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Additive watermark detection in the wavelet domain using 2D-GARCH model

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ABSTRACT

Watermark detection can be generally achieved by statistical decision methods. So, selection of an accurate statistical model is one of the major issues in watermark detection. Usually, watermark detectors assume the wavelet coefficients to be independent and identically distributed, therefore, they cannot take into account important characteristics of the wavelet coefficients such as dependency and heteroscedasticity. This paper presents a novel detector for wavelet domain additive image watermarking. We use two dimensional generalized autoregressive conditional heteroscedasticity (2D-GARCH) model for the wavelet coefficients. This model can capture the dependency, heteroscedasticity and heavy-tailed marginal distribution of these coefficients. Based on 2D-GARCH model, we design a new watermark detector and derive its receiver operating characteristics. Experimental results demonstrate the efficiency of proposed detector and its higher performance compared to alternative watermarking methods in the literature.

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1. Introduction

Rapid growth of the Internet increases the importance of the data security and copyright protection issues. Digital watermarking is a popular solution in which a specific piece of information is embedded within a digital media that is intended to protect. Watermarking approaches consist of two steps, watermark embedding and watermark retrieval. Watermarking has been used in many applications, such as copyright protection, authentication, transaction tracking and broadcast monitoring. In the literature, a wide variety of watermarking methods have been proposed [6,8,22,27] and there are many ways to classify them. Due to the role of the watermark, the existing approaches are classified into watermark detection and watermark decoding groups. In watermark detection, the main goal is to decide whether a received media contains a watermark generated with a certain key (integrity verification) [15,35]. In watermark decoding, the watermark serves as hidden message that should be decoded correctly [5,7,20]. In this paper, we focus on watermark detection that can be formulated as a binary hypothesis test.

Based on the presence or absence of the original media in the detector, watermarking methods are classified into blind and informed groups. In many practical applications, the blind watermark detectors are more suitable [16].

Two main requirements of watermarking schemes are imperceptibility and robustness, which their importance varies due to the applications. Watermark imperceptibility is obtained by taking into account the characteristics of human visual

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system in the embedding step. Watermark embedding techniques can be generally classified into two categories: spread spectrum (SS) based [25,31] and quantization based approaches [12,13,40].

SS watermarking adds a pseudorandom noise-like watermark into the original signal, and it has been demonstrated to be robust against many types of attacks [31]. SS watermarking usually employs a transformed domain for embedding. The transforms often used are the discrete Fourier transform (DFT) [18], extensions of Fourier transform [14,41], the discrete cosine transform (DCT) [15,24,42], and the discrete wavelet transform (DWT) [9,28,31].

In the field of watermarking, some papers propose novel frameworks to provide some special goals [17,21,45]. They may use simple embedding and extraction approaches in their framework such as the work described in [45]. This work uses an additive embedder and a simple correlation based detector in compressive sensing domain to provide secure watermark detection and privacy preserving storage. Some other papers focus on designing the novel detectors and they usually apply simple embedding rules such as [9,10,15,28,31,33,37,38]. The present paper is placed in the second category.

Over the last decade, due to the good properties of wavelet transform, a large number of watermarking methods have been proposed in this domain [1,5,10,23,26,29,31]. The correlation detector has been used most commonly [23,26]. This detector is optimal only when the distribution of data samples is Gaussian. But, studying the statistical properties of wavelet coefficients demonstrates that the Gaussian distribution can not capture the wavelet coefficients density efficiently [2,5].

To achieve an optimal detector, statistical decision approaches can be employed. So, the choice of decision rule and statistical model are of great importance. Since, wavelet domain imperceptible watermarking can be formulated as detecting a weak signal in the noise, one popular solution is Bayesian log-likelihood ratio test. This test is asymptotically optimal when there are a large number of data samples [31]. According to the distribution used for the wavelet coefficients, different types of detectors can be obtained. Several different priors have been considered for the wavelet coefficients in watermark detection such as Laplacian [37], generalized Gaussian [38], modified Gauss–Hermite [31] and Bessel K form [10]. All of these models assume that wavelet coefficients are independent and identically distributed. These two assumptions are not compatible with wavelet coefficients since the dependency among wavelet coefficients and their heteroscedasticity have been demonstrated in many works such as [2,30]. Therefore, statistical detectors designed based on such models show inadequate performance.

In this paper, to overcome the limitations of the previously proposed wavelet domain watermark detectors, a novel detector based on 2D-GARCH model is proposed. One dimensional GARCH model has been introduced by Bollerslev [11] to model financial time series. 2D-GARCH model has been discussed in [2,39]. This heteroscedastic model can efficiently capture the intrascale dependencies (within a scale dependencies) of wavelet coefficients and its conditional variance varies with the location. Based on 2D-GARCH model, we develop a statistical detector and analyze its performance using receiver operating characteristics. The performance of the proposed method is compared with some of the widely used wavelet domain watermarking methods. Experimental results demonstrate the high efficiency of the proposed method.

So, the main innovative aspects of the present work can be summarized as:

(i) Introducing the first heteroscedastic detector that considers the dependencies between the wavelet coefficients based on 2D-GARCH model.
(ii) Analyzing the detector performance analytically based on statistical modeling of log-likelihood ratio.

The rest of this paper is organized as follows. In Section 2, we review the 2D-GARCH model and we study the compatibility between this model and the wavelet coefficients. Section 3 describes the watermark embedding process. In Section 4, we discuss the watermark detection and design the novel 2D-GARCH based watermark detector. The performance of 2D-GARCH based detector is analyzed in Section 5. The experimental results of the proposed detector and some other ones are presented and compared in Section 6. Finally, concluding remarks are given in Section 7.

2. Data modeling

In this section, we review the 2D-GARCH model and study its compatibility with images wavelet coefficients.

2.1. 2D-GARCH model

Generalized Autoregressive Conditional Heteroscedasticity (GARCH) processes are a class of zero mean stochastic processes with non-constant variances conditioned on the past [11]. The two dimensional extension of GARCH processes has been discussed in [2,39]. Two-dimensional GARCH processes are uncorrelated but not independent processses which allow the conditional variance to change over the two dimensions. Let x_{ij} represents a two dimensional stochastic process that follows 2D-GARCH(p_1, p_2 ,q_1, q_2), where (p_1, p_2 ,q_1, q_2) denotes the order of the model. We have

$$x_{ij} = \sqrt{h_{ij}}\varepsilon_{ij} \tag{1}$$

$$h_{ij} = \alpha_0 + \sum_{k\ell\in\Lambda_1} \alpha_{k\ell} x^2_{i-k,j-\ell} + \sum_{k\ell\in\Lambda_2} \beta_{k\ell} h_{i-k,j-\ell}, \tag{2}$$

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