Research on Stereo Image Authentication Watermarking with Self-recovery

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Abstract. With rapid development of three dimensional video systems, the integrity of stereo image has become increasingly important. However, stereo image authentication watermarking methods are rarely reported, and only monocular watermarking methods are extensively studied. In order to ensure authentication and integrity of stereo image, different stereo image watermarking methods are presented in different ways. Firstly, existing monocular watermarking methods are extended directly to stereo image without correlations of stereo image. Secondly, monocular image watermarking methods are extended further as that disparity is used to recover tamper. Finally stereo vision based stereo image watermarking methods are proposed for embedding more recovery bits to improve tamper recovery. Experimental results show that stereo image watermarking method based on correlations of stereo image can improve watermarking performance.

Keywords: Three dimensional video system; Stereo image watermarking; Disparity; Stereo vision.

1 Introduction

With the development of three dimensional (3D) technologies, three dimensional Television (3DTV) are becoming main stream of the consuming entertainment than ever [1]. The flourish of computer has made distribution of 3D contents much easier and faster. Stereo image is a main representation of 3D image, and may be tampered by illegal users. Consequently the integrity of stereo image needs to be authenticated.

Authentication watermarking is a technology to embed particular information inside multimedia contents as a solution to keep integrity of stereo image in advance [2]. Many authentication watermarking methods focus on tamper location and reocvery. Recovery bits generated for each image block are embedded into their unique mapping blocks [3]. If image blocks are tampered, corresponding recovery bits are extracted to recover tampers. However, a tampered block cannot be recovered if its unique mapping block is destroyed as well. In order to solve this problem, recovery bits of each block are embedded twice into two mapping blocks, respectively [4], to improve quality of recovery.

However, above authentication watermarking methods were designed for monocular image. Existing stereo image watermarking methods are mainly designed

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for copyright protection. For example, Campisi extracted objects from depth map computed from left and right views, where watermark is embedded to resist JPEG compression [5]. Authentication stereo image watermarking with self-recovery is rarely reported. Stereo image is different from monocular image, which consists of left and right views. More importantly, two views of stereo image have high correlations, such as disparity and stereo vision. Correlations can be employed to design stereo image watermarking for improving performance.

In this paper, in order to authenticate the integrity of stereo image, firstly, two existing monocular image watermarking methods are directly extended to stereo image, where two views are considered as independent. Then, those two methods are further extended as that disparity between two views is used to recover tamper. Finally, stereo vision base stereo image watermarking method is presented. The comparison results of experiments are tested for five different stereo image watermarking methods, and it proves that stereo image watermarking methods using correlations between two views are superior to directly extended monocular image watermarking methods.

2 Stereo Image Watermarking Methods

In order to authenticate stereo image, five stereo image authentication watermarking methods are presented with self recovery. Let each view of stereo image is of $N_1 \times N_2$.

2.1 Four Extended Monocular Image Watermarking Methods

Firstly, two existing monocular image watermarking methods [3,4] are directly extended to stereo image, where two views are considered as two independent views. Thus first two stereo image watermarking methods just follow methods of [3] and [4] in the processes of watermark embedding, tamper detection. Only in the process of tamper recovery, the inpainting method [6] replaces 3×3 neighborhood method. Two stereo image watermarking methods are named as Lin's and Lee's.

Furthermore, monocular image watermarking methods are extended further using correlations of stereo image, especially in tamper recovery.

Since two views are captured for the same scene from two different cameras, contents are correlated with each other, that is, pixels in left view are matched with pixels in right view. Suppose two views are captured by two parallel cameras, that is, only horizontal disparity is taken into account. Matched pixels of stereo image are defined as.

$$I^L(i, j) \approx I^R(i - d(i, j), j) \tag{1}$$

where $I^L(x,y)$ and $I^R(x,y)$ are pixels in left and right views, respectively, $d(x,y)$ is the disparity for pixels, $1 \le x \le N_1$, and $1 \le y \le N_2$.

Process of tamper recovery in Lin's and Lee's methods is improved as that disparity is employed to recover tamper. However, disparity for pixels takes up 50% compared with stereo image, and it is not suitable to take extra bands for disparity transmission. Thus firstly disparity of pixels is computed [7], and then disparity is

computed for blocks of 4×4. If disparities of pixels are same in same block, which are assigned to disparity of blocks, otherwise, blocks in one view are not matched with any block in the other view. Disparity of blocks takes up 3.125%, and is suitable for real applications.

The tamper recovery process is modified that after tamper recovery from embedded recovery bits, some blocks are not recovered, and those tampered pixels are recovered by using disparities. If after recovery with disparity some pixels are still not recovered, the inpainting method is employed as well. Two further extended methods are named as Lin's+*D* and Lee's+*D*.

2.2 A Novel Stereo Image Watermarking Method

Besides disparity, more correlations of stereo image can be employed for improving performance of stereo image watermarking, such as stereo vision masking. Based on stereo vision masking model, watermark capacity can be increased much without perception of humane eyes. Thus, more recovery reference can be embedded for each block, and performance on tamper recovery can be better.

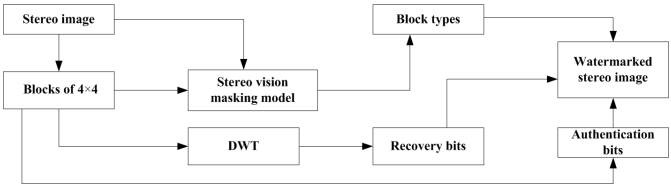


Fig. 1. Flowchart of watermark embedding

Based on stereo vision (SV) masking model, a stereo image watermarking is proposed and named as SV stereo image watermarking method. Watermark embedding process is illustrated in Fig. 1, and main steps are as follows.

Step 1. Stereo image is divided into blocks of 4×4. Just noticeable difference (JND) value of each pixel is computed based on stereo vision masking model, and average JND value for each block is computed as well. If average JND of blocks is equal or greater than 7, three LSBs of each pixel in the block are allocated for watermark embedding, otherwise, two LSBs are allocated. Recovery bits are generated by approximation coefficients of DWT instead of average intensity.

$$X_k(x, y) = Round(D_k(x, y) / Q) \tag{2}$$

where $D_k(x,y)$ is a approximation coefficient of DWT block (x,y), $k \in \{1,2,3,4\}$, and Q=17. $X_k(x,y)$ are represented by 5 bits. Each block can be classified into four types according to Eq. (3).

$$\forall k \left\lfloor X_1(x, y) - X_k(x, y) \right\rfloor \leq \alpha, k \in \{2,3,4\} \tag{3}$$

where α is assigned to 1,3 or 7, and thus 11, 14 or 17 bits are used to represent those types of block. If Eq. (3) is not satisfied for all values of α, 20 bits are used for the last type.

Step 2. Authentication bits are computed by using parity check of pixels, which are combined with recovery bits in their predefined mapping blocks, the way similar as Lin's method [3]. Watermarked stereo image is achieved.

In the process of tamper detection, authentication bits are extracted as the reverse of watermark embedding, which are checked whether they are still same as authentication bits in the process of watermark embedding. If they are not same, blocks are identified as invalid. Two binary masking are for left and right views, respectively, and 1 is invalid and 0 is valid. Moreover, morphological erosion and dilation are operated on those two masking, tampered blocks are detected finally.

If any block is invalid, valid recovery bits are extracted from those mapping blocks as the reverse of recovery bits embedding. Some blocks are not recovered because corresponding mapping blocks are tampered as well, and are recovered by using the inpainting method finally.

3 Experimental Results and Discussions

In order to evaluate performance of proposed five stereo image watermarking methods, the first frame of "Laptop" and "Alt Moabit" with 640×480 pixels are taken as tested stereo images shown in Fig. 2.

(a) Laptop (b) Alt Moabit

Fig. 2. Tested stereo image

3.1 Single Region of Tamper

In this section, four experiments are tested on 'Laptop', where 'Laptop' is pasted by different objects at a single location with different ratios of tamper from around 3.27% to 34.11% of stereo image as shown in Figs. 3(a) to 3(d). Moreover, different texture regions are modified, such as smooth background is covered by 'pumpkin' as shown in Fig. 3(a), and texture background is covered by 'ball' as shown in Fig. 3(b).

(a) 3.27% (b) 10.81% (c) 27.78% (d) 34.11%

Fig. 3. Left view of tampered stereo image with different ratios

Five stereo image watermarking methods can detect tamper with tamper detection ratio of nearly 99%. SV method recovers tamper without visual perception as shown in Fig. 4.

Table 1 shows PSNR of tamper recovery relative to original stereo image with different methods. Lin's+*D* and Lee's+*D* perform better than their directly extended methods without disparity, respectively, and especially tamper ratios are higher. Only 3.27% of stereo image is tampered, methods with or without disparity recover tamper with same PSNR, because embedded recovery bits can recover tamper completely. Thus, disparity plays an important role in tamper recovery. PSNR of SV method is better than those of other four methods, and only is less than Lin's and Lin's+*D* when tamper ratio is around 3.27%. It denotes that proper use of stereo vision can be embedded more recovery bits to improve performance of stereo image watermarking method.

(b) Recovery of tamper for four different ratios of tamper

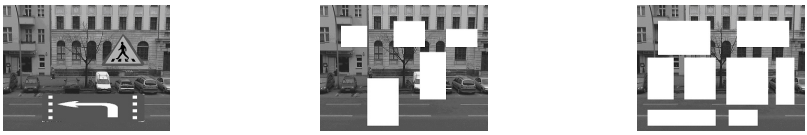
Fig. 4. Left view of tamper detection and recovery with SV method

Table 1. PSNR of tamper recovery for four different tamper ratios of 'Laptop' [.dB]

	Lin's		Lin's+*D*		Lee's		Lee's+D		SV	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
3.27%	43.76	43.25	43.76	43.25	37.57	37.76	37.57	37.76	39.65	38.59
10.81%	35.82	35.83	36.01	36.12	34.40	34.62	35.33	35.78	37.75	36.94
27.78%	34.11	34.02	34.65	34.52	32.71	32.96	33.74	34.09	35.57	35.23
34.11%	34.69	33.94	35.63	35.36	29.78	29.56	30.10	29.34	36.16	35.19

3.2 Multiple Regions of Tamper

In order to show correlations of stereo image can improve performance of watermarking again, 'Alt Moabit' is tampered with multiple regions of tamper as shown in Fig. 5. Pixels being 255 are supposed to be cropped from images as shown in Figs. 5(b) and 5(c).



(a) Two (b) Five (c) Eight

Fig. 5. Left view of tampered stereo image with different number of tampered regions

From Table 2, Lin's+*D* and Lee's+*D* are better than their originals. PSNRs of SV method for left view are better than those of other four methods. Although PSNR of

SV for right view is a little less than Lin's+*D* sometimes, the stereo visual quality is based on the view with better quality according to [10]. Thus, three experiments prove that methods with disparity are better than methods without disparity again. Moreover SV method is superior to other four methods as well. Correlations of stereo image improve stereo image watermarking methods much.

Table 2. PSNR of tamper recovery for tamper of 'Alt Moabit' [.dB]

	Lin's		Lin's+*D*		Lee's		Lee's+D		SV	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Two	36.83	37.13	37.21	37.82	26.62	26.34	27.01	26.89	38.07	36.21
Five	31.88	31.89	33.03	33.33	31.48	31.87	32.27	32.46	33.98	32.95
Eight	27.76	27.29	29.08	29.27	27.88	27.97	28.60	28.57	30.01	29.32

4 Conclusion

This paper has proposed five stereo image watermarking methods. Two methods are directly extended monocular watermarking methods, and other three methods use correlations of stereo image to improve performance in tamper recovery. Experimental results show stereo image watermarking methods with disparity or stereo vision performs better than other two methods.

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