Abstract—To authenticate and protect stereo image simultaneously, this paper proposes a depth perception based multi-purpose stereo image watermarking method for three dimensional television systems. The proposed method embeds semi-fragile and robust watermark for different purpose. In order to assure quality of watermarked stereo images, binocular perception is used to divide stereo image into region of interest (ROI) and non-ROI for embedding semi-fragile and robust watermark, respectively. Parity check of quantization value of discrete cosine transform coefficients is used to embed watermark, and different quantization step values are employed for ROI and non-ROI. Moreover, the quantization step value is determined by using just noticeable difference and an adjusted value for ROI. Experimental results demonstrate that it not only can distinguish common image processing from malicious attack, but also can claim copyright of stereo image under many kinds of attacks, such as JPEG compression, filter, salt and pepper, and so on.

Keywords—three dimensional television system; stereo image; multi-purpose watermarking; copyright protection

I. INTRODUCTION

With the viewer can perceive depth while looking at a stereoscopic screen, three dimensional media is becoming the next generation of humane entertainment [1]. Many movies have been already recorded in a stereoscopic format today, but 3D video has faced a new set of challenging problems such as copyright protection, authentication and content integrity [2]. Digital watermarking is a process of embedding unobtrusive marks or labels into digital content. These embedded marks are typically imperceptible that can later be detected or extracted. There is also a strong necessity for developing stereo image watermark techniques, which can solve these problems [3].

Watermarking technology is divided into fragile, semi-fragile, and robust watermark according to their purpose in general. Firstly, fragile watermarking is usually sensitive to any image processing, and used to authenticate integrity of image [4]. Secondly, semi-fragile watermarking is robust to common image processing, such as JPEG compression with high factor, average filter and median filter with small size, and so on, but is fragile to malicious attack [5], which can authenticate content of image. At last, robust watermark can resist any attack and be used to protect copyright [6]. Most of watermarking methods are studied for one purpose, either robust, semi-fragile or fragile, but in the real world, multi-purpose watermarking methods are paid more attention, that is, two or three kinds of watermark are embedded into image.

Recently only a few methods have focused on watermark with two goals. Lu et al. presented multi-purpose watermark based on discrete wavelet transform (DWT) sub-bands, and watermark can be extracted for different purpose [7]. Lin embedded watermark into DWT sub-bands as well, and verified the copyright and integrity of images [8]. Lin et al. proposed multi-purpose image watermarking method based on mean-removed vector quantization for robust and fragile watermark [9]. Perception is an important characteristic of image, and people always focus what they are interested in. Lin et al. divided image into two regions, that is, region of interest (ROI) and non-ROI. Then, recovery information of ROI is embedded into non-ROI for recovering ROI if it is tempered [10]. Perception is also used to help improve watermarked images. Wu et al. embedded watermark into ROI and non-ROI with different embedding strength [11]. However, above watermarking methods are designed for monocular image, and few multi-purpose watermarking methods are reported for stereo image.

Stereo image is quite different from monocular image, and left and right images from two eyes are successfully combined into one image in the brain. Binocular vision gives depth perception, which monocular vision does not have. Thus, depth perception plays an important role in ROI and non-ROI computation, and stereo image watermarking method is necessary to be designed specially.

This paper proposes a depth perception based multi-purpose stereo image watermarking method for content authentication and copyright protection simultaneously. Depth perception model is established using computing disparity between left and right images, and thus stereo image is divided into ROI and non-ROI. Semi-fragile watermark is embedded into ROI in order to content authentication for distinguishing common image processing from malicious attack, and robust watermark is embedded into non-ROI for further resisting different image attacks. Experimental results demonstrate that the proposed watermarking method not only authenticate stereo image, but also protect copyright of stereo image.
II. THE PROPOSED WATERMARKING METHOD

To solve copyright protection and authentication of stereo images, a multi-purpose stereo image watermarking method is presented. Stereo image is divided into ROI and non-ROI using depth estimation, and robust and semi-fragile watermark is embedded as shown in Fig. 1. In the received side, watermark can extracted from two regions. Let \( W = [w_1, w_2, \ldots, w_a \times b] \) denote binary digital watermark, where \( 1 \leq a \leq M/8 \), and \( 1 \leq b \leq N/8 \), \( M \times N \) is the size of original image.

\[ \begin{align*}
W &= [w_1, w_2, \ldots, w_a \times b] \\
&= [w_1, w_2, \ldots, w_a \times b] \\
&= [w_1, w_2, \ldots, w_a \times b] \\
&= [w_1, w_2, \ldots, w_a \times b]
\end{align*} \]  

\( \begin{align*}
\text{Fig. 1. Flowchart of perception based multi-purpose stereo image watermarking}
\end{align*} \)

A. Depth perception model

First, According to characteristics of the human visual system, stereo vision is different from monocular vision. Depth plays an important role in binocular perception, and thus, depth is used to build stereo perception model, which can distinguish ROI from non-ROI. Disparity is computed from a stereo image, and the bigger disparity values, the corresponding objects are nearer to cameras. Average of disparities is computed, and if disparity values are greater than the average, corresponding pixels are supposed to be in ROI regions. Other pixels are in non-ROI regions. For example, Fig. 2 shows an illustration of the processes of ROI extraction, and black pixels belong to ROI.

Based on the depth perception model, ROI and non-ROI are extracted. A flag denoting whether blocks are in the ROI or non-ROI is transmitted as a secret key denoted as \( F \). Different watermark is embedded into different regions for multi-purpose. Specially, robust watermark is embedded into non-ROI for copyright protection of stereo image, and semi-fragile watermark is embedded into non-ROI for verifying content of stereo image.

\[ \begin{align*}
\text{Fig. 2. Flowchart of perception based multi-purpose stereo image watermarking}
\end{align*} \)

B. Watermark embedding

The proposed depth perception model guides multi-purpose watermark embedding, and main steps are described as follows.

Step 1. Luminance is extracted from color stereo image, and is divided into non-overlapping blocks of \( 8 \times 8 \) pixels. Each block is transformed by using discrete cosine transform.

\[ \begin{align*}
\text{Step 2. For watermark embedding in the all blocks, watermark is embedded into multiple DCT low coefficients, and the locations (2,2), (3,1) and (1,3) are chosen for inserting watermark bits, and Eq. (1) is utilized.}
\end{align*} \]

\[ \begin{align*}
m' = \begin{cases} 
q \times N + N & w_j = 1, \text{mod}(q, 2) = 0 \\
q \times N & w_j = 1, \text{mod}(q, 2) = 1 \\
q \times N & w_j = 0, \text{mod}(q, 2) = 0 \\
q \times N & w_j = 1, \text{mod}(q, 2) = 1 
\end{cases}
\]  

where \( N \) is the quantization step value, which is greater and stable in non-ROI, and it is less and determined by using just noticeable difference (JND) value and a adjusted value denoted as \( A \) in ROI on the contrary. JND and \( A \) setting to \( N \) will be discussed in the following experiments. \( m' \) is the modified DCT coefficient value, and \( q \) is defined as

\[ q = \left\lfloor \frac{m}{N} \right\rfloor \]  

where \( m \) is the original DCT coefficient value.

Step 3. Reconstruct the stereo images with watermark by inversing modified DCT transforms of left and right images.

C. Watermark extraction

In the received side, ROI and non-ROI of stereo image are obtained correctly using \( F \). BER is used to test extracted watermark and confirm whether stereo image is under malicious attack.

\[ \begin{align*}
\text{Step 1. Luminance of received color stereo images is divided into non-overlapping blocks of } 8 \times 8 \text{ pixels. Each block is transformed by using discrete cosine transform.}
\end{align*} \]

\[ \begin{align*}
\text{Step 2. For watermark embedding in the all blocks, watermark is embedded into multiple DCT low coefficients, and the locations (2,2), (3,1) and (1,3) are chosen for inserting watermark bits, and Eq. (1) is utilized.}
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\[ \begin{align*}
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q \times N & w_j = 0, \text{mod}(q, 2) = 0 \\
q \times N & w_j = 1, \text{mod}(q, 2) = 1 
\end{cases}
\]  

where \( N \) is the quantization step value, which is greater and stable in non-ROI, and it is less and determined by using just noticeable difference (JND) value and a adjusted value denoted as \( A \) in ROI on the contrary. JND and \( A \) setting to \( N \) will be discussed in the following experiments. \( m' \) is the modified DCT coefficient value, and \( q \) is defined as

\[ q = \left\lfloor \frac{m}{N} \right\rfloor \]  

where \( m \) is the original DCT coefficient value.

\[ \begin{align*}
\text{Step 3. Reconstruct the stereo images with watermark by inversing modified DCT transforms of left and right images.}
\end{align*} \]
where \( q' \) is computed using Eq. (2) with \( m' \), and \( r \) is the remainder.

Step 3. Compute BER for watermark extracted from ROI. If BER is less than \( \alpha \), stereo image is supposed to be operated by using common image processing, and vice versa. If stereo image attack without malicious is confirmed, watermark extracted from non-ROI with much lower BER can be further used to claim the copyright of stereo image.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

In order to substantiate the effectiveness of the proposed stereo image watermarking method, ‘dog’ from Nagoya University is used to be tested as shown in Fig. 2. A binary watermark as shown in Fig. 3 is embedded into ‘dog’. Watermark is extracted to demonstrate the performance of the proposed watermarking method.

![NING BO](image)

Fig. 3. Original watermark

A. Performance of semi-fragile watermark

Robustness is related to \( N \), how to determine \( N \) by using JND and adjusted coefficient values is discussed in the following sections.

1) JND for quantization step value

In this sub-section, JND only determines \( N \), and the highest JND in each image is supposed to be quantization step for watermark embedding in ROI. As the semi-fragile watermark, it can resist common image processing, such as JPEG compression with high factors. Table 1 shows BER of different JPEG compression using JND, and BER is a little high for the Q=80. In general, if Q≥75, the compression is supposed to be image attack. Thus, it is not satisfactory that only JND determines the value of \( N \).

| BER of JPEG Compression with Different Factors (Q) Using JND |
|---|---|---|---|---|---|
| Q | 95 | 90 | 85 | 80 | 75 |
| BER | 0.2 | 0.29 | 0.22 | 0.45 | 0.75 |
| BER | 0.68 | 0.69 | 0.77 | 0.69 | 0.63 |

2) Combined JND and \( A \) for quantization step value

Combined JND and \( A \) are used to set \( N \) in this sub-section and \( A \) being set to 2, 3,4 in the experiments will be discussed in detail.

When \( A \) is set to 2, 3 and 4, Table 2, 3, and 4 show BER of JPEG compression with different Q, respectively. Q between 70 and 75 is often a jump for the result of BER. When Q is equal or more than 75, corresponding BER is much lower. It denotes the semi-fragile watermark extracted from ROI performs well. Moreover, \( A \) is set to 3 or 4, and the result of watermark extraction is acceptable. Thus, in the following experiments, we will set \( A \) to 3, and \( \alpha=0.4 \).

Table 5 shows BER of different image attacks. We can see scaling attack with different sizes is not malicious, and whether median and average filter is malicious or not based on the size. 3×3 is not malicious, but 5×5 is. Salt and peppers with lower rates is also a common image processing. But cropping is always supposed to be malicious attack whatever size is tampered, and the proposed method cannot distinguish it. Thus it is a little limited to use BER for distinguishing malicious from common image processing.

| BER of Different Image Attacks |
|---|---|---|---|---|
| Attack | BER | Attack | BER |
| Scaling 200% | 0.06 | Average filter (3×3) | 0.26 |
| Scaling 400% | 0.04 | Median filter (3×3) | 0.20 |
| Scaling 25% | 0.10 | Average filter (5×5) | 0.50 |
| Scaling 50% | 0.23 | Median filter (5×5) | 0.47 |
| Cropping 1/8 | 0.04 | Cropping 1/4 | 0.23 |
| Salt peppers 0.005 | 0.27 | Salt peppers 0.01 | 0.19 |

B. Performance of robust watermarking

Semi-fragile watermark extracted from the ROI can authenticate attacked image, and if it is not malicious, robust watermark can be extracted from non-ROI to claim the copyright of stereo image. \( N \) is set to 13 for embedding watermark in non-ROI. Fig. 4 shows extracted watermark from stereo image under different non-malicious attack. The robust watermark resists scaling attack with quite low BER. Extracted
watermark is not same as the original when BER = 0, because extracted watermark shown in Fig.4 consists semi-fragile and robust watermark. BER is computed only relative to robust watermark. Besides scaling attack, watermark from ROI is robust to average filter 3×3, median filter 3×3, cropping 1/8 and 1/4, and salt and pepper 0.005 and 0.01 with BER much lower than 0.4. In all, it proves robustness of the proposed stereo image watermarking method.

![Watermark Images](image1)

Fig. 4. Robust watermark extracted from non-ROI.

IV. CONCLUSION

In this paper a novel multi-purpose stereo image watermarking method based on depth perception is proposed. The depth perception model is used to divide stereo image into ROI and non-ROI, and semi-fragile watermark and robust watermark are embedded for multi-purpose. Experimental results show that the proposed watermarking method can authenticate content of stereo image, and protect its copyright. Depth perception is only used to compute ROI, and textures, saliency information of images are used for improving ROI of stereo image in the future work.

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