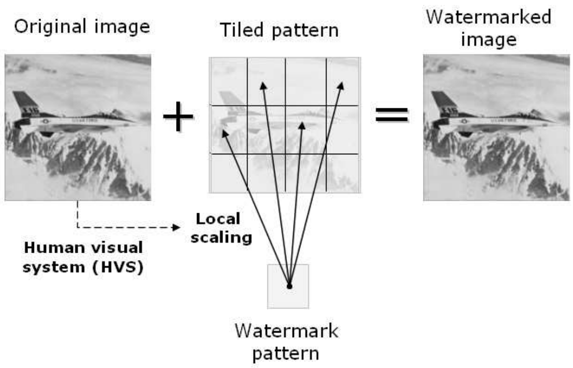

Fig. 1 Embedding of tiled periodic watermark pattern

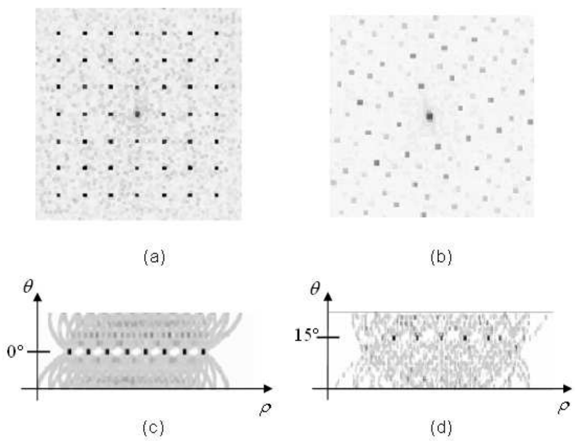

Fig. 2 Autocorrelation of watermarked image and its RT (darker the pixel, bigger the amplitude); (a) Autocorrelation of watermarked image (b) Autocorrelation of rotated watermarked image (c) RT of (a) (d) RT of (b)

Table 1 Probability (%) of correct rotation angle estimation versus quality factor of JPEG compression

Number of candidates	JPEG Q = 90%	JPEG Q = 70%	JPEG Q = 50%	JPEG Q = 30%
1	82.7	90.7	77.3	39.3
3	97.3	97.3	97.3	86.7
5	100	98.7	99.3	94
7	100	98.7	99.3	98.7
9	100	100	100	99.3

Table 2 Probability (%) of correct scaling factor estimation versus quality factor of JPEG compression

Number of candidates	JPEG Q = 90%	JPEG Q = 70%	JPEG Q = 50%	JPEG Q = 30%
1	92	70.7	52.7	6.7
3	99.3	90	83.3	15.4
5	100	96	94	28.9
7	100	98.7	96.7	46.3
9	100	99.3	97.3	61.7