A Novel Watermarking Scheme with Compensation in Bit-Stream Domain for H.264/AVC

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ABSTRACT

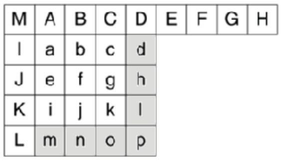
Currently, most of the watermarking algorithms for H.264/AVC video coding standard are encoder-based due to their high perceptual quality. However, for the compressed video, they increase the computational burden to decode the video, embed the watermark, and then re-encode it. Obviously it is a bottleneck for real-time applications. Conventional watermarking algorithms in the bit-stream domain can reduce the computation complexity but result in the error propagation and PSNR loss. In this paper, a new fast watermarking scheme with compensation in bit-stream compressed video domain is proposed, in which the watermark is directly embedded into the quantized residual coefficients. A texture-based perceptual model is employed to decide whether a 4x4-block is appropriate for watermarking or not. A secret key is used to decide the actual location to be embedded in a 4x4-block. With the proposed compensation method, the video watermarking scheme can achieve high robustness and good visual quality without much bit-rate increase. The simulation results have shown that a high PSNR is achieved with little increase in bit rate, and the watermarks can resist common attacks.

I. INTRODUCTION

The video coding standard H.264/AVC with good image quality, network friendliness, and high compression ratio, becomes more and more prevalent. However, the watermarking algorithms designed for H.264/AVC standard are very few due to most of the algorithms are designed for MPEG-2, which cannot be directly applied to H.264/AVC. Recently, several algorithms were proposed for H.264/AVC such as Hsieh and Chang proposed a frequency weighting based watermarking scheme [2] and Marziliano proposed a scheme [3] to embed a robust watermark in the DCT coefficients and a fragile watermark in the motion vectors. In addition, a key that is obtained using the features of a 16x16-macroblock and then the watermark is embedded into a coefficient determined by the key is proposed in [4]. To achieve a better visual quality, a human visual model proposed in [5,6] is used to select the coefficients for embedding watermark, it can also resist common attacks. However, these methods are encoder-based watermarking schemes that require relatively high computational complexity. To tackle the complexity problem, watermarking algorithms in the bit-stream domain with compensation for MPEG-2 video coding standard were proposed in [9,10]. Recently, a watermarking algorithm with compensation for H.264/AVC in the bit-stream domain was proposed in [11]. In the encoder-based algorithms the error introduced by watermarking can be corrected in the future prediction. In the bit-stream domain, compensation methods should be used to eliminate the error propagation effect. Although the methods in [9] and [10] perform well, they are designed for MPEG-2, and cannot be applied to H.264/AVC directly. In [11], watermarks are only embedded into the DC coefficients. In this paper, a novel watermarking scheme with compensation in bit-stream domain is proposed for H.264/AVC, which is robust, fast, and has high capacity. The rest of this paper is organized as follows. The proposed compensation scheme is described in Section 2. Watermark embedding and detection procedure are given in Section 3. Simulation results are given in Section 4. In final, Section 5 concludes our work.

II. ERROR PROPAGATION COMPENSATION

H.264/AVC uses an intra prediction algorithm to reduce spatial redundancy in the I-frames, which uses the pixels in adjacent blocks to predict the current block. H.264/AVC provides four 16x16 intra prediction modes and nine 4x4 intra prediction modes [14]. In this paper, only the 4x4 type is considered. As illustrated in Fig.1, the predicted samples (from a to p) are obtained from the adjacent samples (from A to M) using the prediction formula according to the selected prediction mode. For example,



Mode Number	Mode Name
0	Vertical
1	Horizontal
2	DC
3	Diagonal down left
4	Diagonal down right
5	Vertical right
6	Horizontal down
7	Vertical left
8	Horizontal Up

Fig.1 Intra 4x4 prediction modes

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$$a = f_a(A, B, \cdots M, prediction) \qquad (1)$$

There are two schemes [6-7] for embedding watermarks in the compressed domain. The first approach is to insert the watermarks in the encoder, in which the errors introduced by watermarking can be corrected by future prediction and the error does not propagate to the following block within I frames or to P frames. The major advantage of this approach is that relatively more watermarks can be embedded while maintaining high perceptual quality. However, it is time-consuming with bit-rate increase.

The second approach is to embed watermark into the quantized coefficients in the compressed bit-stream directly. In this case, the bit-rate increase is quite low. However, the error introduced by watermarking cannot be corrected and will propagate within I frames and to P frames. Consequently, the visual quality decreased severely. Thus, how to preserve high visual quality becomes a key issue. When any of A-M is modified in watermarking process, the error will propagate to a-p. Denote the original sample as ξ, and the sample after watermarking as ξ', and the error between original sample and watermarked sample as Δ. To eliminate the effect of error propagation, the propagation error is subtracted from the original signal before watermark embedding. The compensation procedure is given as follows:

(1) Decode the current block without watermarking and the watermarked block and obtain un-watermarked signal ξ and watermarked signal ξ'.

(2) Calculate the difference Δ between un-watermarked signal and watermarked signal as:

$$\Delta = \xi - \xi' \qquad (2)$$

and the propagation error $\Delta_a - \Delta_p$ is obtained.

(3) Apply DCT transform and quantization to the difference,

$$\Delta_{Tran} = \left(C \begin{bmatrix} \Delta_a & \Delta_b & \Delta_c & \Delta_d \\ \Delta_e & \Delta_f & \Delta_g & \Delta_h \\ \Delta_i & \Delta_j & \Delta_k & \Delta_l \\ \Delta_m & \Delta_n & \Delta_o & \Delta_p \end{bmatrix} C^T \right) \otimes E / Q \qquad (3)$$

Where Q is the quantization step size, C is the transform matrix, and E is scaling matrix.

(4) Subtract Δ_{Tran} from the original bit-stream signal χ and obtain the compensated signal χ'. To avoid bit-rate increase, compensation is only carried out in the block which coefficient is non-zero.

$$\chi' = \chi - \Delta_{Tran} \qquad (4)$$

(5) Reconstruct to the current block after watermarking for prediction of next block.

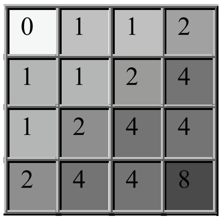
III. WATERMARK EMBEDDING AND DETECTION

1. *Coefficients Selection*

In the proposed method the watermark is embedded in the quantized coding blocks. To increase robustness while preserving the visual quality of the video, the texture-based visual model is adopted [12], which assumes the human eye is more sensitive to errors in plain areas than in highly textured areas. Here we use the weighted sum of the coefficients in each 4x4-block to decide whether the current block can be watermarked or not, as showed in Fig.2. The weighted sum of the coefficients is defined as

$$Sum = \sum_{i=0}^{15} abs(Y_i) * \lambda_i \qquad (5)$$

where Y_i is the quantized DCT coefficients, $abs(Y_i)$ is the absolute value of Y_i, and λ_i is the weighting for coefficient Y_i. In general, the large value of Sum indicates the current block is highly textured. The watermark is embedded only in the block where Sum is larger than a threshold T.



0	1	1	2
1	1	2	4
1	2	4	4
2	4	4	8

Fig. 2 Weighting of the 4x4-block

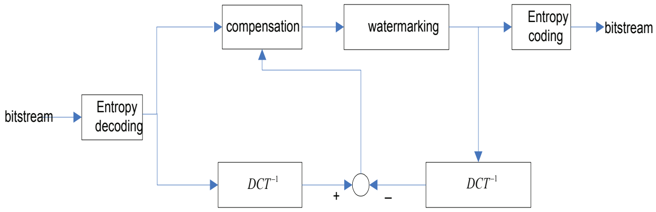


Fig.3 Watermark embedding

To avoid bit-rate increase, the watermark is inserted only in the low frequency. To increase watermark security, a secret key is used to choose the coefficients to be watermarked. The attacker does not have the secret key, thus the attacker can not know the actual location of watermarked coefficients. To eliminate the watermark, attackers need to modify most coefficients so that the video losses value.

2. *Watermark Embedding*

In the proposed scheme, the watermark is embedded in quantized residuals of the I-frame. A bipolar watermark $W \in \{-1,1\}$ is used where mean is zero and variance is one. As illustrated in Fig.3, the embedding procedures are as follows:

(1) Decode the bit-stream partially to get the encoder parameters and 4x4 quantized residual coefficients.

(2) Compensate the error drift for each block.

(3) Use the textured visual model and the secrete key to select the coefficient to be watermarked.

$$CW'_i = CW_i + w_i \qquad (6)$$

where CW'_i, CW_i, w_i represents the watermarked coefficient, un-watermarked coefficient and the watermark respectively.

(4) Encode the watermarked coefficients to the bit-stream.

3. Watermark Detection

A palette generated in the watermarking procedure and the secret key are used to find the actual location of watermarks. The steps are provided as follows:

(1) Partially decode the bit-stream to get the residual.

(2) Use the palette and secret key to locate the watermarked coefficient and apply 4x4-DCT transform to the corresponding block.

(3) Multiply the DCT coefficients watermarked by the original watermark bit and calculate the mean.

$$\begin{aligned} \mu &= E\{\hat{B}_i * w_i\} = \\ &E\{(B_i + \hat{w}_i * Q_{step}) * w_i\} \\ &= E\{B_i * w_i\} + E\{Q_{step}\} * E\{\hat{w}_i * w_i\} \end{aligned} \qquad (7)$$

where $\hat{B}_i$, B_i , $\hat{w}_i$ represents the watermarked DCT coefficients, un-watermarked coefficients, and watermarks embedded, respectively. Because the DCT coefficients are independent of the watermark sequence, and the Q_{step} is a constant, equation (6) can be written as

$$\begin{aligned} \mu &= Q_{step} * E\{\hat{w}_i * w_i\} \\ &= \begin{cases} Q_{step} & if \quad \hat{w}_i = w_i \\ 0 & if \quad \hat{w}_i \neq w_i \end{cases} \end{aligned} \qquad (8)$$

(4) Compare μ to a detection threshold between zero and Q_{step}. If μ is close to Q_{step}, it means that the watermark exists, and otherwise the watermark does not exist.

IV. SIMULATION RESULTS

The proposed scheme is implemented in the H.264/AVC reference software JM12.2. The original sequences are encoded with quantization parameter (QP) = 28, which corresponds to a quantization step size of 16. The effectiveness of error compensation is shown in Fig. 4. It is clearly showed that the frame without compensation has obvious visible degradation, while the frame with compensation has no visual quality degradation.

Four standard QCIF sequences (176×144) were used to evaluate the proposed algorithm. Each sequence has 100 I frames, and only IM4B type is enabled for intra prediction. Table 1 lists the simulation results of embedding performances in terms of bit-rate increase, watermark capacity and PSNR.

One hundred bipolar watermark sequences with zero mean and variance equal to one, which are independent each other were used to test the detection performance. The 50th sequence is the valid watermark. The results are illustrated in Fig.5, where the vertical axis represents the detection statistic μ. As showed, at the location 50, μ is close to the quantization step size 16, and μs at other locations are far from the valid μ, which demonstrates that the watermark can be detected correctly.

Recompression and adding noise attacks were employed to evaluate the robustness of the proposed scheme. The original video sequences were encoded with QP=28, and then recompressed with quantization parameters 20, 24, 32, and 36 respectively. The results are showed in Table 2 and Table 3, where μ_{valid} is the mean for the valid watermark, and the average mean of the rest 99 false watermarks is μ_{avg}. $\mu_{\max}$ and $\mu_{\min}$ are the maximum and minimum mean from the 99 false watermarks respectively, σ^2 is the variance of Gaussian noise. We can see that μ_{valid} is close to the quantization step size 16, and the μ_{avg} is close to zero. When adding noises or re-encoded with different step sizes attacks are employed to the watermarked videos, it is obvious that μ_{valid} and μ_{false} are still far apart enough for correct detections, which demonstrates that our scheme can resist these two kinds of attacks.

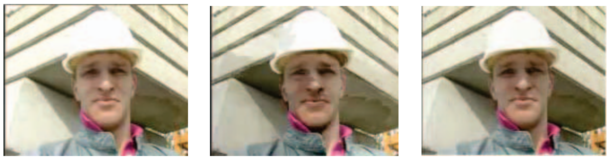

(a) (b) (c)

Fig. 4 Compensation evaluation

(a) The original video signal, (b) Watermarked without compensation PSNR=25.73dB, (c) Watermarked with compensation PSNR=40.23dB.

Table 1 Embedding Performance.

Sequence	Bit-rate increase (%)		Bits embedded in one frame		PSNR(dB)	
	New Scheme	Method [11]	New scheme	Method [11]	New Scheme	Method [11]
mobile	1.05	0.55	1235	1157	36.55	32.37
news	2.35	1.30	429	400	39.94	35.74
silent	2.08	0.65	428	396	39.95	34.28
foreman	2.40	0.80	436	373	38.98	35.91

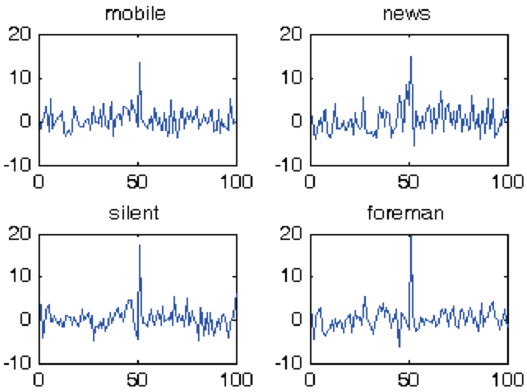


Fig. 5 Detection Performance.

Table 2 Re-encoding Test.

Sequence		QP=20	QP=24	QP=32	QP=36
mobile	μ_{valid}	17.86	17.43	15.19	15.20
	$\mu_{\max}$	3.41	4.08	3.71	3.43
	$\mu_{\min}$	-4.36	-3.06	-3.96	-3.623
	μ_{avg}	0.045	0.055	0.22	0.14
news	μ_{valid}	11.92	13.00	9.71	7.75
	$\mu_{\max}$	4.24	4.01	4.56	5.54
	$\mu_{\min}$	-4.47	-4.79	-4.43	-4.69
	μ_{avg}	-0.21	-0.36	-0.033	0.079
silent	μ_{valid}	15.82	15	11.76	8.19
	$\mu_{\max}$	3.40	4.03	4.16	3.90
	$\mu_{\min}$	-4.30	-4.16	-3.44	-3.57
	μ_{avg}	-0.023	0.097	0.0046	-0.21
foreman	μ_{valid}	11.80	11.72	7.41	6.07
	$\mu_{\max}$	3.35	3.55	3.71	3.61
	$\mu_{\min}$	-3.84	-2.90	-3.10	-3.92
	μ_{avg}	-0.025	0.052	0.13	0.022

Table 3 Noising test.

Sequence		No noise	$\sigma^2 = 33$	$\sigma^2 = 325$
mobile	μ_{valid}	17.22	18.262	19.04
	$\mu_{\max}$	3.09	2.97	2.84
	$\mu_{\min}$	-3.93	-3.14	-3.49
	μ_{avg}	-0.35	-0.054	-0.021
news	μ_{valid}	12.91	15.02	19.57
	$\mu_{\max}$	3.85	7.47	6.89
	$\mu_{\min}$	-5.08	-6.20	-7.03
	μ_{avg}	-0.38	-0.23	-0.17
silent	μ_{valid}	13.96	12.02	13.24
	$\mu_{\max}$	3.014	2.85	4.68
	$\mu_{\min}$	-3.17	-3.87	-5.38
	μ_{avg}	-0.23	-0.37	-0.049
foreman	μ_{valid}	12.15	11.63	12.43
	$\mu_{\max}$	3.53	3.52	4.79
	$\mu_{\min}$	-3.52	-2.63	-3.75
	μ_{avg}	-0.12	0.53	0.57

5. CONCLUSION

In this paper, a novel watermarking scheme with compensation in bit-stream domain is proposed. The watermark is adaptively embedded into the Luma residual blocks using a textural visual model after partially decoding the bit-stream. A secret key is used to locate the actual coefficients to be embedded, which increases the system security. The compensation procedure is carried out before watermarking. The simulation results have shown that in our proposed watermarking scheme a higher PSNR, a larger payload and a greater robustness with minimizing visual distortion can be achieved than other methods with little increase in bit rate, and the watermarks also can resist common attacks with high security.

6. ACKNOWLEDGEMENT

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