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Blind optimum detector for robust image watermarking in nonsubsampled shearlet Domain☆

Xiang-yang Wang*, Yu-nan Liu, Huan Xu, Ai-long Wang, Hong-ying Yang

School of Computer and Information Technology, Liaoning Normal University, Dalian 116029, P.R. China

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A B S T R A C T

In this paper, we propose a blind robust image watermarking approach in the nonsubsampled Shearlet domain using Bessel K Form (BKF) modeling. Nonsubsampled shearlet transform (NSST) is an effective multi-scale and multi-direction analysis method, it not only can exactly compute the shearlet coefficients based on a multiresolution analysis, but also can provide nearly optimal approximation for a piecewise smooth function. In order to achieve more robustness and imperceptibility, watermark information is embedded into the most significant NSST directional subband with the highest energy, by simply modifying the NSST coefficient amplitude according to the watermark data. By modeling the NSST coefficients with BKF probability density function, the distribution of watermarked noisy coefficients is analytically calculated. The tradeoff between the imperceptibility and robustness of watermark data is solved in a novel fashion. At the receiver, based on the Maximum Likelihood (ML) decision rule, a blind statistical watermark detector is proposed. Experimental results on test images demonstrate that the proposed approach can provide better imperceptibility and robustness against various attacks, such as additive white Gaussian noise, salt & pepper noise, median filtering, JPEG compression, rotation, and scaling, in comparison with the recently proposed techniques.

1. Introduction

EASY access to the Internet has enabled easy distribution and sharing of digital media. However, such easy access also makes illegal distribution of digital media easier and poses key challenges on intellectual property protection of digital content. Digital watermarking has been proposed as a technology of copyright protection and content authentication, providing a means to embed a unique code as a “fingerprint” into each copy of the distributed media content [33]. Whilst digital watermarking can be applied to various multimedia contents such as audio, image, and video, this paper focuses on image watermarking [29, 35]. A good image watermarking method should have some important traits such as imperceptibility and robustness. Imperceptibility refers to the ability of the watermarking method to embed watermarks without significantly lowering the image quality. Robustness denotes the capability of the watermarking method to extract the embedded watermarks under various attacks. In addition, blind watermarking methods are preferred as they can extract the embedded watermarks from the watermarked signal without using the host image. Above two constraints, respectively robustness and imperceptibility, are very important for a watermarking scheme but the major problem for researchers is the non-

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* Corresponding author.
E-mail addresses: wxy37@126.com (X.-y. Wang), yhy_65@126.com (H.-y. Yang).

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orthogonality of these constraints [26, 27]. Combining robustness and imperceptibility has been a challenge for many years, and two constraints in the image watermarking can be achieved by taking into account the properties of the human visual system (HVS) during the embedding process [18]. Generally, image watermark embedding approaches can be classified into three categories: additive watermarking, multiplicative watermarking, and quantization-based watermarking.

In fact, robustness of a watermarking scheme can be improved during the embedding process as well as during the detection process. An obvious way to improve the robustness during embedding is to increase the power of embedded watermark information in the host image, but this power implies a strong distortion of the host image content. So, in order to maintain synchronously the robustness and imperceptibility, the power of the watermark should be proportional to the corresponding image feature samples. The simplest way to implement this principle is by means of multiplicative watermarking [2]. Since a disturbance proportional to the signal strength is more difficult to perceive, multiplicative methods can lead to stronger watermark embedding while keeping the quality of the watermarked image at an acceptable level. In order to employ fully the properties of the HVS, multiplicative watermarking is often used in the transform domain [21].

Over the last decade, there has been increasing research interest in multiplicative image watermarking. For these multiplicative image watermarking approaches, the transforms usually selected are Discrete Cosine transform (DCT), Discrete Fourier transform (DFT), Discrete wavelet transform (DWT), Conjugate Symmetric Sequency-ordered complex Hadamard transform (CS-SCHT), Curvelet transform (CT), Ridgelet transform (RT), and Contourlet transform (CT) etc., which concentrate the energy of the host signal in a fewer components. Meanwhile, the Maximum Likelihood (ML) detections are usually designed by modeling the transform coefficients with Gaussian distribution (GD), General Gaussian distribution (GGD), Laplacian distributions, Cauchy distributions, Gauss-Hermite expansion, Weibull distribution, and Alpha-stable distribution. Through in-depth research and analysis, we can see that the multiplicative watermarking exhibit more promising than others in terms of trade-off between robustness and imperceptibility. However, there are some main drawbacks indwelled in current multiplicative image watermarking schemes: First, the adopted transforms have lower work efficiency to a different extent. For DFT, the accuracy of phasor computation will be largely reduced due to the appearance of exponential decaying DC offset in the sampled signal. DCT concentrates most of the signal information in a few low-frequency components. But, it does not consider the data distribution in space. DWT fails to capture the geometric regularity along the singularities of surfaces because of its isotropic support. To exploit the anisotropic regularity of image surface, several multiscale image representations have been proposed, such as Curvelet transform, Ridgelet transform, and Contourlet transform, but they cannot provide nearly optimal approximation for 2D image. Second, according to statistical decision theory, the accuracy of the statistical modeling of transform coefficients largely determines the actual performance of the watermark detection algorithm. But the existing multiplicative watermarking does not apply relatively accurate statistical model in describing the transform coefficients distributions.

Nonsubsampled shearlet transform (NSST) is an effective multi-scale and multi-direction analysis method, it not only can exactly compute the shearlet coefficients based on a multiresolution analysis, but also can provide nearly optimal approximation for a piecewise smooth function. Bessel K form (BKF) probability density function (PDF) is a relatively accurate model in describing the heavy-tailed distributions and in particular, NSST coefficients. In this paper, we proposed a blind multiplicative image watermarking in the NSST domain using BKF modeling. We introduce a new multiplicative watermarking approach to match the watermark message to the NSST coefficients in an optimum way. The NSST coefficients are multiplied by a special functions depending on the value of the watermark bits. For watermark extraction, the maximum-likelihood detector has been used by utilizing BKF property of the NSST coefficients. To this aim, the probability density function of the noisy NSST coefficients is analytically computed.

The rest of the paper is organized as follows. A review of previous related work is presented in Section 2. In Section 3, a brief introduction of NSST is given. Some necessary preliminaries on the BKF are provided in Section 4. We then apply the BKF to model the prior densities of the NSST coefficients on a database of test images. A comparison to other priors is also carried out. In Section 5, we introduce the proposed multiplicative image watermarking method based on the NSST. The blind watermark detector that uses the BKF PDF is developed in Section 6. In Section 7, the performance of the proposed approach is evaluated and compared with other watermarking techniques. Finally, Section 8 concludes this presentation.

2. Related work

In recent years, there have been considerable efforts in the research community on development of image models for multiplicative watermark detection. Barni et al. [4] proposed an optimal detector for watermarking based on the assumption of the Weibull distribution for discrete Fourier transform (DFT) coefficients of the image. In [7], a watermark detector using Cauchy nonlinearities has been proposed for the detection of discrete cosine transform (DCT) domain watermarks. This method performs quite well in detecting DCT domain watermarks. However, since the Cauchy distribution is a special case of more advanced distributions such as alpha-stable distribution, it can fit less type of actual data than other more advanced distributions. Therefore, when the noise distribution deviates from Cauchy, the method cannot obtain optimum performance. Cheng et al. [9] proposed a robust optimum multiplicative detector in the DCT, DWT and DFT domains. The distribution of high frequency coefficients of DCT and DWT are assumed to be Generalized Gaussian (GG) while the magnitude of DFT coefficients are modeled by Weibull distribution. Briassouli et al. [8] designed a new processor for blind watermark detection in DCT domain using the Cauchy member of the alpha-stable family, and analyzed the performance of the new detector in terms of the associated probabilities of detection and false alarm. Akhaee et al. [1] proposed a blind scaling based image