Improved Bit Rate Control for Real-Time MPEG Watermarking

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ABSTRACT

The alteration of compressed video bitstream due to embedding of digital watermark tends to produce unpredictable video bit rate variations which may in turn lead to video playback buffer overflow/underflow or transmission bandwidth violation problems. This paper presents a novel bit rate control technique for real-time MPEG watermarking applications. The proposed bit rate control scheme evaluates the combined bit length of a set of multiple watermarked VLC codewords, and successively replaces watermarked VLC codewords having the largest increase in bit length with their corresponding unmarked VLC codewords until a target bit length is achieved. The proposed method offers much flexibility and scalability compared to the pioneering scheme proposed by Hartung and Girod. Experimental results show that the proposed bit rate control scheme is effective in meeting the bit rate targets and capable of improving the watermark detection robustness for different video contents compressed at different bit rates.

1. INTRODUCTION

Digital watermarking is a technique to embed hidden information, called the watermark data, irremovably and imperceptibly into some audio, image, or video contents, called the host data, by subtly modifying the perceptual contents of the latter. The embedded watermark may carry information about the origin, identity, transaction and/or recipient of the host data [1], hence it can be used to facilitate the proof of ownership, provide data integrity checks, or trace the pirates. With the help of digital watermarking, it is hoped that content providers or owners will have better means to uphold their IP rights.

Due to its large size, video data is typically stored or transmitted in some digital compression formats such as MPEG and H.26x. In digital watermarking systems for compressed video, the compression bit rate of the watermarked video is an important design parameter because bit rate incompatibility may lead to transmission bandwidth violations in the communication network or buffer overflow/underflow during video playback. Hence a well-designed video watermarking system should employ careful *bit rate control* in order to keep within bounds the video bit rate after watermark embedding.

The concept of bit rate control for compressed video watermarking was pioneered by Hartung and Girod in [2][3]. In their approach, a watermarked VLC(variable length coding) codeword is permitted only if it contains the same or smaller number of bits compared to the unmarked/host VLC codeword. Otherwise, no embedding will be effected. We denote this scheme as "Hartung 1" in this paper. In a more elaborate scheme, if a watermarked VLC codeword contains less bits than the unmarked one, the unused bit length is stored as a bit budget for comparing with a future watermarked VLC codeword. This scheme is denoted as "Hartung 2" in this paper. These bit rate control schemes tend to remove a sizeable portion of the embedded watermark, thus reducing the video bit rate and its detection robustness. In [4], Alattar et al. proposed a bit rate control scheme for watermarking low bit-rate MPEG4 video. The proposed scheme set selected non-zero DCT coefficients to zeros until the target bit rate is met. As both the host and watermark data are discarded in this scheme, the authors admitted that in some instances, the resultant video quality is also compromised.

In this paper, we propose and study the performance of a novel bit rate control scheme to alleviate some of the shortcomings described above.

2. PROPOSED BIT RATE CONTROL SCHEME

In this paper, MPEG compression and two common spread-spectrum watermarking schemes, namely additive and multiplicative embedding, are considered. The strength of the additive embedding scheme lies in its simplicity while the multiplicative embedding scheme is favoured for its adaptability to the host data [5]. These watermark embedding operations can be mathematically expressed as:

$$\hat{v}_i = \begin{cases} v_i + \alpha \cdot \beta \cdot p_i \cdot b_i & \text{additive embedding} \\ v_i + \alpha \cdot \beta \cdot p_i \cdot b_i \cdot |v_i| & \text{multiplicative embedding} \end{cases} \quad (1)$$

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where $\hat{v}_i$ is the watermarked data, v_i are non-zero DCT coefficients of the host video at selected mid-frequency locations, α is a global scaling factor called the watermark amplitude which adjust the overall embedding strength, β is a local scaling factor determined by a suitable human visual system (HVS) model to help minimize watermarking artifacts, p_i is a pseudo-noise (PN) sequence of ±1 values used for spreading and de-spreading the watermark data, and b_i is the watermark information data of ±1 values. Each watermark information bit is embedded in s locations, where s is called the spreading factor or chip rate [2].

Blind detection of the embedded watermark data can be achieved by using the well-known correlation detector with or without pre-filtering. Assuming that the spreading factor s is large enough such that the watermark detector output Z is approximately Gaussian distributed with mean μ_Z and variance σ_Z^2, the bit error probability or bit error rate (BER) of the blind watermark detection process can be shown to be:

$$BER = Q\left(\sqrt{\frac{\mu_Z^2}{\sigma_Z^2}}\right) = Q\left(\sqrt{SNR}\right) \qquad (2)$$

where $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{\frac{-t^2}{2}} dt$ and SNR = μ_Z^2/σ_Z^2 is the signal-to-noise ratio of the watermark detector output. So higher SNR value results in lower BER and hence the watermark detection is robust.

Next, we will describe our proposed bit rate control scheme. Essentially, our proposed bit rate control scheme compares the total number of bits (bit length) of two buffers: one (called the *output buffer*) contains VLC codewords in a segment of the watermarked bitstream; the other (called the *host buffer*) contains the corresponding VLC codewords in the host bitstream. If the bit length of the output buffer is more than that of the host buffer by a user-specified threshold T, watermarked VLC codewords in the output buffer with the first few largest increase in number of bits will be successively restored to its unmarked/host counterparts (i.e., the watermark embedded in these codewords will be removed) until the total bit length of the output buffer is no larger than that of the host buffer by T. Once this is achieved, the contents of the resultant output buffer will form the final watermarked bitstream with controlled bit rate. This process of checking and restoring "excessively long" watermarked VLC codewords is repeated for the entire watermarked video bitstream [6].

For illustration, a host buffer containing a segment of six successive host VLC codewords is shown in Figure 1. After watermark embedding, the six corresponding VLC codewords in the watermarked bitstream are placed in the output buffer as shown in Figure 2. Some of these output buffer codewords are longer in bit length than their host counterparts. For example, the watermarked VLC codewords VLC1, VLC3, VLC4, and VLC5 have increase in bit lengths indicated by the shaded regions in Figure 2, whereas VLC2 and VLC6 have a reduction and no change in bit length respectively.

Assuming that the total bit length of the output buffer in Figure 2 exceeds that of the host buffer in Figure 1 by more than the user-specified threshold T, then the watermarked VLC codewords in the output buffer will be modified as follows. First, the watermarked VLC codewords are sorted by the amount of increase in bit length in a descending order. Then, the VLC codeword with the largest increase in bit length (VLC4 in Figure 2) will be restored to its original host VLC codeword. The total bit length of the resultant output buffer is then re-examined. If it still exceeds the resultant host buffer length by more than T, then the next VLC codeword in the ordered list (VLC3 in Figure 2) will be restored. This process is continued until the length of the "shortened" output buffer is no more than T bits longer than the corresponding host buffer, then the output buffer contents are sent as the output watermarked bitstream.

In the bit rate control mechanism described above, the number of VLC codewords in the host/output buffers is user-specified. It can be a slice, a macroblock or any other convenient values. This parameter can be used to control the amount of watermark discarded by the bit rate control scheme, hence it has a direct impact on the detection robustness and visual quality of the final watermarked bitstream. If the host/output buffer is chosen to contain only one VLC codeword, then the earlier proposed scheme reduces to Hartung's schemes. On the other hand, the threshold T, can be used to control the target bit rate to be achieved. For example, $T = 0$ will result in the watermarked bitstream having roughly the same bit rate as the host bitstream, while $T > 0$ will permit the watermarked bitstream to have higher bit rate. With these two adjustable parameters, the proposed bit rate control scheme is considerably more flexible and scalable, hence more versatile, than the existing ones.

3. SIMULATION RESULTS

In this section, the performance of the proposed bit rate control scheme is investigated and analysed via computer experiments. The watermarking source codes are developed from the MPEG-2 video codec source codes provided in [6]. A 1.5Mbps MPEG sequence, *susie.mpg*, is used for testing. It contains 450 frames, each with 352×240 pixels (CIF resolution). Several watermark amplitude (α =1, 2, and 3 for additive embedding; 50%, 100%, and 150% for multiplicative embedding) are used to generate different watermarked MPEG bitstreams. To ensure low visual distortion, the watermarks are embedded selectively into the non-zero DCT coefficients of the luminance blocks from the 16th to the 43rd zig-zag-scan frequency locations. For each video, four watermarking scenarios are studied:

1) Watermarking with no bit rate control technique (denoted as “None”).
2) Watermarking with proposed bit rate control technique (denoted as “Proposed”) with host/output buffer size set to 1 macroblock, and buffer threshold T set to zero, i.e., to maintain the video bit rate to be the same before and after watermarking.
3) Watermarking with “Hartung 1” bit rate control technique (described in Section 1).
4) Watermarking with “Hartung 2” bit rate control technique (described in Section 1).

In each case, random watermark information bits are embedded at a spreading rate of one information bit per frame, and retrieved by correlation detector without pre-filtering. This trial is repeated 1000 times and the resultant correlation outputs are collated to calculate its mean μ_Z and variance σ_Z^2. The robustness of the retrieved watermark is measured in terms of the correlator output SNR = μ_Z^2 / σ_Z^2. This robustness measure is adopted instead of BER because the corresponding BER values are very low and hence tedious to obtain experimentally. Nonetheless, the expected BER values can be estimated from the correlator output SNR values by using Equation (2). The quality of the watermarked video is measured in terms of PSNR (peak-signal-to-noise ratio) averaged over all frames, taken with reference to the MPEG host video of a specified compression bit rate.

The effect of different bit rate control techniques on the resultant watermarked video bit rate under variation of watermark amplitude is investigated in Figure 3. It shows that the bit rate of the watermarked video without bit rate control (“None”) always exceeds the host bit rate. The increase in bit rate varies with the watermark embedding approaches (additive or multiplicative embedding) and watermark amplitude scaling factors. On the other hand, Hartung’s bit rate control schemes (“Hartung1” and “Hartung2”) tend to produce consistently lower bit rate than the host video, while our proposed technique successfully maintain the video bit rate at 1.5Mb/s after watermarking. For illustrations of the video quality after watermarking with different bit rate control schemes, video frames embedded with multiplicative watermark with embedding strength of α = 100% are shown in Figure 4. Their visual qualities are found to be generally acceptable with PSNR values exceeding 40dB compared to the unmarked host frame. Practical value of embedding strength is typically determined by the perceptual quality requirements of the target applications and viewers.

Figure 5 plots the correlator output SNR (indicator of watermark detection robustness) against the PSNR (indicator of perceptual quality) of the watermarked video bitstreams. It shows that our proposed bit rate control technique is able to strike a better compromise between watermark detection robustness and perceptual quality than the Hartung’s schemes for both additive and multiplicative embedding.

4. CONCLUSIONS

In this paper, we present a novel bit rate control scheme for compressed video watermarking to better control the bit rate of watermarked video bitstream. The proposed bit rate control scheme evaluates the combined bit length of a group of watermarked VLC codewords, and successively restores VLC codewords with the largest increments in bit length due to watermarking until the bit length increase of the VLC codeword group is within design bound. Experimental results show that the proposed scheme is effective in meeting bit rate targets. It is also capable of striking better balance between watermark detection robustness/reliability and perceptual quality for both additive and multiplicative watermarks than the existing bit rate control schemes. Although the discussions in this paper assume MPEG video compression and DCT-domain embedding, the proposed bit rate control principle is expected to be equally effective for other video compression formats and watermarking domains.

5. REFERENCES

[1] F. Hartung and M. Kutter, “Multimedia watermarking techniques,” Proceedings of the IEEE, vol. 87, pp. 1079 – 1107, July 1999.

[2] F. Hartung and B. Girod, “Watermarking of uncompressed and compressed video,” Signal Processing, vol. 66, no. 3, pp. 283 – 301, 1998.

[3] F. Hartung and B. Girod, “Digital watermarking of raw and compressed video,” Proc. European EOS/SPIE Symposium on Advanced Imaging and Network Technologies, Germany, 1996

[4] A. M. Alattar, M. U. Celik, and E. T. Lin, “Evaluation of watermarking low bit-rate MPEG-4 bit streams,” Proceedings of SPIE: Security and Watermarking of Multimedia Contents V, vol. 5020, no. 45, January 2003.

[5] M. Barni, C. I. Podilchuk, F. Bartolini, and E. J. Delp, “Watermark embedding: Hiding a signal within a cover image,” IEEE Communications Magazine, vol. 39, no.8, pp. 102 – 108, August 2001.

[6] S Pranata, V Wahadaniah, Y L Guan and H C Chua, " Improved Bit Rate Control for Real-Time MPEG Watermarking ", accepted for publication in EURASIP Journal on Applied Signal Processing (JASP)- Special Issue on Multimedia Security and Rights Management, 2004

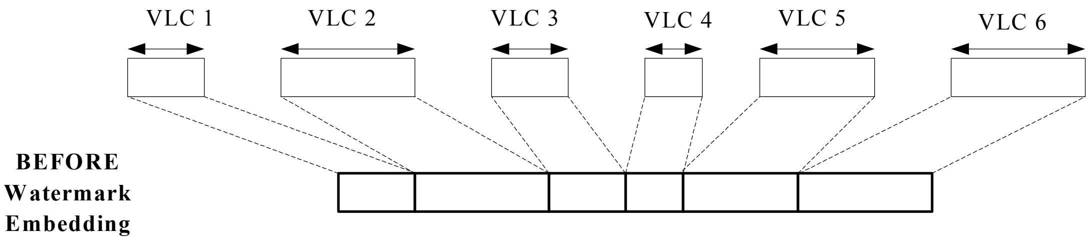

Figure 1. An example of host VLC codewords with different bit-lengths

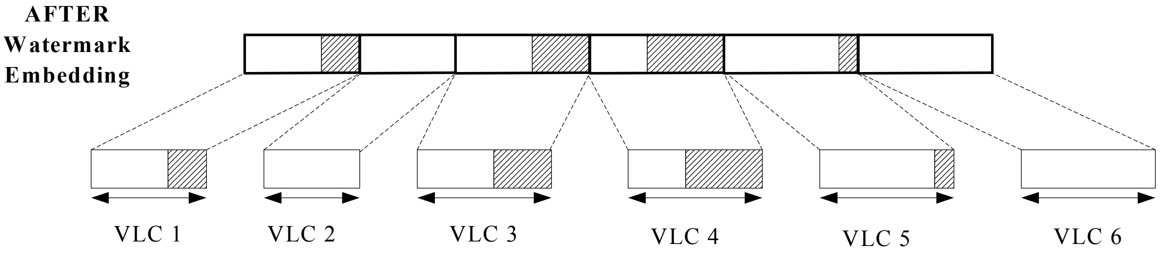

Figure 2. Watermarked VLC codewords corresponding to host codewords shown in Figure 1 (shaded regions represent increase in bit-length after watermarking)

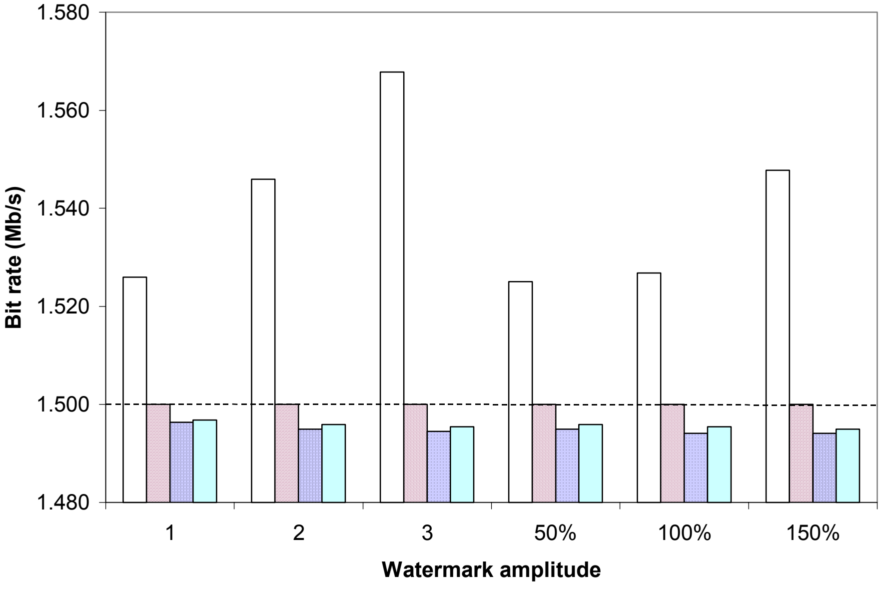

Figure 3. Bit rate of watermarked video generated using different bit rate control schemes (additive embedding: α=1,2,3; multiplicative embedding: α=50%,100%,150%)

Figure 4. A frame from *susie.mpg* (left to right: unmarked, “None”, “Proposed”, “Hartung 1”, “Hartung 2”)

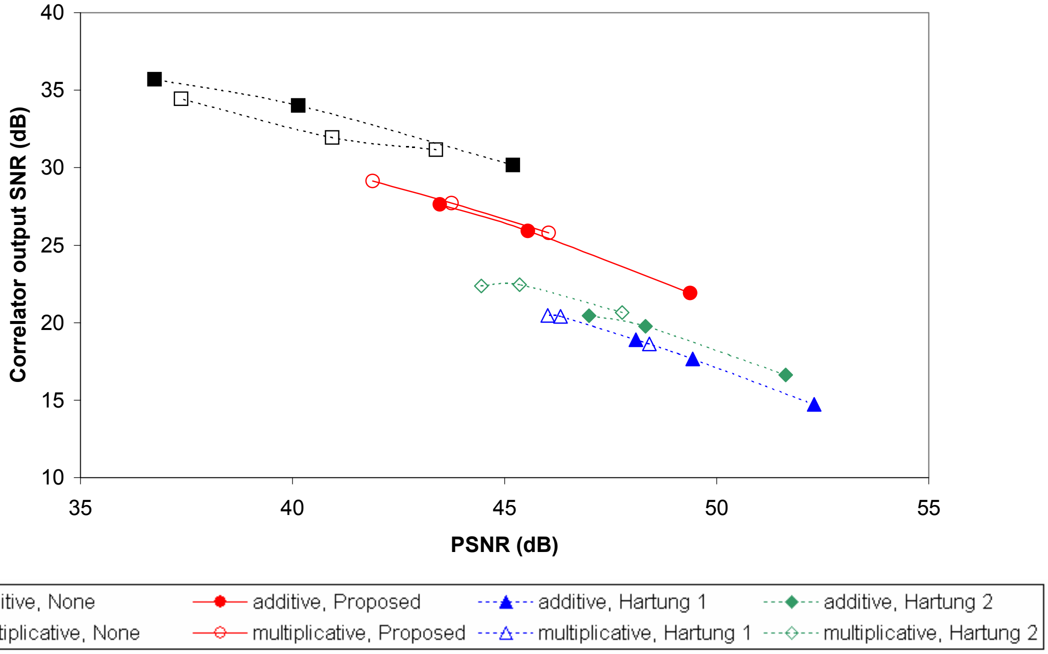

Figure 5. Watermark robustness vs. visual quality of watermarked video under different bit rate control schemes