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Robust Digital Video Watermarking Algorithm Using Dual Watermarks in Block DCT Domain

Byung-Ju Kim†, Suk-Hwan Lee††, Ki-Ryong Kwon†††, Sang-Ho Ahn††††, Tai-Suk Kim†††††, Kuhn-Il Lee††††††

ABSTRACT

We proposed a novel digital video watermarking that embeds dual watermarks in the block DCT domain to solve the deadlock problem. Daul watermarks are composed of private watermarks and robust blind watermarks. Firstly, private watermarks are embedded into the lowest AC coefficients of the P or B-frames in accordance with the motion direction gained from a previous frame. Secondly, blind watermarks that have the robustness are inserted into the DC coefficients of the I-frames using a private key made from temporal I-frame motion information. Thus, when a deadlock situation occurs, the proposed algorithm can efficiently solve the problem. Experimental results confirmed that the proposed algorithm can produce good subjective and objective results for MPEG coding with a variety of bit rates. Furthermore, the proposed watermarking algorithm can potentially be applied to broadcasting monitoring systems due to its simplicity and high robustness.

Keywords: Digital Video Watermarking, Dual Watermark, Blockt DCT, Blind Watermarking

1. INTRODUCTION

Digital Video media, for example, DVD and VOD, can bereadily manipulated, reproduced, and distributed over information networks, yet this efficiency has led to problems regarding copyright protection. Therefore, various digital video watermarking algorithms have been investigated to solve this problem[2,3,6,7]. However, since digital video is usually compressed with MPEG, the watermarking algorithm has to be robust to MPEG coding[1]. In recent video watermarking techniques, a digital video is considered as a sequence of independent images, yet applying an identical watermark to each frame in the video leads to problems of maintaining statistical invisibility. In addition, most current watermarking schemes are unable to resolve rightful ownership of digital data when multiple ownership claims are made, i.e., when a ‘deadlock problem’ arises. A pirate can simply add his or her watermark to the watermarked data or counterfeit a watermark that correlates well or is detected in the contested signal. Current data embedding schemes used as copyright protection algorithms are unable to establish who watermarked the data first. A dual

※ Corresponding Author : Ki-Ryong Kwon, Address : (608-738) 55-1 Uan-Dong, Namgu, Busan, Korea, TEL: +82-51-640-3176, FAX : +82-51-645-4525
E-mail : krkwon@pufs.ac.kr
Receipt date : April 7, 2004, Approval date : June 11, 2004
† School of Electronic and Computer Kyungpook National Univ.
(E-mail : bjleokim@palgong.knu.ac.kr)
†† School of Electronic and Computer Kyungpook National Univ.
(E-mail : skylee@palgong.knu.ac.kr)
††† Division of Digital Information Eng. Pusan Univ. of Foreign Studies
†††† Division of Electronic and Telecomm. Inje Univ.
(E-mail : eleccash@inje.ac.kr)
††††† Dept. of Software Engineering Dong-eui Univ.
(E-mail : tskim@dongeui.ac.kr)
†††††† School of Electronic and Computer Kyungpook National Univ.
(E-mail : kilee@m80.knu.ac.kr)
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watermark technique has been proposed in[1] to overcome a 'deadlock problem'. Accordingly, the current study proposes a novel digital video watermarking algorithm that uses dual watermarks in the block DCT domain to overcome the above-mentioned problems. In the proposed algorithm, private watermarks are inserted into the lowest AC coefficients of the P or B-frames in accordance with the motion direction gained from a previous frame, while very robust second blind watermarks are inserted into the DC coefficients of the I-frames using a private key made from temporal I-frame motion information. The first private watermarks are used for author verification, whereas the second blind watermarks are used to solve a deadlock problem. When a deadlock problem occurs, the problem can be solved by extracting nearly perfectly robust watermarks that contain a real name or time code, etc. Experimental results confirmed that the proposed algorithm can produce good subjective and objective results for MPEG coding with a variety of bit rates.

2. PROPOSED DUAL VIDEO WATERMARKING ALGORITHM

In general, if the original video data are not needed in the detection stage, the scheme is blind, otherwise it is private. However, the requirement of the original video data in a private watermarking system gives rise to a 'deadlock problem' based on subtracting a second watermark from publicly available data, and a blind watermarking system can also suffer from the deadlock problem by inserting of another pirate blind watermark. Thus, a dual watermark system (private+blind) can solve this problem[2].

2.1 Watermark embedding

A block diagram of the proposed dual watermarking embedding algorithm is shown in Fig. 1. First, the private watermarks are embedded into

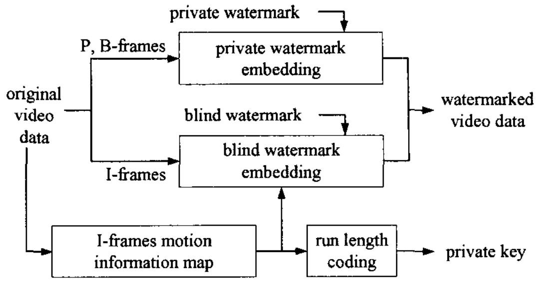


Fig. 1. Block diagram of the proposed dual video watermarking embedding algorithm.

the original P (predicted), or B (bi-directional predicted) location frames, whereas the blind water marks are embedded into the original I (intra) location frames. Second, a motion information map is created using the current and next I-frames from the original video data, then this map information is used for the private key after processing the run length coding to reduce the size of the private key.

2.1.1 Private watermark embedding

In general, human eyes are more insensitive to the noise of blocks with a high variance than flat blocks, and blocks with motion rather than motionless blocks. In particular, visibility decreases in the direction of a moving object. For example, if a block moves in a vertical direction, the vertical frequency coefficient of the block will have a somewhat poor visibility because of a blurring effect. As such, the private watermarks are adaptively embedded into the lowest AC coefficients of a block with a high variance, as the motion direction in the block DCT domain.

First, high variance blocks are selected based on a statistical threshold for the DCT coefficients. Second, one of four motion directions (vertical, horizontal, diagonal, and no motion) is identified from the original previous frame for the selected high variance blocks, and the current frame is transformed into the block DCT domain. Finally, according to one of three motion directions (excepting no motion information), a private watermark is embedded into the same directional lowest coefficient in accordance with the motion direction. The embedding location in accordance with the motion direction in the block DCT region is depicted in Fig. 2, where C_X^i denotes the X-directional coefficient of the i-th block in each frame. In other words, if the motion direction of an 8×8 block is vertical, the watermark is embedded into C_V^i, if motion direction is horizontal, the watermark is embedded into C_H^i, and if the motion direction is diagonal, the watermark is embedded into C_D^i.

The embedding process is as follows:

IF($C_V^i > TH_V$ and $C_H^i > TH_H$ and $C_D^i > TH_D$) {
SWITCH(motion direction) {
Vertical motion: $\tilde{C}_V^i = C_V^i \cdot [1 + \alpha_V \cdot W_P(m)]$
Horizontal motion: $\tilde{C}_H^i = C_H^i \cdot [1 + \alpha_H \cdot W_P(m)]$
Diagonal motion: $\tilde{C}_D^i = C_D^i \cdot [1 + \alpha_D \cdot W_P(m)]$
}
}

where $W_P(m)$ is the m-th binary private watermark and α_X denotes the weight value of the X-directional element. Based on the sensitivity of the HVS as regards the DCT coefficients, the diagonal element is more imperceptible than the vertical or horizontal element. Thus, α_D was chosen to be double the value of α_V or α_H.

The statistical threshold for the DCT coefficients, TH_X (X : V, H, D) is calculated for each frame adaptively, and the threshold is

$$TH_X = \frac{S}{B}\sum_{i=1}^{B} |C_X^i| \tag{1}$$

where B is the number of 8×8 blocks in each frame and S is the scale factor.

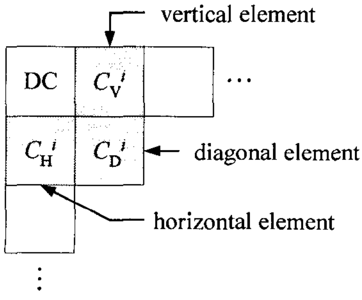


Fig. 2. Embedding location in accordance with the motion direction for private watermark.

2.1.2 Blind watermark embedding

Avery robust blind watermark algorithm is proposed so that the author's real information (name or a time code, etc.) can be almost perfectly extracted when a deadlock problem occurs.

For such robustness, blind watermarks are embedded into the DC coefficient in the motionless blocks of the k-th I-frame in accordance with the $(k+1)$-th I-frame. This 'I-frame motion' is gained from the next I-frame. If the DC coefficient of the i-th block of the k-th I-frame is same as the DC coefficient of the i-th block of the $(k+1)$-th I-frame, the block is classified as a motionless block.

A blind watermark system does not use reference values, unlike a private watermark system, as it does not require the original video data, yet this causes an increase in the bit error rate (BER) in the detection procedure due to the quantization error. Therefore, to overcome this disadvantage, the $(k+1)$-th I-frame is used as the reference for the k-th I-frame.

In general, if the i-th block of the k-th I-frame is motionless (i.e. the i-th DC coefficient of the k-th I-frame is same as the i-th DC coefficient of the $(k+1)$-th I-frame), the two quantized DC coeffieicnts will be almost the same after MPEG coding, because I-frames are almost identically coded. As such, blind watermarks are embedded into the k-th DC coefficient of a motionless block using the $(k+1)$-th DC coefficient as the reference value. For a motionless block, the watermarked i-th DC coefficient of the k-th I-frame is

$$\tilde{C}^i(k) = \begin{cases} C^i(k+1) + Q & \text{if } W_B(m) = 1 \\ C^i(k+1) - Q & \text{if } W_B(m) = 0 \end{cases} \tag{2}$$

$$k = (l-1)N_{GOP} + 1, \; (l = 1, 3, 5, \cdots) \qquad (3)$$

where $W_B(m)$ is the m-th binary blind watermark and N_{GOP} is the GOP (Group of pictures) number. The blind watermarks are also only embedded into odd I-frames to prevent any embedding overlap. The quantization step size of the watermark, Q is

$$Q = DCT(D_{\min}) \qquad (4)$$

where $D\min$ denotes a constant value for the blocking artifact. Based on the HVS Theory[4], since the minimum value for the average difference preventing a blocking artifact is 2 experimentally, $D_{\min}$ is 2.

The k-th I-frame motion map is made of the composed binary motion information for all the blocks and is coded using RLC to reduce the bit amount. After this procedure, the coded k-th I-frame motion map is used as the private key in the detection procedure.

2.1.3 Watermark detection

To determine the rightful owner of a video in the case of a copyright dispute, an arbitrator examines the private watermark using the original video data. In this procedure, if deadlock occurs, the true author's real information can be extracted from the pirate's original video data to solve the problem[2].

For the blocks classified as having a high variance and motion direction from the original video data, the private watermark detection procedure using the original video data is

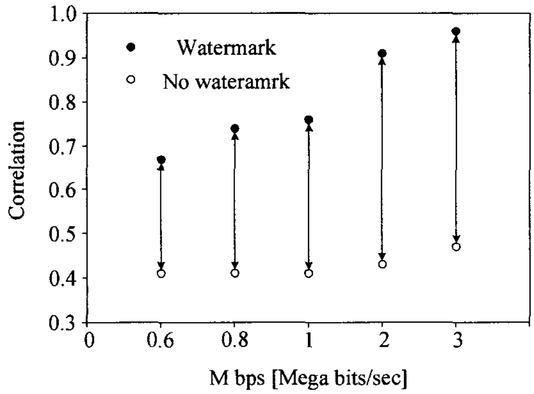
$$W_P(m) = \begin{cases} 1, & [\tilde{C}_X^i - C_X^i] > 0.5 \quad (X: \text{V or H or D}) \\ 0, & other \end{cases} \qquad (5)$$

plus for the blocks classified as motionless, the blind watermark detection procedure using the private key is

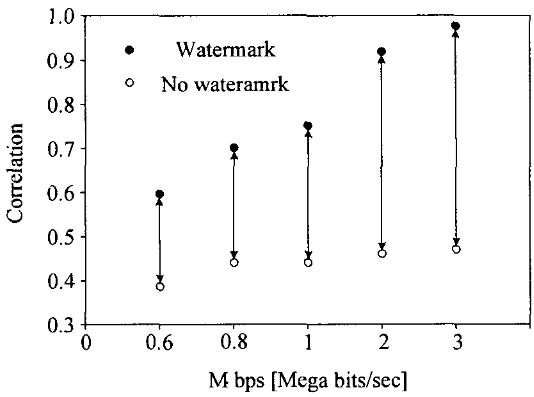
$$W_B(m) = \begin{cases} 1, & [\tilde{C}^i(k) - C^i(k+1)] > 0 \\ 0, & other \end{cases} \qquad (6)$$

3. EXPERIMENTAL RESULTS

Computer simulations were performed using MPEG TM5. The type of watermark was binary (0 or 1). The total number of frames was 20, the GOP was 12, plus the BERs(bit error rates) of the detected watermarks were represented for MPEG coding using variable bit rates. The correlation result of the private watermark is presented in Fig. 3. In this figure, we could know that the algorithm could efficiently verify its authority. The robustness results for the private and blind watermark



(a)



(b)

Fig. 3. Correlation result of the private watermark for the (a) TABLE TENNIS and (b) FOOTBALL video data.

algorithms against an MPEG attack are presented in Tables 1 and 2. In Table 2, the blind watermarks were nearly perfectly detected, even when data were coded with a very low bit rate. That is, we

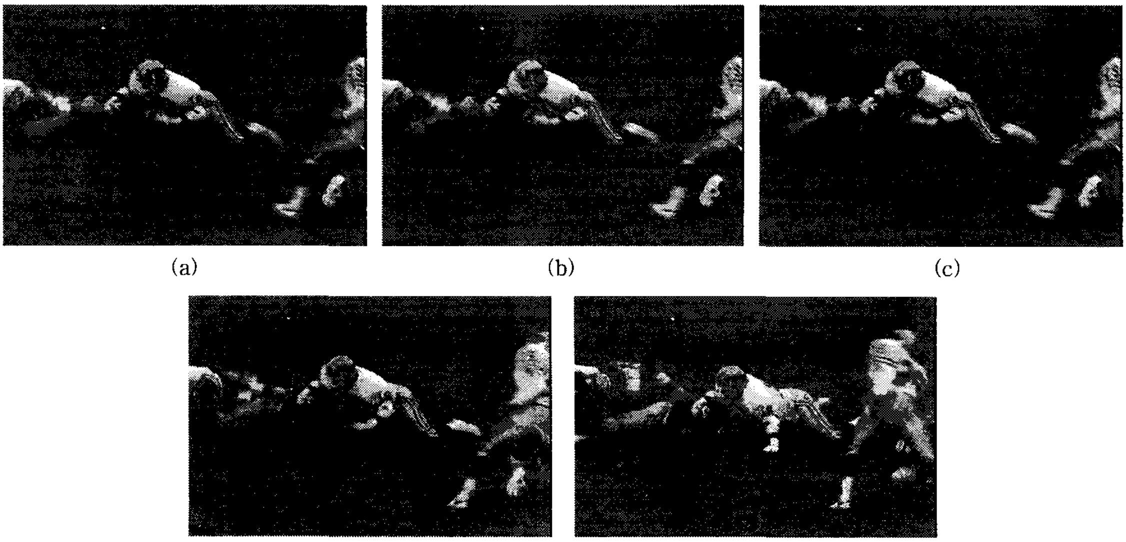
Table 1. Experiment results for the private watermark

	Avg. PSNG of water-marked P, B-data	Bitrate [Mbit/s]	BER [%]				Avg. PSNR after MPEG coding	
			P-frames		B-frames		watermarked	original
TABLE TENNIS	52.36	3.0	**1.52**	(3/197)	**5.07**	(23/454)	34.83	34.87
		2.0	**3.55**	(7/197)	**11.89**	(54/454)	32.19	32.25
		1.0	**16.24**	(32/197)	**26.43**	(120/454)	28.79	28.82
		0.8	**15.23**	(30/197)	**28.85**	(131/454)	27.99	28.01
		0.6	**20.30**	(40/197)	**34.58**	(157/454)	27.09	27.12
FOOT-BALL	50.20	3.0	**1.15**	(4/348)	**4.36**	(36/826)	31.96	32.07
		2.0	**2.59**	(9/348)	**11.02**	(91/826)	29.81	29.83
		1.0	**11.49**	(40/348)	**29.06**	(240/826)	26.55	26.56
		0.8	**16.38**	(57/348)	**32.93**	(272/826)	25.64	25.66
		0.6	**25.57**	(89/348)	**38.01**	(314/826)	24.89	24.91

Table 2. Experiment results for the blind watermark

	TABLE TENNIS				FOOTBALL			
Bitrate [Mbit/s]	BER [%]		PSNR [dB]		BER [%]		PSNR [dB]	
				X				X
3.0	**0.0**	(0/117)	**35.53**	35.62	**0.0**	(0/29)	**38.65**	38.70
2.0	**0.0**	(0/117)	**33.04**	33.09	**0.0**	(0/29)	**35.98**	36.00
1.0	**0.85**	(1/117)	**29.45**	29.47	**0.0**	(0/29)	**32.01**	32.02
0.8	**0.85**	(1/117)	**28.67**	28.69	**3.0**	(1/29)	**30.98**	30.99
0.6	**0.0**	(0/117)	**27.78**	27.79	**6.06**	(2/29)	**29.82**	29.83

X : MPEG coded original video data.
: MPEG coded watermarked video data.



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

Fig. 4. (a) Original image and (b) watermarked image for I-frame, and MPEG image (0.6Mbps) for (c) I-frame, (d) B-frame, and (e) P-frame.

could extract the author's information. Accordingly, the experimental results demonstrated that the proposed technique produced a good performance.

Fig. 4(a), (b) shows original image and watermarked image for I-frame of Football. Fig. 4(c)-(e) are I-frame, B-frame, and P-frame watermarking images of MPEG coding with 0.6 Mbps.

4. CONCLUSIONS

A novel digital video watermarking algorithm was proposed using dual watermarks in the block DCT domain. In the proposed algorithm, private watermarks are inserted into the lowest AC coefficients of the P or B-frames in accordance with the motion direction gained from a previous frame, while very robustsecond blind watermarks are inserted into the DC coefficients of the I-frames using a private key made from temporal I-frame motion information. Thus, when a deadlock situation occurs, the proposed algorithm can efficiently solve the problem. Furthermore, the proposed watermarking algorithm can potentially be applied to broadcasting monitoring systems[5] due to its simplicity and high robustness.

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Byung-Ju Kim

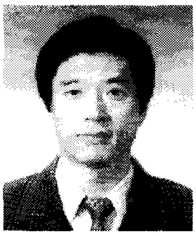
He received a B.S. and a M.S. degree in Kyungpook National University, Korea in 1997 and 1999 respectively and went through the course of Ph. D in Kyungpook National University, Korea in 2001. His research field has been in digital image processing, image communication, and digital watermarking.

Suk-Hwan Lee

He received a B.S., a M.S., and a Ph. D degree in Kyungpook National University, Korea in 1999, 2001, and 2004 respectively. His research field has been in digital image processing, computer graphics, and digital watermarking.

Ki-Ryong Kwon

1986 Elcectonic Engineering, Kyungpook National University(BS)
1990 Elcectonic Engineering, Kyungpook National University(MS)
1994 Elcectonic Engineering, Kyungpook National University(Ph.D)
1986~1988 Research Center, Hundai Motor Company
2000~2002 Visiting Professor, University of Minnesota
1996~Present Associate Professor, Pusan University of Foreign Studies
Research Interests : Multimedia Security, Wavelet Transform, Image Processing 3D Recognition System



Sang-Ho Ahn

He received the B.S., M.S., and Ph.D. degrees in Electronics Engineering from Kyungpook National University, Korea, in 1986, 1988, and 1992, respectively. Since 1993, he has been with School of Electronic Telecommunication Engineering at Inje University where he is now an associate professor. His research interests include IR image processing, stereo vision and watermarking.

Tai-Suk Kim

He received his B.S. degree from the department of electrical engineering, Kyungpook National University in 1981 and his M.S. and Ph.D. degrees from the department of computer science, Keio University in 1989 and 1993, respectively. Since 1994, he has been a faculty member of the Dong-eui University, where he is now an associate professor in the department of software engineering. His current research interests are information system and internet business.

Kuhn-Il Lee

He received a B.S., and a M.S. degree in Kyungpook National University, Korea in 1965, and 1970 respectively and a Ph. D degree in Pusan National University, Korea in 1984. He was a assistant and a associate professor in school of electronics engineering at Kyungpook National University from 1969 to 1984 and was an exchange professor at RPI Institute of Technology, USA. He currently is a professor in school of Electrical Engineering and Computer Science at Kyungpook National University and a member of committee in IEC/TC39.