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Video Watermarking Based on Wavelet Magnitude Modulus Subband

Jinkyung Byun†, Young-Deuk Moon††, Suk-Hwan Lee†††, Seong-Geun Kwon††††, Ki-Ryong Kwon†††††

ABSTRACT

This paper proposes the blind watermarking algorithm for digital video based on magnitude modulus subband in wavelet transform domain. After transforming each of frames into wavelet domain, the proposed algorithm divides LH, HL, and HH subbands of 2-level into 3×3 blocks and calculates average magnitude modulus of all blocks. Then the watermark bit is embedded into a target magnitude modulus comparing with an average magnitude modulus within a block. Experimental results were confirmed that the proposed algorithm has the good robustness against MPEG and frame attacks than the conventional algorithm.

Keywords: Copyright Protection, Blind Video Watermarking, Wavelet Transform, Magnitude modulus

1. INTRODUCTION

Digital video media, such as DVD and VOD, can be readily manipulated, reproduced, and distributed over information networks. However, this efficiency has led to problems regarding copyright protection. Therefore, various digital video watermarking algorithms have been investigated to solve this problem. However, since digital video is usually compressed with MPEG, the watermarking algorithm has to be robust against various MPEG coding rates. Since video watermarking techniques consider the digital video as a sequence of independent images and embed the identical watermarks into each frame in the video, they have the difficulty for maintaining statistical invisibility.

Watson *et al.*[1] proposed the frequency sensitivity threshold for perceptual quantization and perceptual bit allocation in the wavelet image compression. These visual thresholds had been modeled hierarchically in each of 4 levels using 9/7 biorthogonal filter[2]. Many DWT watermarking algorithms have been proposed based on these visual thresholds in each of subbands. As a general still image watermarking, Podilchuk *et al.*[3] transformed an image into multiresolution image using DWT and selected the embedding coefficients using JND (just noticeable difference) in each of subbands. They embedded the watermark into the selected coefficients by using the embedding strength of JND. Hartung *et al.*[4]'s algorithm converts video signal of 2D frame and times axis into 1D signal by using line-scanning and embeds the

※ Corresponding Author : Ki-Ryong Kwon, Address : (608-738)599-1 Daeyeon-dong, Nam-gu, Busan, Korea, TEL : +82-51-620-6495, FAX : +82-51-620-6350, E-mail : krkwon@pknu.ac.kr
Receipt date : Dec. 29, 2006, Approval date : June 7, 2007.
† Pusan University of Foreign Studies (E-mail : byunjk84@yahoo.co.kr)
†† Pusan University of Foreign Studies (E-mail : ydm@pufs.ac.kr)
††† Tongmyong University (E-mail : skylee@tit.ac.kr)
†††† R&D Group, Mobile Communication Division, Samsung Electronics Co. (E-mail : seonggeunkwon@hanmail.net)
††††† Pukyong National University
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watermark based on secure spread spectrum technique. Swanson *et al.*[5] proposed multi-resolution scene-based video watermarking. This algorithm generates the watermark of static and dynamic elements from the temporal wavelet transform in video scene and embed the watermark into wavelet coefficients based on spatial masking, frequency masking and temporal properties. Zhongjie *et al.*[6] presented video watermarking in MPEG-2 compression encoding process that the watermark is embedded into motion vectors for P and B frame. This algorithm has blocking artifacts that occur seriously in high compression ratio. Wang *et al.*[7] proposed blind video watermarking technique based on full-DCT framework for MPEG-2 system. They embedded the binary watermark into some randomly selected frames using the average of nearest two frames. But, because it is based on full-DCT framework, the method has so huge calculation complexity.

This paper presented a blind video watermarking algorithm based on magnitude modulus in DWT domain. The proposed algorithm decomposes each of video frames into 4-level DWT and creates a MAG subband that is composed of magnitude modulus of three 2-level subbands (LH_2, HL_2, HH_2) in a frame. The watermark bits are embedded into target magnitude modulus in a MAG subband considering average magnitude modulus. As experimental result, we confirmed that the proposed algorithm has good robustness against MPEG compression, frame dropping, frame averaging and signal processing than Wang's algorithm.

2. PROPOSED VIDEO WATERMARKING ALGORITHM

We consider that video watermarking has to satisfy two conditions. The first condition is that the watermark can be extracted without any data and the second condition is that the watermark can be robust against video attacks such as MPEG compression, frame dropping and frame averaging. To satisfy these conditions at once, we proposed blind video watermarking that the same watermark is embedded into the magnitude modulus in MAG subband of all frames. A MAG subband in a frame can be obtained from wavelet coefficients of 2-level LH, HL, HH subbands in DWT domain. Firstly we explain DWT briefly in the following subsection although it is well-known. And the proposed video watermarking is explained in the next subsection.

2.1 Wavelet Transform

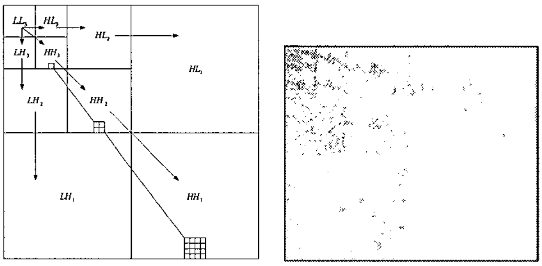
Wavelet transform provides a compact multi-resolution representation of the image. It inherits an excellent energy compaction property suitable to exploit redundancy in an image to achieve compression. Discrete wavelet transform (DWT) can be implemented using two-channel wavelet filter bank in a recursive fashion. For an image, 2D-DWT is generally calculated using a separable approach. Input image is first scanned in a horizontal direction and passed through low-pass and high-pass decomposition filters. The decomposed data is then sub-sampled vertically to produce low frequency as well as high frequency data in horizontal direction. This filtered output data is then scanned in a vertical direction and again these filters are applied separately to generate different frequency subbands. After sub-sampling of the resultant data in horizontal direction, the transform generates subbands LL, LH, HL and HH each with one forth the size of the original image. Most of the energy is concentrated in low frequency subband LL and represents a down sampled low resolution version of the original image, whereas higher frequency subbands contain detail information of the image in horizontal, vertical and diagonal directions respectively. After one level of transformation, the image can be further decomposed by again applying 2-D DWT to the existing LL subband in the similar manner. This iterative process results in multiple levels of transformation with energy further compacted into few low frequency coefficients. An example of 4-level decomposition of image into subbands using wavelet transform is illustrated in fig. 1.

2.2 Watermark embedding

The block diagram of the proposed watermarking embedding algorithm is shown in fig. 2. Firstly, the proposed algorithm transforms all frames into wavelet domain and obtain MAG subband from 2-level LH, HL, HH subbands as shown in fig. 3 (a).

$$MAG_2 = (|LH_2| + |HL_2| + |HH_2|)/3 \quad (1)$$

A MAG_2 is a 2-level MAG subband that represents an average magnitude modulus of horizontal, vertical, diagonal wavelet coefficients in 2-level and shows the singularity points in a frame. The



(a) (b)

Fig. 1. (a) 4-level wavelet transform of structure and (b) the first frame of FOOTBALL decomposed by 4-level wavelet.

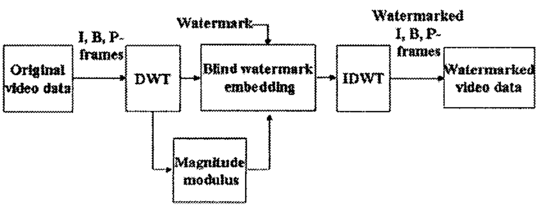
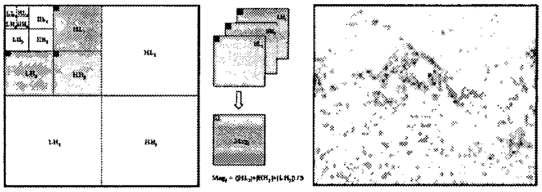


Fig. 2. The block diagram of the proposed watermark embedding algorithm.



(a) (b)

Fig. 3. (a) The obtaining process of a MAG_2 subband from 2-level LH, HL, HH subbands in a frame and (b) a MAG2 subband in the first frame of FOOTBALL sequence.

size of a MAG_2 subband is $NV/4 \times NH/4$. NV and NH are respectively vertical and horizontal sizes in a frame. Let $Mag_2(i, j)$ $(0 \le i < NV, 0 \le j < NH)$ be (i, j) th. average magnitude modulus in a MAG_2 subband. Fig. 3 (b) shows a MAG_2 subband with $352/4 \times 240/4$ size in the first frame of FOOTBALL sequence and also shows the singularity points in its frame.

To embed the watermark bit into a MAG_2 subband, the proposed algorithm divides this subband into 3×3 blocks and selects the center modulus as the embedding target modulus. A watermark bit is embedded into a center modulus in a 3×3 block. Thus, the number of the available embedding watermark bit is $Int((NV/4)/3) \times Int((NH/4)/3)$ in a frame. $Int(\cdot)$ is the integer function. Let arbitrary center modulus be $Mag_2 X_{u,v}$.

$$\begin{aligned} &Mag_2 X_{u,v} = Mag_2(3u+1, 3v+1) = , \\ &(|w_{LH_2}(u,v)| + |w_{HL_2}(u,v)| + |w_{HH_2}(u,v)|)/3 \\ &0 \le 3u+1 < NV, 0 \le 3v+1 < NH \end{aligned} \quad (2)$$

where u, v are positive integer and W_{LH2}, W_{HL2}, W_{HH2}, are respectively wavelet coefficients in 2-level LH, HL and HH subband. $Mag_2 \widetilde{X}_{u,v}$ is an average modulus of 4-neighboring modulus as shown in fig. 4.

$$\begin{aligned} Mag_2 \widetilde{X}_{u,v} = [&Mag_2(3u+1, 3v) + Mag_2(3u, 3v+1) + \\ &Mag_2(3u+1, 3v+2) + Mag_2(3u+2, 3v+1)]/4 \end{aligned} \quad (3)$$

A watermark bit W_k $(0 \le k < Int((NV/4)/3 \times Int((NV/4)/3)$ is embedded into a center

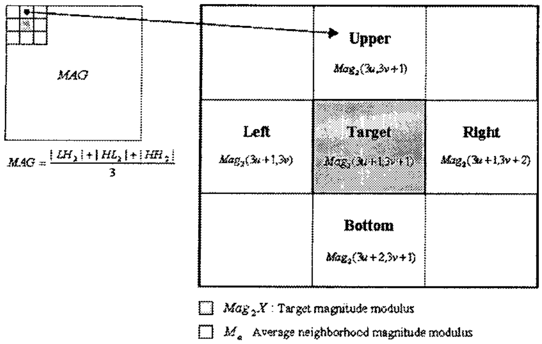


Fig. 4. A target modulus and 4-neighboring modulus in a block of MAG2 subband.

modulus $Mag_2X_{u,v}$ as follows;

$$if(|Mag_2X_{u,v} - Mag_2\tilde{X}_{u,v}| > \alpha \times Mag_2\tilde{X}_{u,v})$$
$$Mag_2X'_{u,v} = \begin{cases} Mag_2X_{u,v}, & w_k = 1 \\ Mag_2\tilde{X}_{u,v}, & w_k = 0 \end{cases} \quad (4)$$
$$if(|Mag_2X_{u,v} - Mag_2\tilde{X}_{u,v}| \le \alpha \times Mag_2\tilde{X}_{u,v})$$
$$Mag_2X'_{u,v} = \begin{cases} (1 \pm 2\alpha) \times Mag_2\tilde{X}_{u,v}, & w_k = 1 \\ Mag_2X_{u,v}, & w_k = 0 \end{cases} \quad (5)$$

Thus, If a watermark bit W_k is 0, then a center modulus $Mag_2X_{u,v}$ will be within a range $[(1-\alpha)Mag_2\tilde{X}_{u,v}, (1+\alpha)Mag_2\tilde{X}_{u,v}]$. Otherwise a center modulus $Mag_2X_{u,v}$ will be gone out of this range as shown in fig. 5. α is the embedding strength that are determined to 0.25 experimentally.

From Eq. (4) and Eq. (5), a center modulus $Mag_2X_{u,v}$ have to be changed to $Mag_2\tilde{X}_{u,v}$ if $|Mag_2X_{u,v} - Mag_2\tilde{X}_{u,v}| > \alpha \times Mag_2\tilde{X}_{u,v}$ and w_k is 0 or to $(1 \pm 2\alpha) \times Mag_2\tilde{X}_{u,v}$ if $|Mag_2X_{u,v} - Mag_2\tilde{X}_{u,v}| \le \alpha \times Mag_2\tilde{X}_{u,v}$ and w_k is 1. To change a center modulus $Mag_2X_{u,v}$, wavelet coefficients $w_{LH_2}(u,v)$, $w_{HL_2}(u,v)$, $w_{HH_2}(u,v)$ in Eq. (2) have to be changed. In case that a center modulus $Mag_2X_{u,v}$ has to be changed to $Mag_2\tilde{X}_{u,v}$ from Eq. (4),

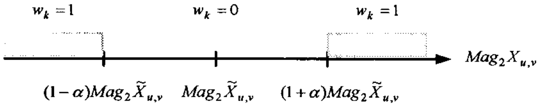


Fig. 5. The embedding region according to a watermark bit w_k.

$$w'_{LH_2}(u,v) = \mathrm{sgn}(Mag_2\tilde{X}_{u,v} - |w_{HL_2}(u,v)| - |w_{HH_2}(u,v)|),$$
$$w'_{HL_2}(u,v) = \mathrm{sgn}(Mag_2\tilde{X}_{u,v} - |w_{LH_2}(u,v)| - |w_{HH_2}(u,v)|),$$
$$w'_{HH_2}(u,v) = \mathrm{sgn}(Mag_2\tilde{X}_{u,v} - |w_{LH_2}(u,v)| - |w_{HL_2}(u,v)|) \quad (6)$$

$(1 \pm 2\alpha) \times Mag_2\tilde{X}_{u,v}$ can be used instead of $Mag_2\tilde{X}_{u,v}$ in Eq. (6) in case that a center modulus $Mag_2X_{u,v}$ has to be changed to $(1 \pm 2\alpha) \times Mag_2\tilde{X}_{u,v}$ from Eq. (5). sgn is a sign of wavelet coefficient.

2.3 Watermark Extracting

The proposed watermarking can extract the watermark without original video data as well as any data such as key information. The watermark extracting process is similar as the embedding process. After obtaining a MAG subband in each frame, the watermark is extracted as follows

$$w_k^{*} = \begin{cases} 1, |Mag_2X'_{u,v} - Mag_2\tilde{X}'_{u,v}| \ge \alpha \times Mag_2\tilde{X}'_{u,v} \\ 0, |Mag_2X'_{u,v} - Mag_2\tilde{X}'_{u,v}| < \alpha \times Mag_2\tilde{X}'_{u,v} \end{cases} \quad (7)$$

where w_k^{*} is the k-th extracted watermark bit. $Mag_2X'_{u,v}$ is a center modulus in MAG subband of attacked frame and $Mag_2\tilde{X}'_{u,v}$ is an average modulus adjacent to $Mag_2X'_{u,v}$. From Eq. (7), if $|Mag_2X'_{u,v} - Mag_2\tilde{X}'_{u,v}|$ is bigger or same than $\alpha \times Mag_2\tilde{X}'_{u,v}$, w_k^{*} is 1, otherwise w_k^{*} is 0.

3. EXPERIMENTAL RESULTS

For the performance evaluation, we performed computer simulations about the proposed algorithm and Wang's one, and compared the results of two methods. After converting Gaussian random sequence to binary data, this binary data was used as the watermark in our experiment. Test video sequences are TABLE TENNIS and FOOTBALL with 352×240 (QCIF) size and 20 frames. The number of embedding bit in a frame is $Int((352/4)/3) \times Int((240/4)/3) = 29 \times 20 = 580$.

Our experiment used PSNR (peak signal to noise ratio) for invisibility measure and BER (bit error rate) of the extracted watermark for robustness measure about MPEG compression, frame dropping and frame average. In the proposed method, the average PSNR of TABLE TENNIS and FOOTBALL are about 33.53 dB and 32.97 dB respectively. And, In Wang's method, the average PSNR of TABLE TENNIS and FOOTBALL are about 37.22 dB and 25.77 dB respectively. In case of TABLE TENNIS sequences, though the PSNR about Wang's method is relatively batter than the proposed method's, but in case of FOOTBALL sequences that have large interframe motions, proposed algorithm is so better than Wang's method's. Therefore, at the considering interframe motions, our method have good performance in respect to PSNR. Fig. 5 shows SNRs of all frames in watermarked FOOTBALL and TABLE TENNIS sequences. The second frame and the watermarked frame in test sequences are shown in fig. 6. From these fig., we confirmed the invisibility of the watermark since the difference of the watermarked frame and the original frame can't be identified.

For robustness evaluation, we attacked the watermarked sequences to MPEG compression, frame dropping and frame averaging and then measured BER of the extracted watermark in attacked sequences. Table 1 shows average BERs of the extracted watermark in MPEG compressed sequences. In case of the proposed algorithm above 90% of the watermark can be extracted without bit error. Furthermore, above 75% of the watermark

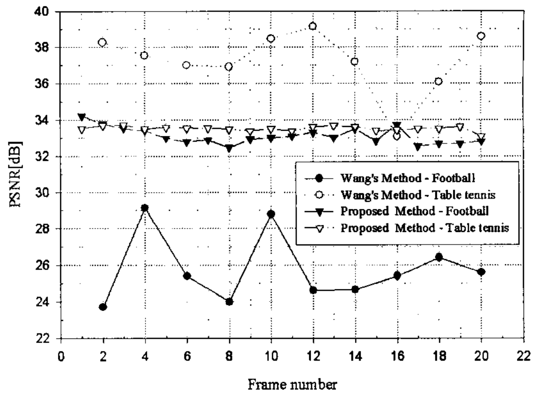


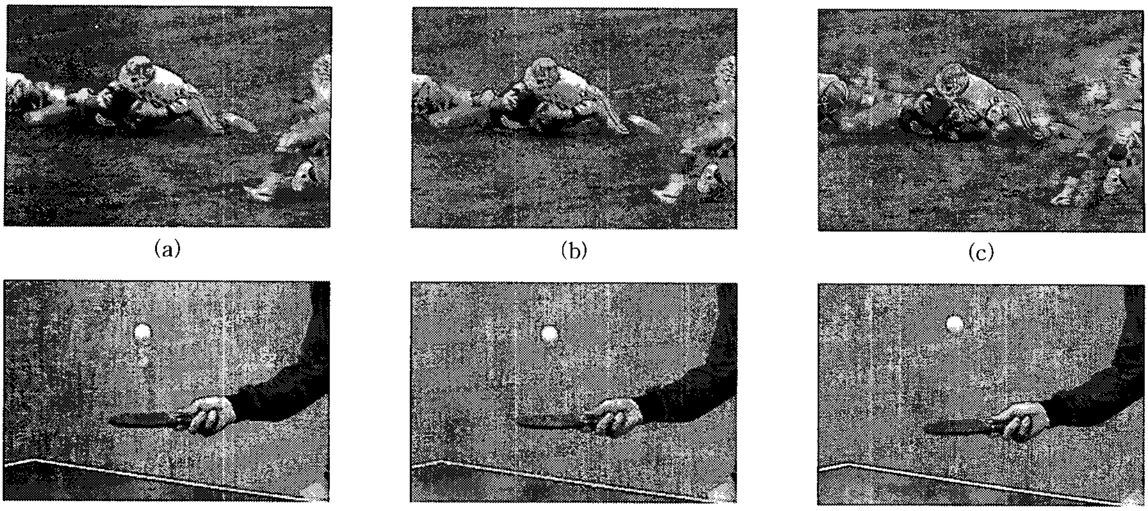
Fig. 6. PSNR of each frame in watermarked test sequences about the proposed and Wang's methods.

can be extracted without bit error in case high compression ratio. But, in Wang's algorithm, above 30% of the watermark cannot survive below 1.0Mbps of compression ratio. Fig. 7 shows BERs in all frames of 1Mbps and 2Mbps compressed sequences. In the proposed method, BER of the extracted watermark is about 0.10-0.18 in 1Mbps compressed sequences and about 0.035-0.065 in 2Mbps compressed sequences, however, in Wang's one, BER of the extracted watermark is about 0.10-0.18 in 1Mbps compressed sequences and about 0.035-0.065 in 2Mbps compressed sequences.

Video data can be edited easily by frame attack, such as frame dropping and frame averaging, unlike image data. In our experiment, the watermarked sequences were attacked by frame dropping and frame averaging. In frame dropping ex-

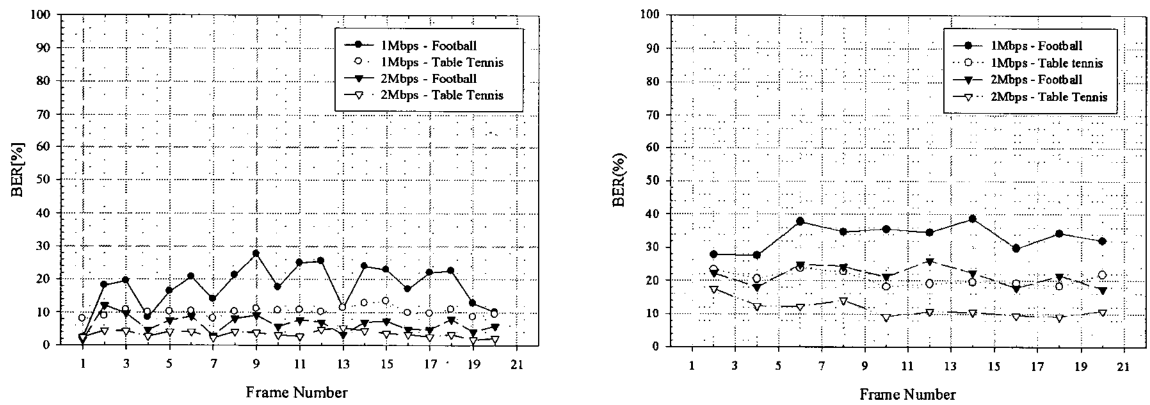
Table 1. Averaged BERs of the extracted watermarks in the proposed method and Wang's method about MPEG compression.

Avg. bps	BER			
	Proposed method		Wang's method	
	TABLE TENNIS	FOOTBALL	TABLE TENNIS	FOOTBALL
3.0 Mbps	0.0166	0.0329	0.0766	0.1486
2.0 Mbps	0.0347	0.0651	0.1162	0.2162
1.0 Mbps	0.1022	0.1795	0.2072	0.3326
0.8 Mbps	0.1216	0.2271	0.2397	0.3724
0.6 Mbps	0.1599	0.2663	0.2838	0.3941



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

Fig. 7. (a) Original second frame, (b) watermarked second frame by proposed method, (c) watermarked second frame by Wang's method in FOOTBALL sequences and (d) Original second frame, (e) watermarked second frame by proposed method, (f) watermarked second frame by Wang's method in TABLE TENNIS sequences.



(a) (b)

Fig. 8. BERs of the extracted watermark in all frames of 1Mbps and 2Mbps MPEG compressed sequences about (a)proposed method and (b)Wang's method.

periment, we dropped even frames among all frames. Actually the embedded watermarks in even frames must be removed by frame dropping. But the proposed algorithm embeds the same watermark in all frames. Therefore, the watermark can be extracted in other odd frames. However, Wang's algorithm embeds the watermark into odd frames. So, the watermark can not be extracted in other frames. In frame averaging experiment, we exchanged even frames to average frames of nearest two odd frames. BER of the extracted watermark in averaging frames is about 0.0105-.0298. Thus, the most watermark bits can be extracted without bit error. But, Wang's one loses watermarked frame and about this attack, BER is very high. From our experimental results, we confirmed that the proposed algorithm has the invisibility of the watermark and the robustness against MPEG compression, frame dropping and frame averaging.

Table 2. BER of the extracted watermark about frame attacks.

Attacks	BER			
	Proposed method		Wang's method	
	TABLE TENNIS	FOOTBALL	TABLE TENNIS	FOOTBALL
Frame dropping	0.0	0.0	0.5801	0.5173
Frame averaging	0.0298	0.0105	0.5064	0.4803

4. CONCLUSIONS

This paper presented a blind digital video watermarking algorithm based on average magnitude modulus in DWT domain. The proposed algorithm decomposes each of video frames into 4-level DWT. And then, after creating MAG average magnitude modulus of 3 subbands (LH_2, HL_2, HH_2) in 2-level for each frame. The watermark bits are embedded into target magnitude modulus in MAG according to the environment of neighborhood magnitude modulus. From experimental results, we confirmed that the proposed algorithm satisfies the invisibility of watermark in each frame and the robustness against MPEG compression, frame dropping and frame averaging. Thus, BER of the proposed algorithm is below about 0.06-0.15 dB in MPEG compression and below about 0.48-0.58 dB in frame attacks than BER of Wang's algorithm. Furthermore, the proposed watermarking algorithm can potentially be applied to broadcasting monitoring systems [8] due to its simplicity and high robustness.

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Jinkyung Byun

He received a B.S. and a M.S. in Computer and Electronics Engineering from Pusan University of Foreign Studies, Korea in 2004 and 2006 respectively. Her current research interests are in the area of digital image processing, multimedia security and watermarking.

Young-Deuk Moon

Young-Deuk Moon received the B.S., M.S., and Ph.D. degrees in eletronics engineering from Dong-A University, Korea in 1973, 1977, and· 1987 respectively. He visited University of Manchester at 1991~1992 ,U.K and University of Alberta at 2003~2004, CANADA with visiting professor. He is currently in Division of Digital Media at Pusan University of Foreign Studies. His current reseach interests are in the area of digital image processing ,multimedia contents design ,and digital circuit design & test.

Suk-Hwan Lee

He received a B.S., a M.S., and a Ph. D. degree in Electrical Engineering from Kyungpook National University, Korea in 1999, 2001, and 2004 respectively. He is currently an assistant professor in department of Information Security at Tongmyong University. His research interests include multimedia security, digital image processing, and computer graphics.

Seong-Geun Kwon

He received a B.S., a M.S., and a Ph. D. degree in Electrical Engineering from Kyungpook National University, Korea in 1996, 1998, and 2002 respectively. He is currently in senior engineering in R&D Group, Mobile Communication Division, Samsung Electronics Co. His research interests include multimedia security, visual communication, and image processing.

Ki-Ryong Kwon

Ki-Ryong Kwon received the B.S., M.S., and Ph.D. degrees in electronics engineering from Kyungpook National University in 1986, 1990, and 1994 respectively. He worked at Hyundai Motor Company from 1986-1988 and at Pusan University of Foreign Language form 1996-2006. In 2006, he joined the Pukyong National University, where he is an associate professor. His current research interests are in the area of digital image processing, multimedia security and watermarking, wavelet transform.