DIGITAL WATERMARKING OF MPEG-2 CODED VIDEO IN THE BITSTREAM DOMAIN

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ABSTRACT
Embedding information into multimedia data, also called watermarking, is a topic that has gained increased attention recently. For video broadcast applications, watermarking schemes operating on compressed video are desirable. We present a scheme for robust watermarking of MPEG-2 encoded video. The watermark is embedded into the MPEG-2 bitstream without increasing the bit-rate, and can be retrieved even from the decoded video and without knowledge of the original, unwatermarked video. The scheme is robust and of much lower complexity than a complete decoding process followed by watermarking in the pixel domain and re-encoding. Although an existing MPEG-2 bitstream is partly altered, the scheme avoids visible artifacts by adding a drift compensation signal. The scheme has been implemented and the results confirm that a robust watermark can be embedded into MPEG encoded video which can be used to securely transmit arbitrary binary information at a data rate of several bytes/second. The scheme is also applicable to other hybrid coding schemes like MPEG-1, H.261, and H.263.

1 INTRODUCTION
In today's video delivery and broadcast networks, issues of copyright protection have become more urgent than in analog times, since the duplication of digital video does not result in the inherent decrease in quality suffered by analog video. One method of copyright protection is the addition of a "watermark" to the video signal. The watermark is a digital code embedded in the video which typically indicates the copyright owner or, if applied to individual copies of the video, the identity of the receiver of each copy. This allows illegally reproduced copies to be traced back to the receiver from which they originated, as shown in Fig. 1. For watermarking of video, a number of different characteristics of the watermark are desirable. These requirements include invisibility (the embedded watermark should be invisible), security (without knowledge of the exact parameters, unauthorized removal of the watermark must be impossible once it has been embedded, even if the basic scheme of watermark embedding is known), robustness (the watermark should be such that it cannot be manipulated without, at the same time, degrading the perceived quality of the video significantly), low complexity, compressed domain processing (for video stored in compressed format, decoding + watermarking + re-encoding is not feasible), constant bit-rate (the watermarked sequence must not occupy more bit-rate than the unwatermarked), and interoperability between uncompressed and compressed domains (the watermark is embedded into compressed video and must be retrievable from decompressed copies). Previous work on watermarking includes watermarking of still images [1, 2, 3, 4, 5], audio [6], and multimedia data in general [7]. We present a new scheme for watermarking of MPEG-2 compressed video which is of considerably lower complexity than schemes for watermarking of uncompressed video which require decompression and re-compression when a compressed video sequence has to be watermarked. For pay-per-view broadcast applications with individual encryption, watermarking of compressed video gives the possibility of performing the watermarking at the receiver as shown in Fig. 2. This reduces the complexity on the server side and makes individual watermarking of different copies of a video more feasible. If decryption and watermarking are implemented in a single chip or ASIC, and the decrypted signal is not accessible before watermarking, this is a secure mechanism.

In section 2, we briefly introduce a scheme for watermarking of unencoded video that is based on ideas from spread spectrum communications. In section 3, we extend the scheme to the domain of MPEG-2 compressed video. We incorporate the watermark into pre-compressed MPEG-2 bitstreams, and can retrieve it from the video even after decoding and without knowledge of the original video. Since the encoded video is partly altered, we have to consider drift due to motion compensation which we can compensate within our scheme, as explained in section 3.2. In section 4, we discuss practical aspects. We have implemented our scheme for watermarking of MPEG-2 encoded video which works...
Figure 2. Broadcasting of video with individual watermark embedding at the receiver side.

robustly and can embed arbitrary watermark information into encoded video at a data-rate of several bytes/second.

2 DIGITAL WATERMARKING OF UNCODED VIDEO IN THE PIXEL DOMAIN

The basic idea of watermarking for video is the same as for images [2, 5, 7]: adding a noise-like signal to the video pixels that is below the threshold of perception and that can not be identified, and thus removed, without knowledge of the parameters of the watermarking algorithm. Our approach to accomplish this is a direct extension of ideas from direct-sequence spread spectrum communications [8]. The approach in [7] is similar and was developed independently.

Fig. 3 shows the basic steps of watermark embedding in the pixel domain. For a mathematical formulation, please refer to [9]. To embed a watermark, the information bits \(a_j \in \{-1, 1\}\) to be hidden are first spread by a large spreading factor \(cr\), in analogy to spread spectrum communications called the chip-rate. The purpose of spreading is to embed one bit of information into many (exactly, into \(cr\) pixels of the video sequence. The spread bits are then modulated with a pseudo-noise sequence, yielding the watermark signal. The amplitude of the watermark signal may be amplified before finally adding it to the pixels of the line-scanned video sequence. The amplification factor can be varied according to local properties of the image and can be used to exploit spatial and temporal masking effects of the human visual system (HVS). Because we use a pseudo-noise signal for modulation, also the watermark is a noise-like signal and thus difficult to detect, locate, and manipulate.

The recovery of the hidden information at the watermark decoder is easily accomplished by correlating the watermarked video signal with the same pseudo-noise sequence that was used in the encoder (see Fig. 4), where correlation can be understood as demodulation followed by summation over the correlation window. In our case, the width of the correlation window for each information bit is just the chip-rate.

3 DIGITAL WATERMARKING OF CODED VIDEO IN THE MPEG-2 BITSTREAM DOMAIN

MPEG-2 bitstream syntax allows for user data being incorporated into the bitstream. However, this is not a suitable means of embedding a watermark, since the user data can easily be stripped off the bitstream, and vanishes after decoding anyway. Again the key idea is to incorporate the watermark into the signal itself, i.e., into the bitstream representing the video frames.

In the following, we present a scheme for watermarking of previously encoded video that is compatible with the scheme for watermarking of unencoded video given in the previous section. Again, for a more rigid but less comprehensive formulation of the algorithm, please refer to [9].

3.1 Basic scheme

The principle of MPEG-2 video compression is motion-compensated hybrid coding. I-frames are split into blocks of 8 by 8 pixels which are compressed using the DCT, quantization, zig-zag-scan, run-level-coding and entropy coding (see Fig. 5). P- and B-frames are motion compensated and the residual prediction error signal frames are split into blocks of 8 by 8 pixels which are compressed in the same way as blocks of I-frames. Instead of adding the watermark in the pixel domain, we extract, for each encoded 8 x 8-block of the video, the corresponding block from the watermark signal. We then transform the watermark block using the
embedded, watermarking and unwatermarked bitstreams are divided into many pixels and thus many DCT coefficients. 

If no watermark is embedded, there is no watermark signal besides the watermark block and the watermarked video signals. An interesting application of watermarking is that the embedded watermark signal besides the watermark block and the watermarked video signals

Figure 8: Scheme for watermarking of compressed video with drift compensation.
We have presented a new scheme for watermarking of video. It can be regarded as a linear operation if no clipping is applied. Thus the two MC prediction blocks of Fig. 8 can be consolidated into one. Additionally, entropy coding or decoding can be moved out of the loop, yielding a lower complexity than decoding alone. Typical parameters are

\[ \text{Complexity} \leq 1 \text{ complexity} \leq 2 \text{ parameters} \]

for the size of the watermark. The watermark survived all attacks. Left clockwise DCT compression, different approaches, the watermark survived all attacks. Figure 9 details of a video sequence attacked by the scheme for watermarking of video. The watermark survived a frame, an object, and a local permutation of pixels. Figure 10 shows a visual impression of the watermark.