

## Novel Scheme for Watermarking Stereo Video

Zengnian Zhang<sup>1</sup>, Zhongjie Zhu<sup>1</sup>, Lifeng Xi<sup>+ 2</sup>

<sup>1</sup> Ningbo Key Lab. of DSP,

Zhejiang Wanli University Ningbo, Zhejiang, 315100, P. R. China

<sup>2</sup> Institute of Mathematics,

Zhejiang Wanli University, Ningbo, Zhejiang, 315100, P. R. China

*(Received 23 December 2006, accepted 7 January 2007)*

**Abstract:** Based on previous research work on both digital watermarking and stereo video, a novel scheme for watermarking stereo video is introduced. Firstly, an adaptive watermarking model based on disparity vectors is proposed after analyzing the characteristics of stereo video. Then a new watermarking algorithm is introduced. Adaptive scheme and pre-encoding with low density parity check (LDPC) codes are employed to enhance the watermarking robustness. Watermark can be blindly extracted without the need of original video sequence. Experimental results reveal that the proposed algorithm is effective, which can resist some common attacks such as recoding and noise pollution.

**Keywords:** fractal; stereo video; watermarking; adaptive algorithm; disparity vectors

## 1 Introduction

Stereoscopic video attracts great attention recently and is viewed as an important developing trend of video technology [1-4]. Although up to now the stereoscopic video has not been widely industrialized, its copyright protection should be considered in advance to avoid piracy. Video watermarking is currently a hot research topic of watermarking technology [5-8]. Compared with image watermarking, there are higher requirements for video watermarking [9-10]. Firstly, video watermarking algorithm should be simple and fast so as to meet real-time requirement. Secondly, watermark embedding should not affect the integrity of the whole bits-stream and should be compatible with existing widely-used video compression standards. Thirdly, the embedding and extracting of watermark should be implemented directly in compressed domain. Finally, watermark should be blindly extracted. In fact, the techniques of fractals and chaos are also helpful [16-20].

For encoding stereo video, usually joint motion compensated prediction (MCP) and disparity compensated prediction (DCP) technology is used to acquire high efficiency [11]. The compressed stereo video stream contains abundant disparity vectors using such technology. In this paper, the proposed watermarking algorithm directly embeds watermark into disparity vectors. Embedding watermark into disparity vectors has following merits. Firstly, watermark embedding does not affect the base-layer structure. And the quality of base-layer reconstructed image will not be affected at all. It only has slight affection on the enhancement-layer reconstructed image. Due to the HVS, slight quality degradation of the enhancement-layer reconstructed image does not affect the overall stereoscopic visual effect. Secondly, both watermark embedding and watermark extraction can be implemented in compressed domain. Thirdly, watermark can be blindly extracted without the need of original video sequence.

---

<sup>2+</sup> **Corresponding author.** Tel: +86-574-8822 2249; Fax: +86-574-8822 2249.

*E-mail address:* lifenghi@nbip.net.

In order to enhance the robustness of the proposed algorithm, two measures are employed. First, one adaptive method is used to select a best embedding and extracting scheme for each frame among the six fundamental schemes proposed in this paper. Second, the LDPC-based pre-coding technology is used to encode the original watermark before it is embedded into disparity vectors. After the computer simulation, experimental results show that the proposed algorithm is robust and effective.

## 2 Adaptive Watermarking Model Based on Disparity Vectors

For disparity-vector based algorithm, the recoding and noise pollution are two fundamental attacks. In the following part, we mainly take these two attacks for example to analyze the disparity-vector based algorithm.

Let  $f_i(x, y)$  denote the  $i$ -th frame to be embedded with watermark,  $(D_{i,l,x}, D_{i,l,y})$  denote the disparity vector of the  $l$ -th macro-block (MB),  $M_{i,l}$ , of the  $i$ -th frame and  $(\hat{D}_{i,l,x}, \hat{D}_{i,l,y})$  denote the watermarked disparity vector after watermark embedding. Here,  $(D_{i,l,x}, D_{i,l,y})$  may or may not equal to  $(\hat{D}_{i,l,x}, \hat{D}_{i,l,y})$ . Let  $M_{i,l}^r$  and  $\hat{M}_{i,l}^r$  denote the match MBs corresponding to  $(D_{i,l,x}, D_{i,l,y})$  and  $(\hat{D}_{i,l,x}, \hat{D}_{i,l,y})$  in the reference frame, respectively. Since only  $(\hat{D}_{i,l,x}, \hat{D}_{i,l,y})$  contains watermark information,  $M_{i,l}$  should be matched to  $\hat{M}_{i,l}^r$  during the recoding in order that watermark can be detected. But the first encoding results show that  $M_{i,l}^r$  is the best match MB for  $M_{i,l}$ . During the recoding process  $M_{i,l}$  still prefers matching to  $M_{i,l}^r$  and the watermark information will get lost.

In order to make  $\hat{M}_{i,l}^r$  match to  $M_{i,l}$  during the recoding process, two improved methods can be adopted as follows:

1. Use larger steps to quantify the DCT coefficients of transformed residual image to make the residual image weight slightly in the reconstructed image. Then  $M_{i,l}$  may match to  $\hat{M}_{i,l}^r$  during the recoding process. The drawback of this method is that the quality of the reconstructed image will degrade greatly.
2. If most of the watermarked disparity vectors meet  $(D_{i,l,x}, D_{i,l,y}) = (\hat{D}_{i,l,x}, \hat{D}_{i,l,y})$ , then not only  $M_{i,l}$  can match to  $\hat{M}_{i,l}^r$  during the recoding process but also the quality of the reconstructed image will degrade slightly. Using this method the disparity vectors to be embedded with watermark should be carefully selected.

Let  $N_{total}$  be the number of total watermarked disparity vectors and  $N_c$  be the number of those that meet  $(D_{i,l,x}, D_{i,l,y}) \neq (\hat{D}_{i,l,x}, \hat{D}_{i,l,y})$ . Define  $r_i$  as

$$r_i = N_c / N_{total}. \quad (1)$$

Then  $r_i$  represents the ratio of the disparity vectors to be changed to those not to be changed during the watermark embedding process in the  $i$ -th frame. Obviously, the smaller  $r_i$  is, the more resistant to recoding attack the watermarking algorithm will be. In this paper we employ the second method.

Let  $(D_{i,l,x}, D_{i,l,y})$  denote the disparity vector of the  $l$ -th MB,  $M_{i,l}$ , to be watermarked, define its eigenvalue  $\rho_{i,l}$  as

$$\rho_{i,l} = \text{mod}(2D_{i,l,x}, 2) + 2\text{mod}(2D_{i,l,y}, 2), \quad (2)$$

where  $\text{mod}(\bullet, 2)$  denotes the modular operation of  $\bullet$  by 2,  $\rho_l$  gets one of the values of  $\{0, 1, 2, 3\}$ . Let  $w_{i,l}$  be the watermark bit to be embedded into  $(D_{i,l,x}, D_{i,l,y})$ . The watermark embedding process in essence can be viewed as establishing a relationship between  $w_{i,l}$  and  $\rho_{i,l}$ . That is,  $\rho_{i,l}$  can be viewed as a function of  $w_{i,l}$ . Note that  $\rho_{i,l}$  can take four values and  $w_{i,l}$  takes either 0 or 1, there exist several functions that can be defined. For example, one of them can be defined as

$$\rho_{i,l} = \begin{cases} 0 & w_{i,l} = 0, \\ 1 & w_{i,l} = 1. \end{cases} \quad (3)$$

We rewrite the above function as following form, denoting a fundamental watermarking scheme.

$$f_s : w_{i,l} \rightarrow \rho_{i,l} \mid (0, 1) \rightarrow (0, 1). \quad (4)$$

The process of watermarking embedding is to alter  $(D_{i,l,x}, D_{i,l,y})$  to make  $w_{i,l}$  and  $\rho_{i,l}$  meet equation (3). That is, when  $w_{i,l} = 0$ , if  $\rho_{i,l} \neq 0$ , then alter  $D_{i,l,x}$  and  $D_{i,l,y}$  to make  $\rho_{i,l} = 0$ ; when  $w_{i,l} = 1$ , if  $\rho_{i,l} \neq 1$ , then alter  $D_{i,l,x}$  and  $D_{i,l,y}$  to make  $\rho_{i,l} = 1$ . Altering  $D_{i,l,x}$  and  $D_{i,l,y}$  means the operation  $D_{i,l,x} = D_{i,l,x} + 0.5$  or  $D_{i,l,y} = D_{i,l,y} + 0.5$ , or both. In this paper, the following six fundamental watermarking schemes are defined:

$$f_s(k) : w_{i,l} \rightarrow \rho_{i,l} \mid (0, 1) \rightarrow \Gamma \text{ for } k = 0, 1, \dots, 5, \quad (5)$$

where  $\Gamma = \{(0, 1), (0, 2), (0, 3), (1, 2), (1, 3), (2, 3)\}$ , each  $f_s(k)$  denotes a fundamental scheme. There are altogether six fundamental schemes. The ideal of adaptive algorithm is to select a best scheme for each frame according to the features of disparity vectors to make the altering of disparity vectors smallest. Let  $\{000, 001, 010, 100, 101, 110\}$  denote the scheme codes for the six schemes and they are embedded into the bit stream with a same preset scheme in our watermarking algorithm.

Considering the similarity between communication system and watermarking system, in this paper we apply the error-correcting coding technology to the watermarking system. The original watermark is encoded with LDPC codes before embedding to enhance the robustness. LDPC codes are good error-correcting codes, which can approach Shannon's capacity limit [12][13][14][15]. Since LDPC decoding algorithm is simple, the LDPC-based watermarking algorithm meet the simplicity and fast requirements of video watermarking.

### 3 Proposed Algorithm

#### 3.1 Watermark Embedding

The flow chart of watermarking embedding is shown in Figure 1. Let  $\{w_k\}$  ( $k = 0, \dots, T_{total} - 1$ ) be the original watermark bit-stream,  $T_{total}$  the length of the bit-stream and  $T_i$  the number of watermark bits to be embedded into the  $i$ -th frame. The embedding algorithm is briefly introduced as follows:

1. Encode  $\{w_k\}$  ( $k = 0 \sim T_{total} - 1$ ) with LDPC codes firstly, and let  $\{\hat{w}_k\}$  ( $k = 0 \sim \hat{T}_{total} - 1$ ) denote the encoded bits stream.
2. Select disparity vectors  $(D_{i,l,x}, D_{i,l,y})$  ( $l = 0 \sim \hat{T}_i - 1$ ) from the  $i$ -th frame with the given *Key*, which are to be embedded with watermark bits.
3. Select a fundamental embedding scheme for the  $i$ -th frame according to  $(D_{i,l,x}, D_{i,l,y})$  ( $l = 0 \sim \hat{T}_i - 1$ ) and the principle that  $r_i$  should be the smallest.
4. Embed scheme code of the fundamental scheme selected in step 3 with the predetermined algorithm.
5. Embed all the  $\hat{T}_i$  watermark bits with the scheme selected in 3.
6. Work on the next frame, Reiterate 2-5 until the whole  $\{\hat{w}_k\}$  ( $k = 0, \dots, \hat{T}_{total} - 1$ ) is embedded.

#### 3.2 Watermark Extraction

Watermark extracting is the inverse process of watermark embedding. The proposed watermark extracting algorithm is simple and watermark can be blindly extracted.

Let  $\{w_k^*\}$  and  $\{\hat{w}_k^*\}$  denote the extracted watermark bit-stream corresponding to  $\{w_k\}$  and  $\{\hat{w}_k\}$  respectively. The watermark extracting algorithm is briefly introduced as follows:

1. Starting with the first watermarked frame, that is,  $i = 1$ .
2. Inversely extract the scheme code of the  $i$ -th frame with the default watermark scheme.
3. Inversely extract all the  $\hat{T}_i$  watermark bits of the  $i$ -th frame with the *Key* and the fundamental scheme determined in step 2.
4. Reiterate 2-3 till the whole  $\{\hat{w}_k^*\}$  ( $k = 0, \dots, \hat{T}_{total} - 1$ ) is extracted.
5. Decode  $\{\hat{w}_k^*\}$  with LDPC codes, finally get the restored  $\{w_k^*\}$  ( $k = 0, \dots, T_{total} - 1$ ).

## 4 Experimental Results

To evaluate the performance of the proposed algorithm, experiments are simulated. The following two performances of the proposed algorithm are tested.

- Firstly, normal watermark embedding and extracting processes are simulated to test effectiveness of the proposed algorithm.
- Secondly, test robustness of the algorithm against recoding and noise pollution attacks.

The following four video sequences are used in our experiments:

1. *Train\_and\_Tunnel* video sequence: altogether 192 frames with image size  $720 \times 576$ .
2. *Herve* video sequence: altogether 22 frames with image size  $512 \times 512$ .
3. *Pascal* video sequence: altogether 22 frames with image size  $512 \times 512$ .
4. *lml* video sequence: altogether 22 frames with image size  $512 \times 512$ .

We define watermark detection ratio (*WDR*) as:

$$WDR = \frac{e_0 e_1}{m_0 m_1}, \quad (6)$$

where  $m_0$  and  $m_1$  denote the numbers of 0's and 1's of the original watermark respectively, and  $e_0$  and  $e_1$  denote the numbers of properly extracted 0's and 1's after watermark extraction respectively.

Let  $\alpha_i$  and  $\beta_i$  denote PSNRs of the  $i$ -th non-watermarked and watermarked video image respectively, and let  $\bar{\alpha}$  and  $\bar{\beta}$  denote the corresponding mean PSNRs. Let  $\bar{\delta}$  denote the mean loss of PSNR and  $Q$  denote the number of frames. That is,

$$\bar{\alpha} = \frac{1}{Q} \sum_{i=0}^{Q-1} \alpha_i, \quad \bar{\beta}_{dB} = \frac{1}{Q} \sum_{i=0}^{Q-1} \beta_i, \quad (7)$$

$$\bar{\delta} = \bar{\alpha} - \bar{\beta}. \quad (8)$$

The testing results of effectiveness are shown in Figure 4 and Table 1, where Figure 4 shows the extracted watermark from the watermarked video sequence and Table 1 shows the PSNR loss of the watermarked video images and the WDR. Figure 5 and Figure 6 give the experimental results of robustness, where Figure 5 is the extracted watermark from watermarked video sequence after recoding, Figure 6 is the extracted watermark from watermarked video sequence after both recoding and noise pollution. Finally, comparison results of non-adaptive algorithm and the proposed algorithm are shown in Table 2.

Figure 4-6 and Table 1-2 show that the PSNR loss of the watermarked video image is minor which will not affect the whole visual quality. The WDR of the watermarked video after recoding attack is rather good and it is still fairly good after both recoding and noise pollution attacks.

## 5 Conclusion

Stereo video is one of the important developing trends of video technology and the copyright protection for stereo video is a problem which should be considered in advance. In this paper, based on our previous work, a new robust digital watermarking scheme for stereo video is proposed. In the proposed algorithm, watermark information is only embedded into the enhancement-layer, which does not need to alter the fundamental-layer's structure and has slight affection on the whole stereo visual effect due to the adaptive method. The watermark embedding and extracting processes are implemented in compressed domain without the need of re-coding and re-decoding processes. Watermark is pre-coded with LDPC codes before embedded into video sequence. Experimental results show that the proposed scheme is effective.

**Figures and Tables:**

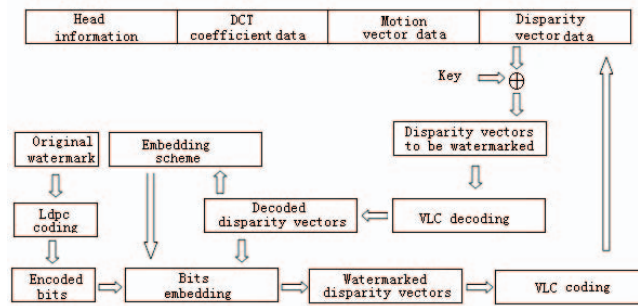


Figure 1: Flow chart of watermark embedding

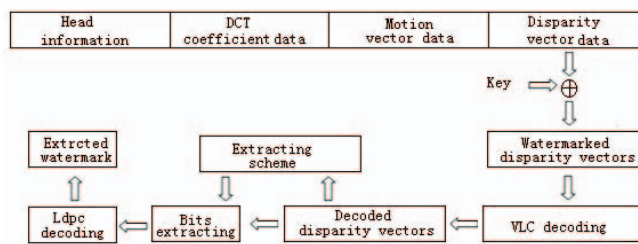


Figure 2: Flow chart of Watermark extraction



(a) *Im1* (b) *Pascal* (c) *Herve* (d) *Train\_and\_Tunnel*

Figure 3: Original enhancement-layer image



Figure 4: Extracted watermarks from video sequences without any attacks, where (a) is the original watermark, (b) is the extracted result from *Im1* sequence, (c) is the extracted result from *Pascal* sequence, (d) is the extracted result from *Herve* sequence, (e) is the extracted result from *Train\_and\_Tunnel* sequence.



Figure 5: Extracted watermark after recoding, where (a) is the extracted result from *Im1* sequence, (b) is the extracted result from *Pascal* sequence, (c) is the extracted result from *Herve* sequence, (d) is the extracted result from *Train\_and\_Tunnel* sequence.



Figure 6: Extracted watermark after both recoding and noise pollution, where (a) is the extracted result from *Im1* sequence, (b) is the extracted result from *Pascal* sequence, (c) is the extracted result from *Herve* sequence, (d) is the extracted result from *Train\_and\_Tunnel* sequence.

Table 1: Image degradation of the watermarked video sequence

Video sequence	Index	
	$\delta_{dB}$	WDR
<i>Iml</i>	0.0228	1.0
<i>Pascal</i>	0.0387	1.0
<i>Herve</i>	0.0878	1.0
<i>Train_and_Tunnel</i>	0.1089	1.0

Table 2: Comparison of the proposed algorithm and non-adaptive algorithm

Video sequence	WDR			
	WDR after recoding		WDR after both recoding and noise pollution	
	Non-adaptive algorithm	Proposed algorithm	Non-adaptive algorithm	Proposed algorithm
<i>Iml</i>	0.2624	0.7834	0.2538	0.7482
<i>Pascal</i>	0.4136	0.8846	0.3981	0.8536
<i>Herve</i>	0.2896	0.8937	0.2859	0.8041
<i>Train_and_tunnel</i>	0.3158	0.9012	0.3140	0.8852

## Acknowledgements

This research is supported by National Natural Science Foundation of China (Grant No. 10671180) and Natural Science Foundation of Ningbo City, China(No. 2006A610013).

## References

- [1] H. Rhys: Digital stereo video: display, compression and transmission. *Ph. D. thesis*. the Australian National University. Australian (2002)
- [2] G. P. Li, Y. He: A novel multi-view video coding scheme based on H.264. *ICICS-PCM(2003)* 493-497(2003)
- [3] H. Z. Jia, W. Gao, Y. Lu: Stereoscopic video coding based on global displacement compensated prediction. *Proceedings of the International Conference on Information and Communications Security(2003)*. 61-65(2003)
- [4] L. F. Ding, S. Y. Chien, Y. W. Huang, Y. L. Chang: Stereo video coding system with hybrid coding based on joint prediction scheme. *Proceedings of 2005 International Symposium on Circuits and Systems*. 6082-6085(2005)
- [5] M. Barni, F. Bartolini, N. Checcacci: Watermarking of MPEG-4 video objects. *IEEE Transactions on Multimedia*. 7: 23-32(2005)
- [6] F. Cayre, C. Fontaine, T. Furon: Watermarking security: theory and practice. *IEEE Transactions on Signal Processing*. 53: 3976-3987(2005)
- [7] B. G. Mobasseri, R. J. Berger: A foundation for watermarking in compressed domain. *IEEE Signal Processing Letters*. 12: 399-402 (2005)

- [8] C. L. Lei, P. L. Yu, P. L. Tsa, M. H. Chan: An efficient and anonymous Buyer-Seller watermarking protocol. *IEEE Transaction on Image Processing*. 13: 1618-1626(2004)
- [9] G. C. Langelaar: Real-time watermarking techniques for compressed video data. *Ph. D. thesis*. Delft University of Technology. Holland (2000)
- [10] Z. J. Zhu, G. Y. Jiang, M. Yu, X. W. Wu: New algorithm for video watermarking. *Proceeding of the 6th International Conference on Signal Processing.(Beijing)* 576-579(2002)
- [11] Z. J. Zhu, G. Y. Jiang, M. Yu, X. W. Wu: Fast disparity estimation algorithm for stereo video coding. *Proceedings of 2002 IEEE Region 10 Conference on Computers. Communications. Control and Power Engineering*. 285-288(2002)
- [12] R. G. Gallager: Low-density parity-check codes. Cambridge, MA: *M.I.T. Press* (1963)
- [13] M. G. Luby, M. Mitzenmacher, M. A. Shokrollahi: Improved low-density parity-check codes using irregular graphs. *IEEE Trans. Inf. Theory*. 47: 585-598(2001)
- [14] M. Greferath, M. E. Sullivan, R. Smarandache: Construction of good LDPC codes using dilation matrices. *Proceedings of the 2004 IEEE International Symposium on Information and Theory*. (2004)
- [15] H. Tang, J. Xu, Y. Kou, S. Lin, G. K. Abdel: On algebraic construction of gallager and circulant low-density parity-check codes. *IEEE Trans. Inform. Theory*. 50: 1269–1279(2004)
- [16] L. F. Xi: *Lipschitz equivalence of self-conformal sets*. *J. London Math. Soc. (2)* 70,369-382(2004)
- [17] Mei Sun, Lixin Tian, Jian Yin: Hopf bifurcation analysis of the energy resource chaotic System. *International Journal of Nonlinear Science*. 1(1),49-53(2006)
- [18] Guoliang Cai, Juanjuan Huang, Lixin Tian, Qingchao Wang: Adaptive control and slow manifold analysis of a new chaotic system. *International Journal of Nonlinear Science*. 2(1),50-60(2006)
- [19] Xuedi Wang, Lixin Tian, Liqin Yu: Linear feedback controlling and synchronization of the Chen's chaotic system. *International Journal of Nonlinear Science*. 2(1),43-49(2006)
- [20] Meifeng Dai, Xi Liu: Lipschitz equivalence between two Sierpinski Gasketse. *International Journal of Nonlinear Science*. 2(2), 77-82(2006)