A Robust Hybrid Watermarking Scheme Based on DCT and SVD for Copyright Protection of Stereo Images

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***Abstract*—Digital watermarking is a technique that is widely used to protect rightful ownership of digital images. In this paper, we proposed a hybrid watermarking scheme for stereo images copyright protection. According to the property of stereo images, similar block pairs are located by using a certain key. Then, each block pair is transformed into DCT domain and DCT coefficients are extracted from the anti-diagonal of such block pair to form matrix *A*. Watermark image is embedded into singular values by applying SVD transformation on the matrix *A*. The experimental results showed that the proposed scheme can resist to different types of image attacks, such as salt and pepper, noise, and gaussian (density up to 5%). In addition the bit correlation ratio of extracted watermarked images is obtained up to 95%.**

Keywords—Watermarking, Stereo image, Copyright protection, DCT, SVD.

I. Introduction

In recent years, with the fast development of high-speed communication network and multimedia, the exponential increase of digital images is being transmitted over the Internet. Moreover, with the advance of technologies, more and more three-dimensional (3D) videos/images are generated every second. Especially, stereo images, on type of 3D images, which are captured by two spatially-separated cameras [1]–[3] hold powerful attraction to users. Stereo images are pairs of images, left image and right image, taken from slightly different viewpoints of the same scene by binoculars and emerging as new visual standard. Disparity information obtained from the image pairs plays an important role in computer vision, autonomous navigation or surgery [4]–[6]. However, in today's forgery world, digital images can be easily manipulated and modified by software while communicating data over insecure channels such as the Internet. Therefore, the protection of ownership and the prevention unauthorized tampering of stereo images have become an urgent matter. The solutions to these problems can be known as cryptography and data hiding [7]–[10]. In the cryptography technique, data is transformed to meaningless form and that is transmitted to the receiver. Conversely, data hiding conceals secret information into carrier objects to avoid the suspicion from adversaries. In fact, data hiding is two different types, including the steganography and watermarking methods. Steganography hides the secret information in digital signals such as stereo images. If the secret information is disclosed, the steganography fails. In contrast, watermarking mainly deals with the image integrity and authentication [10], [11]. Thus, the goal of watermarking is used to protect the copyright and authenticate the entire of watermarked images. Watermarking can be classified into fragile watermarking and robust watermarking. The fragile watermark is really sensitive to any small modification in the watermarked image. Thus, it is used for content authentication and tamper detection [12], [13]. The robust watermarking schemes maintain the existence of watermark in the watermarked images even when such watermarked images are attacked by image processing operations. Therefore, the robust watermarking is applied to prevent illegal copies of copyrighted content.

Recently, several watermarking schemes have been proposed for stereo images based on Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT) [14]–[16]. In [14], Hwang et al. introduced a stereo watermarking scheme based on the DCT algorithm and the disparity map. In their scheme, the watermark is embedded into one of the two images of stereo images and the another image is used for the restoration of stereo images. Lee et al. [15] proposed a watermarking scheme to protect the copyright of stereo images

based on DCT. In this scheme, Lee et al. used adaptive disparity matching algorithm for hiding the watermark. Hwang et al. [16] combined the DWT and the adaptive disparity estimation for embedding watermark. In 2015, Abdou and Saleh [3] proposed a robust watermarking methods for stereo images for reducing the complex. However, DCT watermarking schemes for stereo images are vulnerable to transformation algorithms, i.e. cropping and resizing While DWT-based watermarking schemes embedded the watermark in the middle and high frequency regions, thus these scheme are limited in capturing directional information [17]. In recent years, singular value decomposition (SVD) is being emerged as a different transform technique in watermarking [18]–[22]. Due to changing on singular values (SVs), that slightly does not affect the watermarked image quality. Moreover, the aforementioned schemes are not generally referred to as inter-correlation between the two views (left and right) of a stereo image, i.e. where the special feature of a stereo image shares the left and right similarity. In 2015, Yang and Chen [23] proposed a reversible data hiding in DCT domain for stereo images, wherein the similar block pairs are found based on the lower frequency quantized DCT (QDCT) coefficients for embedding secret bits. Therefore, to excavate the property belonged to a pair of stereo images, having many similar blocks, and to further improve the robustness of stereo image watermarking scheme, a novel robust hybrid watermarking scheme for stereo images is proposed based on combination of DCT and SVD algorithms. In addition, to achieve better robustness, after transforming by DCT algorithm, the proposed scheme uses a certain key to locate the similar block pairs of stereo image. Then, SVD is implemented on the anti-diagonal of the founded similar block pairs in DCT domain for embedding watermark. The experimental results demonstrated that the proposed scheme is resilient to image processing attacks, i.e. JPEG compression, Salt and Pepper noise, Gaussian filtering, and cropping. Furthermore, the high quality of watermarked images is guaranteed.

The rest of the paper is organized as follows: Section 2 provides the preliminaries of DCT and SVD, Section 3 describes the proposed scheme involving the watermark embedding and extracting procedures, the experimental results are performed in Section 4, and Section 5 serves as the conclusion.

II. PRELIMINARIES

A. Discrete cosine transforms (DCT) and quantized DCT

DCT is an important method for transformation the presentation of digital data from space domain to frequency domain. One-dimensional DCT (1-D DCT) is applied in audio compression scheme where only time is measured. Meanwhile, two-dimensional DCT (2-D DCT) is used in image compression in which the vertical and horizontal dimensional are considered. The formula of the 2-D DCT [24] is defined as follows:

$$F(u,v) = \frac{c(u)c(v)}{4}\sum_{x=1}^{8}\sum_{y=1}^{8} f(x,y)\cos\left(\frac{(2x+1)u\pi}{16}\right)cos\left(\frac{(2y+1)v\pi}{16}\right) \quad (1)$$

where $c(u), c(v) = \begin{cases} \frac{1}{\sqrt{2}}, & if\ u,v = 0 \\ 1, & otherwise \end{cases}$

In image processing, 2-D DCT function is one of the image compression technique due to its capability in term of reducing the redundant information. First, an image is partitioned into 8×8 blocks. Each block of the original image is converted to the frequency domain by using Equation (1). Therefore, $F(u,v)$ is the DCT coefficient at the coordinate (u, v) and $f(x,y)$ means the corresponding pixel value at the same coordinate (x,y). To compress the image data, these coefficients are then quantized by using a quantization table with 64 entries as following equation:

$$D(u,v) = round\left(\frac{F(u,v)}{Q(u,v)}\right) \quad (2)$$

where $D(u,v)$ is considered as quantized DCT coefficient, $Q(u,v)$ is the corresponding value in the quantization table.

B. Singular value decomposition (SVD) transformation

SVD is a linear algebraic algorithm, any $M \times N$ matrix A can be decomposed as the product of an $M \times N$ column orthogonal matrix U and $N \times N$ diagonal matrix S and the transpose of an $N \times N$ orthogonal matrix V [25], [26], that can be defined as:

$$A = U.S.V^T \quad (3)$$

SVD is a useful tool in signal and image processing. One of advantages of SVD in image processing applications is that the SVs obtained by SVD processing are stable i.e. when small disturbances are added to an image, the SVs remain intact.

III. PROPOSED SCHEME

This section describes our proposed DCT-SVD based hybrid watermarking scheme by searching similar block pairs in DCT domain depended on the key k. Watermarked image is then embedded into the SVD transformation of 2 anti-diagonals of similar block pairs. Our scheme can be divided into two procedures: watermark embedding procedure and watermark extracting procedure. The two procedures are described in the Subsections 3.1 and 3.2, respectively.

A. Watermark embedding procedure

The watermark embedding processing is classified into three stages. In the first stage, the searching for similar blocks

is applied as was done in Yang et al.'s method [23]. In the second stage, a binary watermark is implanted in the SVD transformation of both anti-diagonal DCT similar blocks. In the final stage, the inverse transformations are performed to obtain the watermarked stereo image. The details of three phases are given below.

Stage 1:

In this stage, a cover left and right images of the stereo image is divided into non-overlapping blocks sized of 8×8 pixels, and transformed by the 2D-DCT to generate 8×8 block of DCT coefficients. Next, the quantization algorithm is implemented on the DCT coefficients to obtain QDCT coefficients. Later, for each block in the left image, the similar block is determined in the right image based on the different value of the QDCT coefficients of these two blocks in the searching area as seen in Fig. 1.

To increase watermarking security, both the blocks are correlated if the difference value is smaller or equal to the certain k defined in the following equation:

$$\sum_{u,v=1}^{u+v\leq 4} \left[C_{B^L}(u,v) - C_{B^R}(u,v)\right]^2 \leq k \tag{4}$$

where $C(u,v)$ stands for the QDCT coefficient at (u, v) coordinate in the block.

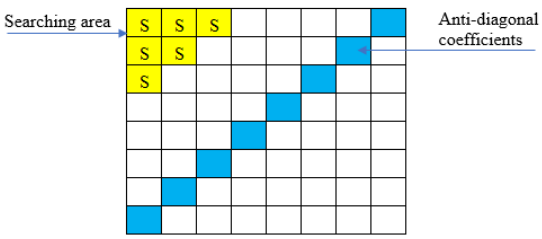


Fig. 1. Searching are of an 8×8 block in QDCT domain

Stage 2:

A matrix A sized of 4×4 is formed by two anti-diagonals, matched block pair. Block A then is transformed into three matrices U, S and V based on SVD transformation. Next, the binary watermark image is partitioned into blocks w of size 4×4 and embedded into matrix S as following

$$S_w = S + \sigma . w \tag{5}$$

where, σ is the robustness factor of the embedded watermark.

Later, perform an SVD on S_w to get three matrices U_1, S_1 and V_1 such that.

$$S_w = U_1 . S_1 . V_1^T \tag{6}$$

Stage 3:

In last stage, we conduct inverse transformation on matrices U, S_1 and V to get matrix $\hat{A}$ as the following equation:

$$\hat{A} = U . S_1 . V^T \tag{7}$$

Next, coefficients of $\hat{A}$ have been distributed to the matched block pair and then inverse 2-D DCT transformation is performed to reconstruct the watermarked block.

B. Watermark extracting procedure

Generally, the watermarked image can be extracted from the watermarked stereo image. The watermarked extraction process encompasses two stages described as follows.

Stage 1:

The first stage of the watermark extracting procedure is similar to the first stage of the watermark embedding procedure i.e. matched block pairs are selected from the watermarked left and right images based on the equation (4) with the key k. Extracted coefficients on the anti-diagonal of similar block pair in the QDCT domain to form matrix $\check{A}$.

Stage 2:

In this stage, the watermark extraction process of our scheme is divided into three steps. Assume, U_1, S, V_1 and σ are possesed by the owner the watermarked stereo image. Then, to prove the ownership of this watermarked stereo image, he/she will provide these parameters. The computational steps of extraction process are implemented by following steps:

Step 1: Perform SVD operation on matrix $\check{A}$ to decompose it into three matrices $\check{U}$, $\check{S}_w$ and $\check{V}$ such that.

$$\check{A} = \check{U} . \check{S}_w . \check{V}^T \tag{8}$$

Step 2: Calculate the possibly distorted $\tilde{S}_1$

$$\tilde{S}_1 = U_1 . \check{S}_w . V_1^T \tag{9}$$

Step 3: Extract watermark w'

$$w' = \frac{\tilde{S}_1 - S}{\sigma} \tag{10}$$

IV. EXPERIMENTAL RESULTS

To verify the performance of the proposed scheme, the experiments are implemented in the Matlab platform on the cover stereo image dataset from Middlebury [27]. The watermark image is the Can Tho University logo sized of 128×128. The proposed hybrid watermarking scheme based on DCT an SVD are evaluated on various experiments such as imperceptibility and robustness.

To evaluate the invisibility, an alteration of the visual image quality should be determined. The peak signal-to-noise ratio (PSNR) is used to calculate visual similarity between a

host image and a watermarked image. PSNR can be defined as follows.

$$PSNR = 10 \times \log_{10} \frac{255^2}{MSE} \quad (11)$$

where *MSE* is the mean squared error representing the difference between the host image and watermarked image and is described as follows.

$$MSE = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} (x_{i,j} - x'_{i,j})^2 \quad (12)$$

with the notations *M* and *N* represent the height and width of the cover image, respectively, and $x_{i,j}$ and $x'_{i,j}$ refer to the pixels located at the *i*th row and *j*th column of host and watermarked image, respectively.

To evaluate the robustness property of the proposed scheme, the bit correlation error (BCR) is used to measure the correction ratio of the extracted watermark that is defined as Equation (13).

$$BCR = \frac{\sum_{i=1}^{n \times n} \overline{w_i \oplus w'_i}}{n \times n} \times 100\% \quad (13)$$

where w_i and w'_i are the *i*th binary value of the original watermark and of the extracted watermark, respectively. Notation ⊕ indicates an exclusive-OR operator.

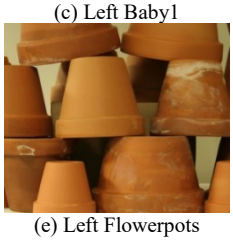
With robustness factor σ=5 and the selected key similar block *k*=30, Table 1 summarizes the experimental results for the proposed scheme with test images shown as Fig. 2 in the context of PSNR and BCR without attack of watermarked image.

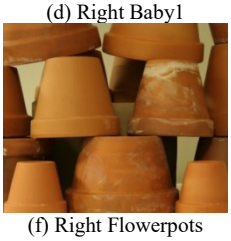

(a) Left Aloe


(b) Right Aloe


(c) Left Baby1


(d) Right Baby1


(e) Left Flowerpots


(f) Right Flowerpots


(g) Left Bowling1


(h) Right Bowling1


(i) CTU logo

Fig. 2. (a)-(h) four pairs of cover stereo images in the dataset [27], (i) watermark logo.

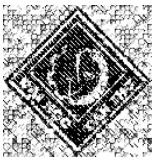
Table 1. Imperceptibility measurement table of the proposed scheme and BCR without attack with σ=5 and k=30.

σ = 5, *k* = 30		
Stereo images	PSNR	BCR
Aloe	56.48	0.98
Baby1	55.19	0.95
Flowerpots	54.35	0.91
Bowling1	54.59	0.98

Fig. 3 illustrates the performance of the proposed scheme with σ=5 and *k*=30 in term of the image quality and the BCR under various attacks on the test image "Aloe". As can be seen in Fig.3 even though the watermarked image is attacked by JPEG compression with quality factor of 90 or cropping 6.25%, the BCRs of both restored watermark images are still 88.28% and 83.59%, respectively. For the remain of attacks such salt and pepper noise (density 5%) and gaussian 5%, the restored watermark images are up to 95%.


(a) Left Aloe, JPEG 90 (PSNR=36.38)

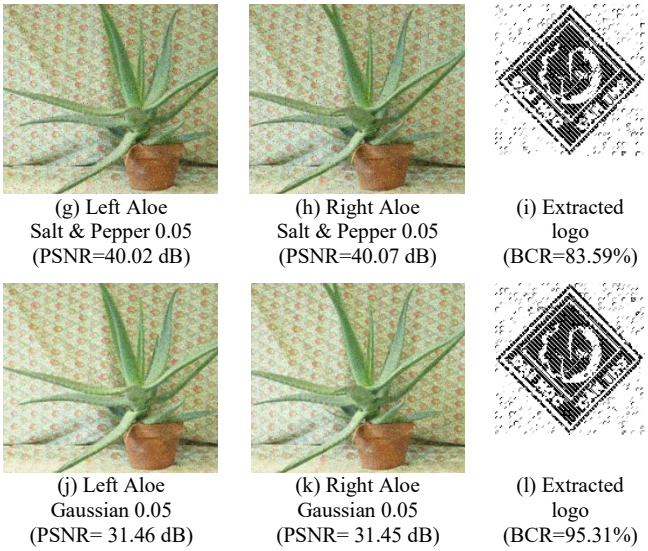

(b) Right Aloe, JPEG 90 (PSNR=28.35)


(c) Extracted logo (BCR=88.28%)


(d) Left Aloe Cropping 6.25% (PSNR=36.06 dB)


(e) Right Aloe Cropping 6.25% (PSNR=36.07 dB)


(f) Extracted logo (BCR=83.59%)



(g) Left Aloe Salt & Pepper 0.05 (PSNR=40.02 dB) (h) Right Aloe Salt & Pepper 0.05 (PSNR=40.07 dB) (i) Extracted logo (BCR=83.59%)

(j) Left Aloe Gaussian 0.05 (PSNR= 31.46 dB) (k) Right Aloe Gaussian 0.05 (PSNR= 31.45 dB) (l) Extracted logo (BCR=95.31%)

Fig. 3. PSNRs of attacked watermarked images and BCRs of extracted logo under various types of attacks.

V. CONCLUSIONS

In this paper, a DCT-SVD-based, robust, hybrid image-watermarking scheme for stereo image copyright protection has been proposed. The scheme embeds the watermark image into the SVs after applying SVD on the matrix A which is formed from coefficients of the anti-diagonals of similar block pairs to increase the robustness of watermarking. the experimental results showed that the proposed scheme can resist to different types of image processing attacks. Moreover, to further improve the security, the proposed scheme has used the key for searching the match similar blocks for embedding watermark.

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