

High-Capacity Data Hiding in MPEG-2 Compressed Video

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Abstract

A technique for high capacity data hiding in MPEG-2 streams is presented. The objective is to maximise the payload while keeping robustness and simplicity. Ancillary data is embedded in the host signal by modulating the quantized block DCT coefficients of I frames. To achieve robustness, each information bit is embedded in more than one DCT coefficient within each intra coded block. The extraction process is blind. Thus, the presented technique is suitable for side information delivery. The scheme is less complex than a complete decoding process followed by watermarking in the pixel domain and re-encoding. Selected results of computer simulations are also reported.

1 Introduction

Digital watermarking, or information hiding, refers to techniques for embedding additional data in host media. Most of the previous research has focused on still image watermarking. Although video watermarking has more potential for commercial applications, less research has been conducted on high capacity data hiding in video streams. Ancillary data embedded in a video stream can carry information about the content itself, low-level descriptors for video indexing, retrieval and segmentation. Other applications include annotation, subtitling, multi-lingual services, tele-text, etc. Due to the data intensive nature of video, in most applications it is required to hide data in the compressed stream. Compared with still images, video watermarking presents a much higher capacity or bandwidth. At the same time the computational complexity in video watermarking is higher due to the amount of data that need to be processed. In this paper, we focus on a blind data hiding technique tailored to MPEG-2 video streams.

Although most known techniques for video watermarking are robust, the extraction process is not blind [1], [2]. Consequently, these methods are not suitable for applications like those mentioned previously. Relevant methods for video watermarking proposed recently include [6]-[9]. These methods hide ancillary data using the motion vectors of MPEG-1 or MPEG-2 compressed streams. In [6] and [7], first the optimum motion vector v_{opt} is extracted from the coded frames. According to the bit to be embedded, a motion vector v is selected from nine neighbouring positions at half-pixel accuracy including v_{opt} . That is, if the bit to be embedded is '0', v is extracted from the search area $v_{opt} + \delta_{v0}$, where $\delta_{v0} \in \{(0.5, 0.5), (0, 0), (0.5, -0.5), (-0.5, 0.5), (-0.5, -0.5)\}$ and $(0, 0)$ represents the integer-pel position of v_{opt} . If the bit to be embedded is '1', then v is extracted from the search area $v_{opt} + \delta_{v1}$, where $\delta_{v1} \in \{(0.5, 0), (0, 0.5), (-0.5, 0), (0, -0.5)\}$. However, once the MPEG bitstream is re-encoded, the same motion vectors are not always detectable. As a result, the embedded watermark can easily get lost by simple re-encoding.

In this paper an alternative to embed large digital watermarks in MPEG compressed video is presented. In Fig. 1 an overview of the implemented system is shown. Data embedding and detection are carried out using a technique similar to that reported in [10] for still images. The basic idea is to use the middle frequency bands of DCT coefficients in intra coded frames. The technique is robust against common signal processing including MPEG transcoding.

The detailed embedding scheme is introduced in section 2, including the adaptive selection of I frames and macro-blocks. The detection process is also outlined in this section. Selected experimental results are presented in section 3. The paper closes with some concluding remarks.

2 The Proposed scheme

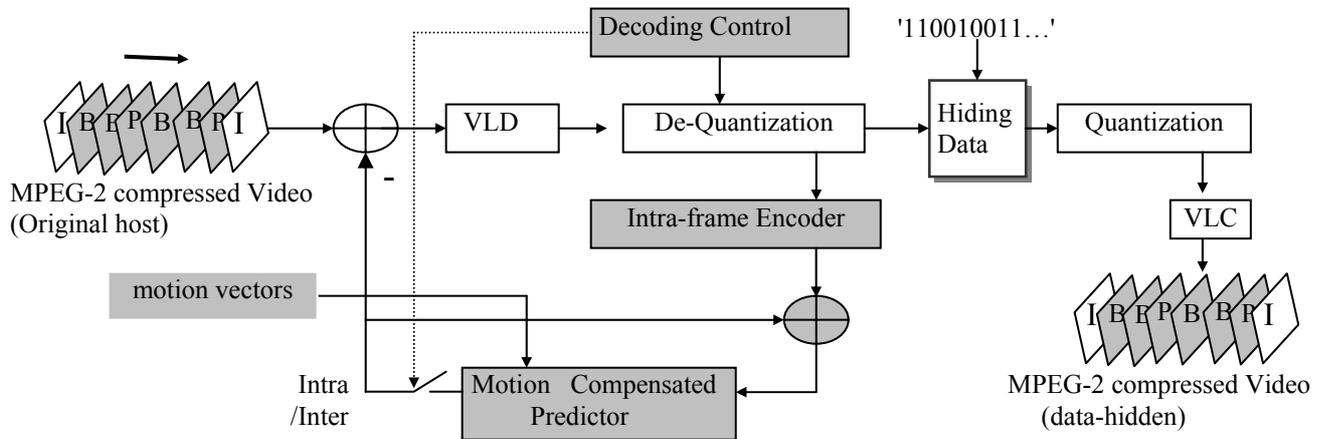
Since a video can be viewed as sequences of still images, video watermarking is an extension of image watermarking. The applications for still image watermarking can thus be extended to video watermarking by embedding data in single frames. In order to minimize the color distortion in the watermarked video, the Y component of the YUV color space is used for the data embedding process. Embedding the watermark into the U and the V components may result in undesirable color distortions. As enlightened by [10] and [11], we can use the similar data hiding method for video. The Y component of MPEG-2 intraframes (I frames) is used to embed the watermark signal. Fig. 1 outlines the embedding process. In order to avoid strong reduction of the video quality, due to concatenation of MPEG-2 coding, the embedding stage is not carried out on the fully decompressed data. Only data extracted directly from the compressed stream is used.

The complete data hiding process is outlined in the sequel. First, the candidate I frame for data hiding is extracted. Then the Variable Length Code (VLC) of the intracoded block is obtained. The VLC of AC components of the selected block

is decoded to get the quantized values which are integer numbers. The watermark is embedded in these AC components by applying the following modulation rule:

To embed the bit '1', the value of the selected AC component is changed to the nearest even number. To embed bit '0', the value of the selected AC component is changed to the nearest odd number.

Finally, the modulated AC component is encoded back using variable-length coding as shown in Fig. 2.



NB: VLC=variable-length coder ,VLD =variable-length decoder .The grey parts above are not used during hiding data.

Fig. 1: Embedding information in I frames of the MPEG-2 compressed video

Since embedding the same amount of data in different I frames (or in different macroblocks of the same I frame) has different effect on the introduced distortion, adaptive masking is applied. Frames in the Group of Pictures (GOP) which the largest motion entropy are skipped. P and B macroblocks within a I frame are also sensitive to distortions. If the number of motion vectors is larger than a threshold N1, the number of macro types B and P are larger than a threshold N2 and the quantization coefficient is larger than a parameter K1, then the I frame within the GOP will not be used to embed data. The parameters N1, N2 and K1 are set experimentally. Once the candidate blocks of the I frame are selected, they are classified by calculating the energy of their DCT coefficients. This process is carried out using the following template according to the frequency distribution:

- d d h h h . . . E_h = horizontal energy summed over h elements
- d d h h h . . . E_d = diagonal energy summed over d elements
- v v d d . . . E_v = vertical energy summed over v elements
- v v d d . . . E_a = average high frequency energy
- v v . . . E_m = minimum value of E_h, E_d, E_v
- E_M = maximum value of E_h, E_d, E_v
- $E_{m/M}$ = ratio between E_m and E_M
- d, h and v refer to the diagonal, horizontal and vertical terms, respectively.

Since E_a represents the average high frequency energy of a block, it is used to segment the blocks into low activity and high-activity blocks. High-activity blocks are further classified according to their texture and edgeness using E_m and $E_{m/M}$. This classification is performed as follows:

- Uniform block: $E_a < T1$
- Textured block: $E_a \geq T1$ and $E_m \geq T2$ and $E_{m/M} > T3$

T1, T2 and T3 are parameter determined experimentally.

The watermark is embedded adaptively in DCT coefficients whose value are larger than the mean value of all the AC coefficients over the selected macroblock. This strategy minimizes the perceptual distortion caused by the embedded data. Observe that many coefficients become close to zero after quantization. The information embedded in such coefficients would be very fragile would introduce a large distortions into the host video. The overall embedding method

is straightforward and presents a low computational cost. Fig. 2 outlines the process and highlights the fact that most data in the original bitstream remain unchanged. Changes occur only in selected macroblocks of I frames.

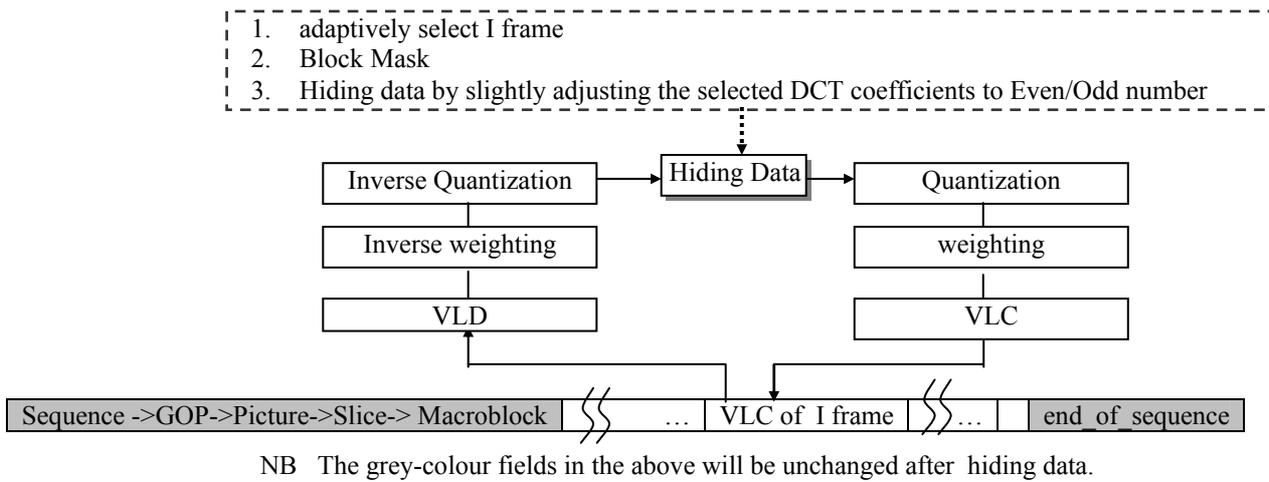


Fig. 2: Data hiding in the MPEG-2 Bit stream domain.

3. Experimental results

Since MPEG-2 is the most popular video compression standard, several experiments have been conducted to validate the proposed approach. In these experiment the watermark is embedded in the mid-frequencies bands of compressed video sequences. The watermark remains detectable even when the video undergoes compression ratios at which the host signal is significantly degraded. Since very person has a different visual sensitivity threshold, it is hard to give theoretical limits. The performed experiments show that even the 'perfect eyes' cannot detect the watermark in a movie unless they do a frame by frame assessment using the original sequences to find the differences.

Fig. 3(a) is a 352x288 I-frame extracted from MPEG-2 compressed video SUSSIE is shown. Fig. 3(b) is the counterpart of 3(a) in which 64-bit information has been embedded. Fig. 3(c) is the amplified difference between Fig. 3(a) and Fig. 3(b). Fig. 3(d) shows a 720x576 I-frame extracted from MPEG-2 compressed video "Mobile & Calendar". Figure 3(e) is the counterpart of Fig. 3(d) in which 100-bit information is embedded. Fig. 3(f) shows the amplified difference between Fig. 3(d) and Fig. 3(e).

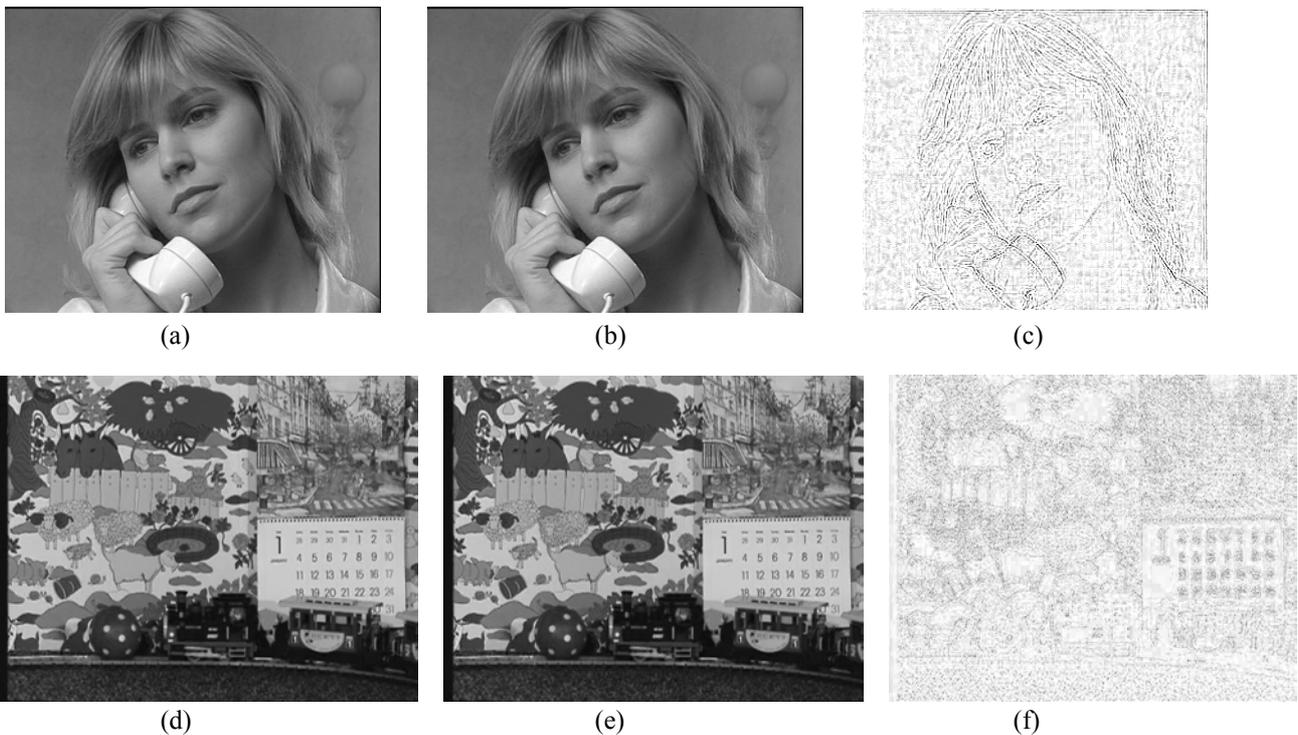


Fig. 3: Comparison between the original and watermarked frames. a) Original I-frame extracted from SUSSIE. b) Corresponding watermarked frame. c) Enlarged difference between a) and b). d) Original I-frame extracted from Mobile & Calendar. e) Corresponding watermarked frame. f) Enlarged difference between d) and e).

4. Conclusion

The key contribution of this paper is the use of quantization-based embedding prescribed by information theory. The embedding method is highly optimized for MPEG compression attacks. This offers excellent performance without error correction coding. In particular, the hiding capacity obtained under MPEG attack using our schemes can be very high without requiring complicated embedding and decoding schemes. The proposed watermark method for video is at least robust against MPEG-1/ MPEG-2 compression attacks.

An adaptive masking criterion is used to select the macroblocks in which the ancillary information is embedded. The embedding scheme adapts the amount of data to be embedded to the characteristics of the host frames. For highly textured frames, high embedding rate can be achieved. The entropy threshold allows greater flexibility between embedding capacity and induced distortion. In order to avoid perceptible distortion propagation to P and B frames in the same Group of picture, the process skip or embed less information in the I frame containing high motion entropy. The presented technique is a kind of attack-oriented one targeting the conventional compression attacks. Further developments will include extensions to more elaborated but less frequent attacks like geometric distortions and fraudulent ones.

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