New Block-Relationships Based Stereo Image Watermarking Algorithm

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***Abstract*—A new relationship based stereo image watermarking algorithm for three dimensional video system on the concept of intra-blocks and inter-blocks relationships is given. Corresponding coefficients of discrete cosine transform and discrete wavelet transform in the same position blocks are employed for defining intra-block relationship. Direct current coefficients for stereo pair in the same position blocks are used to describe inter-block relationship. Both of relationships are used to embed digital watermarks into stereo image pair; moreover, parity quantization is designed for watermark embedding when relationships can not work well. Experimental results show that the proposed algorithm can embed a watermark into images invisibly and the watermark can be detected blindly. At same time, the proposed algorithm is robust to attacks, such as JPEG compression, noise, filter, cropping, and so on.**

Keywords- Three dimensional video system; Stereo image watermark; Intra- and inter-block relationships.

I. INTRODUCTION

Three dimensional video (3DTV) systems [1] have been recently developed which significantly improve visualization. Many people believe that 3DTV will be next important development step towards a more natural and life-like home entertainment experience. Meanwhile, as computer network and multimedia-related technologies are in its rapid developing period, it is inevitable to transmit 3D media through communication channels in great quantity. A great chance of developing the copyright protection technologies of 3DTV will be produced as well. Watermarking [2] is one of technologies, which is the process of embedding the particular information inside the 3D digital contents as a solution to prove the ownerships.

In the past, many kinds of watermarking algorithms are designed for text, audio, digital still images, and video sequences, very few algorithms have been proposed for watermarking of stereo images. Patrizio described an object-oriented method for watermarking stereo images [3], and the watermark embedding is performed in the wavelet domain using quantization index modulations method, and the proposed algorithm is fragile against attacks. Hwang et al. proposed stereo image watermarking schemes based on discrete cosine transform (DCT) or discrete wavelet transform (DWT) [4][5]. The watermark is embedded into the right image of a stereo image pair in the frequency domain in [4], and is embedded into the left image of a stereo image pair by using DWT [5].

A stereo image includes left and right images which are composing the same scene are taken by two cameras corresponding to the right and left eye-views. Differences between left and right images are called the "disparity" between them. Stereo image pair must have some relations which can be used to embed digital watermarks. However few algorithms based on pair relationships are depicted in the literature. In the past years a lot of digital watermarking algorithms based on relationships are proposed for mono-images and videos. Langelaar used energy differences between DCT blocks [6] for watermarking. Ling et al. addressed the real time requirement of video watermarking based on energy difference. Chen et al. designed the watermark embedding based on the relationships between wavelet coefficients [8]. Kim et al. presented watermark algorithm based on relationship between blocks in DCT transform [9]. However, those above relationships are used in mono-image watermarking, and new relationships will be designed for stereo images in this paper.

Most of above algorithms employ transformations to embed watermark such as DCT and DWT. Haj presented combined DWT-DCT digital image watermarking [10] because of the advantages of DCT domain and DWT domain. Thus, DCT will be used in the proposed algorithm as well.

In this paper, a new relationships based stereo image watermarking algorithm is presented. The proposed algorithm is linked to the nature of the stereo pair and the watermark is embedded into both of left and right images partly, not only into one image for transparency. The experiments show the transparency and robustness against attacks such as noise, JPEG compression, filtering and cropping. The rest of paper is organized as follows: the proposed algorithm is described in section Ⅱ; section Ⅲ demonstrates some experimental results of the proposed algorithm; finally, Section Ⅳ gives the conclusions.

II. THE PROPOSED ALGORITHM

In this work, the left and right images are divided into non-overlapping $n\times n$ blocks. Let binary watermark denote W with $m\times m$ size, and $m\times m\leq(M\times N)/(n\times n)$, where $M\times N$ is the size of original images,. In the domain of the information security, the scrambling image is a usual way for image processing. Thus the 2-dimensional Arnold transformation is employed for watermarks and $\hat{W}=\{w_1,w_2,\dots w_i;\ 0<i\leq m\times m\}$ is achieved. The watermark will be embedded into the intra-block, inter-block relationships or quantization as depicted in Fig.1. Either of three choices will be designed for watermark

 ISBN: 978-1-61208-166-3

embedding according to the preferences. Each component will be introduced in the following sections.

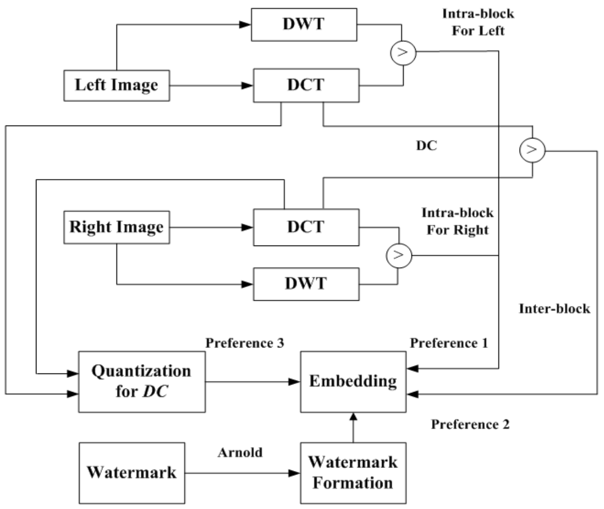


Figure 1. The main processes for embedding

A. Intra-block and Inter-block Relationships

The stereo image includes left image and right image with same size, which are divided into blocks with $n \times n$. DCT and DWT are applied in all blocks respectively. The direct current (*DC*) coefficient of the DCT domain and low frequency coefficient of two-level DWT domain have the similar transformation trend when images are on the attack. Thus the intra-block relationship is between *DC* coefficient in DCT domain and the second value ($LL2_{i2}$) of low frequency matrix in DWT domain, which are applied in the same blocks of images. Let the intra-block value denote IAB_i which is defined as

$$IAB_i = \begin{cases} 1 & DC_i > LL2_{i2} \\ 0 & DC_i \le LL2_{i2} \end{cases} \quad (1)$$

where DC_i is the *DC* coefficient of DCT domain for block *i*.

For left image and right image are high similarities, especially in the background area. *DC* strands for the basic energy of image block, therefore *DC* for both same position blocks of stereo pair have similar trends when attacks are on pair. The inter-block relationship is built on $DC_{L,i,}$ *and* $DC_{R,i}$. $DC_{L,i,}$ is *DC* coefficient of left image block *i* and $DC_{R,i}$ is *DC* coefficient of right image block *i*. If $DC_{L,i,}$ is greater than $DC_{R,i}$, the value of inter-block IRB_i is "1", and otherwise, IRB_i is "0".

Each w_i of the binary watermark only has one value "0" or "1". For relationship embedding, if IAB_i for left and right image are same as w_i, any coefficient of the blocks *i* is not to be modified. When three values are not the same, IRB_i will be compared with w_i. If they are same, any coefficient of the blocks is still unchanged, and otherwise, the *DC* coefficient of either left or right image needs to be changed and quantization step is required.

B. Parity Quantization

In this step, parity quantization is employed for the algorithm. $DC_{L,i,}$ and $DC_{R,i}$ are quantized by the quantization step value *S*, and $Q_{L,i}$ and $Q_{R,i}$ are calculated as

$$Q = \lfloor DC / S \rfloor \quad (2)$$

The processes for the quantization are described as follows.

If w_i =1 and $Q_{L,i}$ mod 2 =$Q_{R,i}$ mod 2, neither of *DCs* will be update. Otherwise, either $DC_{L,i,}$ or $DC_{R,i}$ will be modified for same parity of $Q_{L,i}$ and $Q_{R,I}$. The modification rule is that the range of *DC* modification is least.

$$x' = \min\{|x|, Q'_{L,i} \bmod 2 = Q_{R,i} \bmod 2\} \quad (3)$$

$$y' = \min\{|y|, Q'_{R,i} \bmod 2 = Q_{L,i} \bmod 2\} \quad (4)$$

where $Q'_{L,i}$=*floor*(($DC_{L,i,}$+*x*)/*S*), $Q'_{R,i}$=*floor*(($DC_{R,i,}$+*y*)/*S*). If $x'/DC_{L,i}$ is less, the $DC_{L,i}$ should be modified, and vice verse. If w_i =0 and $Q_{L,i}$ mod 2 =$Q_{R,i}$ mod 2, the *DC* coefficient will not be changed either, otherwise, $DC_{L,i,}$ or $DC_{R,i}$ will be modified according to the rule of quantization.

For the parameter *S*, it is related to the quality image, and according to transparency and robustness, *S* is set to 10 in the experiments.

C. Main Steps for Watermaring

Four secret keys are designed for the algorithm. 1×2 matrix *EM* is used for recording embedding methods as key_1, *L* times Arnold transformation is key_2 and cycle of transformation *T* is key_3 and *S* is key_4. The main steps for embedding watermark are depicted as following five steps.

Step 1: The left and right images are divided into non-overlap blocks of size 8×8 and it is block transformed using DCT and two-level DWT technique respectively. The watermark *W* is transformed to $\hat{W}$ with Arnold transformation, and set *i*=1;

Step 2: Compute intra-block IAB_i for block *i* of left and right image and inter-block IRB_i relationships..

Step 3: Preference 1: if IAB_i of left and IAB_i of right images are both equal to w_i, then EM_i="00", and go to step 4. Otherwise, the preference 2 is chosen. Preference 2: if IRB_i is equal to w_i, then EM_i="01", and go to step 4 as well. Otherwise, preference 3 will be selected. Preference 3: compute the $Q_{L,i}$ and $Q_{R,i}$, and set EM_i="10". Update corresponding *DC* coefficients according to the processes of the quantization.

Step 4: If i$\leq m \times m$, then i++ and go back to the step 3, otherwise, go to next step.

Step 5: Reconstruct the stereo images with watermark by inversing modified DCT transforms of left and right images.

D. Main Steps for Extracting Watermark

For a given stereo image pair, the recorded information about the embedded watermark (key_1, key_2, key_3 and key_4) should be provided for the watermark extraction from the images. The detailed extracting procedure is described as follows.

Step 1: the given embedded watermark stereo image pair is divided into non-overlap blocks of size 8×8 and it is block transformed using DCT and two-level DWT respectively.

Step 2: set i=1, and get the *DC* coefficient $DCE_{L,i}$, $DCE_{R,i}$ for block i of left and right images, and get the second low frequency coefficient as well. If *DC* is greater than DWT coefficient in the same block, then intra-block value is "1", otherwise is "0". Thus $IABL'_i$ is the intra-block value for block i of left image, and $IABR'_i$ is the intra-block value for block i of right image. Suppose $DCE_{L,i}$ and $DCE_{R,i}$ are *DC* for block i of left and right image, and the inter-block relationship IRB'_i is calculated by

$$IRB'_i = \begin{cases} 1 & DCE_{L,i} > DCE_{R,i} \\ 0 & DCE_{L,i} \le DCE_{R,i} \end{cases} \quad (5)$$

Step 3: via key_1 get embedding methods matrix *EM*. Get the Arnold transformation watermark w'_i. When EM_i="00", w'_i is calculated by:

$$w'_i = \begin{cases} 1 & IABL'i = IABR'i = 1 \\ 0 & IABL'i = IABR'i = 0 \end{cases} \quad (6)$$

Suppose EM_i="01", w'_i is computed by:

$$w'_i = \begin{cases} 1 & IRB'_i = 1 \\ 0 & IRB'_i = 0 \end{cases} \quad (7)$$

If EM_i="10", and the quantization values for left and right images are calculated according to Eq.(1) and key_4. If they have same parity w'_i=1, otherwise w'_i =0.

Step 4: if $i \leqslant m \times m$, then i++ and go back to the step 2, otherwise, go to next step.

Step 5:the Arnold transformation watermark $W'=\{w'_1, w'_2, w'_3, \ldots, w'_{m\times m}\}$ is gained, and with key_2 and key_3, the final recovered watermark *WN* is achieved via (key_3 -key_2) Arnold transformation.

III. Experimental Results and Discussions

In order to show the transparency and robustness of the proposed algorithm, a series of experiments will be tested in this section. The first frame of stereo image pair of "Puppy" with 640×480 pixels are taken for test images as illustrated in Fig 2. And a binary watermark with 64×64 pixels as shown in Fig 4(a).

A. Watermark Evaluation

To evaluate the quality of watermarked stereo images, the watermark recovering rates is defined with *HC*.

$$HC = 1 - \frac{\sum W \oplus W'}{m \times m} \quad (8)$$

where $\oplus$ is exclusive-OR.

B. Transparency of Watermark

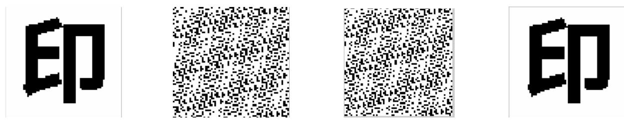
In the experiment, L=28, T=48, S=10. The watermark is transformed by Arnold as illustrated in Fig. 4(b). The watermark is embedded into the pair of stereo images shown in the Fig.3. Obviously the watermark is transparent to visualization. The peak signal to noise ratio (PSNR) is used to evaluate the perceptual distortion. The PSNR of watermarked left image and right image are 52.14dB 51.99dB, respectively. It means the proposed algorithm has transparency ability. Moreover the watermark can be detected by the algorithm totally as illustrated in Fig. 4(c) and 4(d) when images are not under the attacks, and *HC* is 1.

C. Robustness to Attacks

Here, JPEG compression, salt and pepper noise, filtering, and cropping are used to attack watermark embedding images (left and right images are attacked to the same extents) respectively, the experiments results confirms the robustness and stability of the proposed algorithm.

Figure 2. Original image. (a) left image and (b) right image

Figure 3. (a) left watermarked image; (b) right watermarked image.



(a) (b) (c) (d)

Figure 4. (a) original watermark; (b) Arnold transformation of watermark; (c) extractedArnold transforamtion watermark; (d) recovered watermark.

(a) Q=90 HC=0.9765
(b) Q=70 HC=0.9685
(c) Q=50 HC=0.9248
(d) Q=30 HC=0.8982

Figure 5. Recorvered watermarks after JPEG compression.

 ISBN: 978-1-61208-166-3

(a) r=1% HC=0.9231 (b) r=2% HC=0.9133 (c) r=3% HC=0.9055 (d) r=4% HC=0.9006 (e) r=5% HC=0.8943

Figure 6. Recorvered watermarks after salt and peppers noise

(a) Median(s=3) HC=0.9685 (b) Median (s=5) HC=0.9460 (c) Median (s=9) HC=0.9160

(d) Average (s=3) HC=0.9775 (e) Average (s=5) HC=0.9351 (f) Average (s=9) HC=0.9216

Figure 7. Recorvered watermarks after median filter and average of different sizes ($s \times s$).

(a) 1/4 left-top HC=0.8345 (b) 1/8 left-top HC=0.9614 (c) 1/4 middle HC=0.6506 (d) 1/8 middle HC=0.8284

Figure 8. Recorvered watermarks after cropped from different parts..

Attacks with JPEG Compression: Fig.5 shows recovered watermarks after JPEG compression with different quality and corresponding *HC*. Visually watermarks can be recognized and the values of *HC* are all around 0.9. It proves the robustness. When *Q* is from 90 to 30, the *HC* is decreased steadily and not dropped like *Q* decreased. So the proposed algorithm is still stabile.

Attacks with salt and peppers noise: after distorting the watermarked images by different rates salt and pepper noise, the recovered watermarks are shown in Fig. 6. The watermark can be detected clearly and the most of *HC* are greater than 0.9. It proves the robustness again. Moreover, the changing scope of *HC* is tiny, which shows the stability of the proposed algorithm.

Filtering: when the watermarked images are filtered by median and average filter of different sizes, all watermarks can be examined as illustrated in Fig. 7. Furthermore, the values of *HC* are all greater than 0.92. Thus, the proposed algorithm has the ability against filtering.

Cropped: the proposed algorithm is tested against cropping as well. Watermarked images are cropped from different parts: 1/4 top-left, 1/8 top-left corner, 1/4 middle and 1/8 middle. Apparently watermarks can be detected as shown in Fig. 8.

IV. CONCLUSTION

In this paper, a novel stereo image watermarking algorithm based on relationships and quantization is proposed. The intra-block and inter-block relationships are employed for embedding watermarks. Moreover quantization of direct current coefficients in DCT domain is used for watermark embedding when relationships cannot work well. The experiments demonstrate the transparency of the proposed algorithm. Furthermore, when watermarked pairs of stereo images are on the attack, the watermark can be still detected well and it proves the robustness. However, cropping attack affects the quality of watermarked images much, and we will improve it in the future work.

ACKNOWLEDGMENT

This work was supported by Natural Science Foundation of China (61071120, 60872094, 60832003), Natural Science Foundation of Zhejiang Province (Y1101240), the projects of Chinese Ministry of Education (200816460003), and Natural Science Foundation of Ningbo (2011A610197).

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