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Controversy Corner

A robust DWT-based copyright verification scheme with Fuzzy ART

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A B S T R A C T

Protecting the intellectual property rights (IPR) of digital media is important because the illegal reproduction and modification of digital media has become increasingly serious. A robust DWT-based copyright verification scheme with Fuzzy ART that does not require the original image for ownership verification is proposed in this paper. The proposed scheme, which combines DWT, Fuzzy ART, and the quantization process, converts an image into a short robust table with the embedded ownership information. Unlike general classification, such as k-mean and fuzzy c-means, the number of clusters can be adaptively decided by the vigilance parameter of Fuzzy ART. Experimental results demonstrate that the proposed scheme is robust against common image processing, geometric distortions, and intentional attacks. The original image is not required to extract the embedded ownership image.

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1. Introduction

With the rapid development of multimedia and networking technologies, digital media, including images, audio and video, are easily duplicated and rapidly distributed over the Internet. The illegal reproduction and modification of digital media has become more increasingly serious. Therefore, it is important to protect the intellectual property rights (IPR) of digital media. Although cryptography can be used to protect data, security is weak for the decrypted data. Digital watermarking technology was devised to compensate for this drawback of encryption.

In recent years, digital watermarking has received considerable attention for tracing the unauthorized use of digital content. The term digital watermarking refers to embedding a watermark, such as a trademark, a seal, or a sequence number, into an image for copyright protection. It also provides the corresponding authentication mechanism. The watermark extracted from a watermarked image can be used to verify ownership.

Generally speaking, image watermarking can be divided into two categories: spatial domain methods, which directly modify the intensity value of the image, and frequency domain methods, which change the frequency coefficients. Schyndel et al. (1994) proposed two digital watermarking techniques for spatial domain methods. The first method is based on bit plane manipulation of the least significant bit (LSB), while the second method utilizes a linear addition of the watermark to the cover image. However, these methods are not sufficiently robust. Yu et al. (2001) proposed a digital watermarking technique based on a neural network for color images. Their method embeds a watermark in the blue component of the image, which is not sensitive for the human eye, to achieve imperceptibility. Neural networks were used to learn the characteristics of the embedded watermark related to the watermarked image, making the method more robust against image processing attacks. Chang and Su (2005) utilized the bidirectional mapping of the full counter-propagation neural network (FCNN) to embed a watermark in the synapses rather than in the cover image. Hence, the quality of the watermarked image is almost the same as that of the original. Huang et al. (2001) proposed an efficient robust watermarking algorithm with vector quantization (VQ). The characteristics of natural images and an efficient VQ compression technique were used to embed the watermark into the secret key. Hence, the quality of the watermarked image is guaranteed. To achieve content authentication and copyright protection, Lu et al. (2005) proposed a multipurpose image watermarking algorithm based on multistage vector quantization. The semi-fragile watermark and the robust watermark were embedded in different VQ stages using different techniques; both can be extracted without the original image. Chang and Lin (2008) proposed an adaptive watermark mechanism for rightful ownership protection which allows image owners to adjust the strength of watermarks using a threshold, to increase the robustness of the watermark.

There are many methods proposed in frequency domain (Chen and Lin, 2003; Chu, 2003; Cox et al., 1997; Joo et al., 2002; Liu et al., 2006; Shieh et al., 2004), Hsu and Wu (1999) proposed an image authentication technique which embeds the watermark with visually recognizable patterns into the images by selectively modifying the middle-frequency components of the image, balancing imperceptibility and robustness. In order to make the watermarking scheme more robust, Chang et al. (2005) utilized Fuzzy

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ART to cluster the image blocks, and then gave each image block different embedding strengths according to its complexity. However, the drawback of this method is that the original image is required to extract the embedded watermark. Huang et al. (2000) presented an adaptive watermarking algorithm which combines features of the human visual system (HVS). This method embeds watermarks in the DC component for increasing robustness. Lin and Chen (2000) proposed a watermarking technique which embeds the watermark into the low frequency component. To increase imperceptibility, the watermarked image is adjusted by the weighted correction in the spatial domain. Kundur and Hatzinakos (1999) proposed a fragile watermarking approach which embeds the watermark in the discrete wavelet domain of the image by quantizing the corresponding coefficients. Tsai et al. (2000) proposed a watermarking scheme which utilizes the wavelet domain image frequency components and chaotic transformation to select the location for watermark embedding. Hu and Kwong (2001) proposed a watermarking scheme using pixel-based scaling, where the scaling factors for the pixel-based method are adaptively determined by the effect of luminance and local spatial characteristics. Barni et al. (2001) proposed a watermarking algorithm based on the masking of the watermark according to the characteristics of the human visual system (HVS). Bao and Ma (2005) proposed an image-adaptive watermarking scheme for image authentication by applying a simple quantization-index-modulation process on wavelet domain singular value decomposition.

To increase the security of the watermarking technique, many studies use a digital signature and timestamp to present counterfeit/copy attacks and to make public verification possible (Chen et al., 2005; Lee and Chen, 2002; Chang et al., 2002). Chen et al. (2005) proposed a wavelet-based copyright-proving scheme which combines digital signatures and digital timestamps. In certification generation, the original image is decomposed by performing t level wavelet transform to obtain the sub-band LL_t and the logo is permutated based on a two-dimension pseudorandom permutation. The components of LL_t are used to construct the polarity table. After obtaining the polarity table, the verification key is computed as the bitwise exclusive-OR of the polarity table and permutated logo. Then the digital signature and timestamp are used to verify the copyright logo corresponding to the test image. In logo verification, anyone can use the public key to verify the timestamp TS and use the owner's public key to verify the signature and to check the validation of the security parameters. If successful, the verification will be 'verified', otherwise the algorithm returns 'fail' and stops. The verification steps are similar to the certificate generation steps. The test image is performed by t-level wavelet transform and the polarity table is constructed. Then the logo is extracted with the verification key and performed the inversely permuting to reconstruct the logo. The scheme is blind and it handles binary, gray scale, and multiple logos. It is lossless as it does not modify the original image for certificate generation. However, the main drawback of existing image watermarking methods is their limited resistance to extensive geometric attacks. In addition, the weakness of multiple watermarking, which was initially devised to resist geometric attacks, is its inability to withstand watermark-estimation attacks (WEAs) (Lu and Hsu, 2003), which reduces resistance to geometric attacks. In view of these facts, Lu et al. (2006) proposed a robust image watermarking scheme that can withstand geometric distortions as well as WEAs.

We propose a robust DWT-based copyright verification scheme with Fuzzy ART in this paper (different from general watermarking) that combines DWT, Fuzzy ART, and the quantization process to convert an image into a short robust polarity table. Firstly, the low frequency sub-band image LL_t is obtained using t-level wavelet transformation. Thus, most noise is excluded, avoiding the weakness of Fuzzy ART, which is sensitive to noise and outliers. The indices among neighboring image blocks are similar for natural images. Therefore, the variance of each index and the indices of its surrounding image blocks are calculated, and the concept of the quantization process is utilized to construct the polarity table. Finally, an ownership image is embedded in the polarity table; i.e., the quantization interval of the variance. Unlike general classification, such as k-mean and fuzzy c-means, the number of clusters can be adaptively decided by the vigilance parameter of Fuzzy ART. Experimental results demonstrate that the proposed scheme is robust against common image processing, geometric distortions, and intentional attacks. The original image is not required in the verification process.

The rest of this paper is organized as follows. In Section 2, we briefly review the applied techniques: discrete wavelet transformation (DWT) and fuzzy adaptive resonance theory (Fuzzy ART). The proposed scheme is presented in Section 3. Experimental results and discussion are shown in Section 4. Finally, conclusions are given in Section 5.

2. Background and problem formulation

2.1. Discrete wavelet transformation (DWT)

The wavelet transformation is a mathematical tool which can examine an image in the time and frequency domains, simultaneously. The transformed image is obtained by repeatedly filtering the image on a row-by-row and column-by-column basis. After each level wavelet transformation (once through each row and column), the low frequency component which, contains most of the energy in the image, may be transformed again. This process can be repeated until the height or width of the area to be transformed is no longer divisible by two. An example of decomposing an image by a 2-level wavelet transformation is shown in Fig. 1. If the process is repeated t times, we can obtain the low frequency components (LL_t sub-band) through t-level wavelet transformation.

2.2. Fuzzy adaptive resonance theory (Fuzzy ART)

Fuzzy ART, proposed by Carpenter, is an unsupervised learning network (Carpenter et al., 1991; Kim et al., 2001). It can be considered as a modified ART1 neural network which only learns to categorize binary input vectors. By incorporating computations from fuzzy set theory into ART1, Fuzzy ART can be used to categorize both discrete and analog input vectors. Fig. 2 shows the basic architecture of Fuzzy ART. The F_0 field, called the input layer, is used as the preprocessing area. The F_1 field, called the feature representation field, receives the input vectors from the F_0 field. The F_2 field is called the category representation field or winner-take-all layer because it is the field where category representations are formed. These category representations represent the clusters to which the input vectors belong. Let each input I be an input vector with m elements $(I_1, I_2, I_3, \ldots, I_m)$, where each element I_i is in the interval [0, 1]. The number of potential categories n is arbitrary. The Fuzzy ART weight vector w_j subsumes both the bottom-up and top-down weight vectors of ART1. The Fuzzy ART algorithm proposed by Carpenter (1991) is summarized as follows:

Step 1: Initialization

Initially, each category j $(1 \leqslant j \leqslant n)$ in the F_2 field is said to be uncommitted and corresponds to a weight vector $w_j = [w_{j1}, w_{j2}, \ldots, w_{jm}]$, which is set as:

$$w_{j1}(0) = w_{j2}(0) = \cdots = w_{jm}(0) = 1 \tag{1}$$

where w_{ji} is the weight between the ith neuron in the input layer (F_1) and the jth neuron in the output layer (F_2). According to the

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