Capacity Enhancement of Compressed Video Watermarking Using Turbo Codes

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ABSTRACT

MPEG2 compression, as compression in general, tends to reduce information spatial and temporal redundancy. In that way, it reduces the watermark insertion space and power of the embedded signal. This paper describes scheme for capacity enhancement using state-of-the-art error correction technique - turbo coding. A spread spectrum watermarking technique is used to insert watermark. We are proposing new watermark composition, amplitude adjustment in DCT domain and bit-rate preserving. However, it was essential to introduce an error correction technique in order to achieve desired level of capacity and robustness. In addition, experimental results on perceptibility and robustness on transcoding are presented.

1. INTRODUCTION

Several techniques have been reported in the literature aiming at watermarking in the compressed domain. Many of these are based on embedding a watermark into a video sequence using a spread spectrum paradigm - via a pseudo-noise sequence [1], [2], and [3]. F. Hartung and B. Girod in [1] proposed to extend their technique for spread spectrum watermarking in uncompressed domain to compressed domain. This is done by transforming a watermark signal into DCT values and then adding to DCT coefficients of the video sequence. In [2] and [3], other authors extended this technique further and introduced watermark amplitude dependent on local image content. The power of the watermarking signal is bounded by perceptual visibility. The watermark must be embedded in such way that it does not introduce visual artefacts to the host signal.

In compressed domain watermarking, the second limiting factor is that the video bit-rate must remain the same, so the number of watermarked coefficients is smaller, and consequently the power of the watermarked signal is limited. It will be shown that with novel approach to watermark signal composition and bit-rate preserving it is possible to increase number of watermarked coefficients and to improve watermark capacity and detection rate.

The latest generation of watermarking techniques model the process as communication through a noisy channel. The channel noise is originated by two different sources. The video itself, which does not carry any useful information regarding the watermark message and from a watermarking point of view it can be considered as noise. The other is noise originated by attacks. The later is usually modelled as Gaussian white noise.

The most appealing approach to overcome the noise introduced by the host signal is watermarking with side information as shown at *al* in [4]. However, the complexity of this approach makes it less useful in the compressed domain. Extraction of side information from video needs one extra pass through the video, which introduces additional overheads, increasing the computational costs opposing the requirements for fast watermark embedding.

Another approach uses error correction coding to correct errors due to channel low signal-to-noise ratio. In 1993, C. Berrou, A. Glavieux, and P. Thitimajshima made a major breakthrough in channel coding theory with their pioneering work introducing Turbo coders, which enable near Shannon limit capacity [5]. This technique is widely used in communication via low SNR channels, such as mobile communication, deep space communication and more recently in watermarking.

In order to boost the capacity of spread spectrum watermarking, we introduced turbo coding. In the following section a short overview of these techniques is given.

2. DESCRIPTION OF IMPLEMENTED WATERMARKING TECHNIQUE

Spread spectrum technique proposed in [1] is chosen as starting point for implemented technique. This technique uses well-established methods from spread spectrum communication theories, where a narrow-band signal is transmitted via wide-band channel by frequencies spreading. In the case of watermarking, the idea is to transmit the watermark signal as a narrow-band signal via the video signal, which acts the wide-band channel.

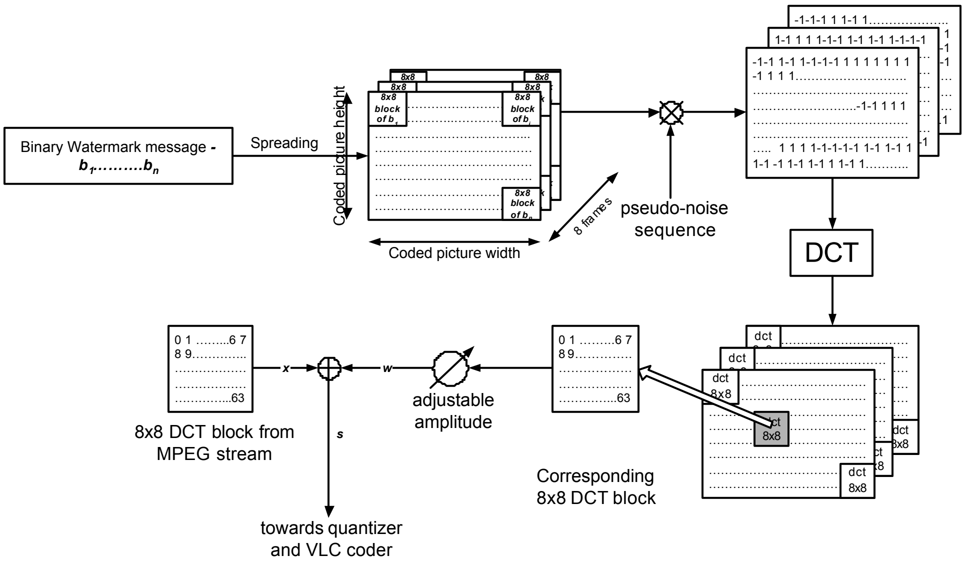

Figure 1 Watermark composition scheme

The algorithm inherits basic spread-spectrum ideas and the DCT domain insertion point of watermark. In original scheme it is proposed to spread every watermark bit by large chip factor, adjust amplitude and then modulate it by pseudo-sequence in order to get watermark frames. The common problem in this scheme is that one bit could be embedded in a smooth area of frame and because of low Signal-to-Noise ratio wrongly decoded, while another could be embedded in a highly textured area and then correctly decoded with a very huge margin. In order to avoid that, we propose to spread n bits of watermark message through n 8x8 DCT blocks, where every bit is spread through one block, and then to repeat this sequence desired number of times (Figure 1). Since in that way, every watermark bit has almost the same Signal-to-Noise ratio, chip rate needs to be much smaller to provide enough watermark power to get correct detection.

Watermark frames are modulated by pseudo-noise sequence and then DCT transformed. Since DCT is linear transformation, local amplitude adjusting is moved to DCT domain using the information from corresponding DCT block of the original sequence. DCT block is first classified with respect to its energy distribution. It is well known that perceptibility is much larger in uniform blocks and in blocks with strong edge characteristics then in highly textured blocks. Blocks that have more then 60% of block energy in the elements that represent vertical, diagonal or horizontal edges are not watermarked. Watermark amplitude in other blocks is adjusted according to percentage of energy in AC coefficients (1).

$$a_j = \begin{cases} mws \dfrac{\sum_{i=1}^{63} c_{ij}}{\sum_{i=0}^{63} c_{ij}} , & \begin{array}{l} (c_{1j} + c_{2j} + c_{3j} < 0.6 \cdot \sum_{i=0}^{63} c_{ij}) \wedge \\ (c_{8j} + c_{16j} + c_{27j} < 0.6 \cdot \sum_{i=0}^{63} c_{ij}) \wedge \\ (c_{9j} + c_{10j} + c_{17j} < 0.6 \cdot \sum_{i=0}^{63} c_{ij}) \end{array} \\ 0 , & other \end{cases} \quad (1)$$

where:

a_j - amplitude of j^{th} watermark block

mws - predefined maximum watermark strength

c_{ij} - i^{th} element of j^{th} DCT block of original sequence

The other restriction is that the bit rate of the video must not be increased. It is proposed in [1] that DCT coefficients are to be changed only if VLC of watermarked coefficient is smaller or equal to the original one. Typically, 10-20% of non-zero DCT coefficients of the input video are altered which leads us to conclusion that chip rate needs to be significantly larger.

Because of synchronization problems, bit-rate must not be smaller than original too, so length of slices must be preserved. In our scheme, VLC of watermarked coefficient is compared with the original one increased by difference between previous coefficients in slices. If difference still exists at the end of the slice, zeroes are added to compensate the difference. With this method, we are altering approximately 5% more coefficient than in original scheme

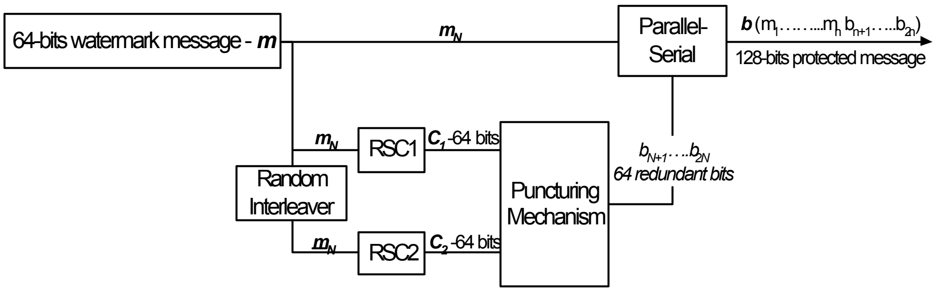

Figure 2. Parallel-concatenated convolutional coder

3. TURBO-CODING PROTECTION OF WATERMARKING CHANNEL

The watermarking channel, as stated previously, has a small signal to noise ratio and a potentially large bit error rate due to noise introduced by the host signal and attacks. In such an environment, it is essential to protect the watermark message by introducing redundant bits, which will be used for error correction. Turbo coding and soft Viterbi decoding, as usual maximum likelihood decoder for the AWGN channel, lead to significant gain of capacity.

Prior to watermark spreading, the 64-bits watermark message (***m***) is coded with a parallel-concatenated convolutional coder with rate 0.5 as shown in Figure 2. Redundant bits are produced by two Recursive Systematic Coders (RSC). The interleaver permutes the sequence $\boldsymbol{m}_N$ into $\underline{\boldsymbol{m}}_N$ to provide randomness to the input sequence, which will also increase the weights of codewords. If the input sequence is a low weight codeword, the interleaver permutes it into a high weight codeword, which gives a mid weight codeword ***b*** and by doing that enhanced coding performance is achieved.

RSCs are encoding the input bit taking into the account the previous bits. RSC outputs ($\boldsymbol{C}_1$ and $\boldsymbol{C}_2$) are punctured in the way that only even bits are included in the watermarking message ($\boldsymbol{b}_{N+1}\ldots\boldsymbol{b}_{2N}$). These 64 additional bits will give enough information to the decoder to correct corrupted messages.

At the decoder side, a convolutional coder is used to extract 128-bits from the received video: the first 64 bits present received message $\boldsymbol{m}^r$ and the later two groups of 32-bits are the received parity bits $\boldsymbol{b}^r_1$ and $\boldsymbol{b}^r_2$ which are used for error correction in the iterative decoder as shown in Figure 3. The two decoders are connected in a loop to provide soft information between them, using only the information not available to other decoder, i.e. L_{12} represents soft information produced by the first decoder using parity bits $\boldsymbol{b}^r_1$. The final decision can be made either by the first or second decoder after the desired number of iterations.

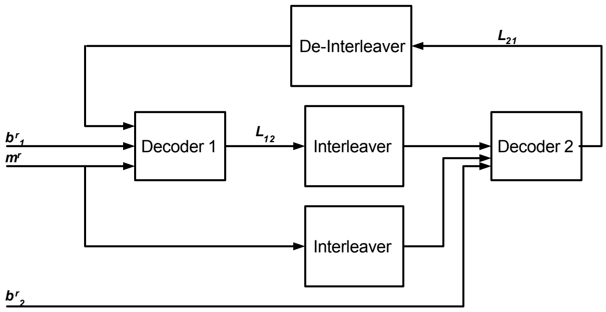

Figure 3. Iterative turbo decoder

4. EXPERIMENTAL RESULTS

The presented technique has been evaluated using typical MPEG-2 testing sequences (Tempete, Football, New York, Kiel Harbour...). All sequences were 259 frames long, NTSC (720x480, 30 fps), with GoP size of 15 frames and bit-rate of 6 mbps.

First test was perceptibility test. Watermark was embedded and frame-by-frame PSNR were calculated (Figure 4). Since watermark is embedded into I frames, PSNR is lowest for I frame of every GoP. Figure 4 is also showing frame 46 with lowest PSNR 36.48 dB. Frame from original and watermarked sequence were presented, as well as frame difference.

We also tested watermark robustness to transcoding. 64-bit watermark message and 64 parity bits were spread through 8 I frames (5 seconds of video sequence) and embedded in sequences. Sequences were then transcoded to 4, 3, 2 and 1.5 mbps. Watermark message was extracted from every 8 consecutive I frames and compared with original message. Bit Error Rate (BER) with and without turbo coding is presented in Figure 5. It is possible to see that scheme with turbo coding protection is robust to transcoding.

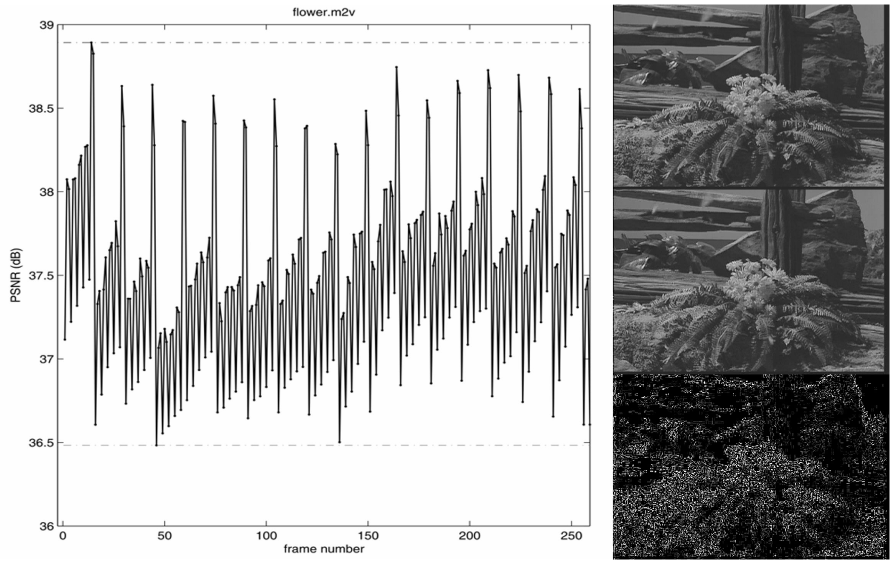

Figure 4. PSNR for 'Tempete' sequence, frame 46 from original and watermark sequence and frame difference

5. CONCLUSIONS

Presented watermarking technique was implemented in order to embed 64-bit content tag that will be possible to extract from 5 seconds of video and that will be robust to common video processes. Improvements in terms of watermark composition, strength adjustment and bit rate preserving made it possible to achieve desired imperceptibility and real-time decoding. However, it was essential to implement error correction coding to fulfil requirements for capacity and robustness.

Results of perceptibility test and robustness to transcoding were presented. Our temporary and future work is based on experimenting with robustness on other video editing processes, such as logo insertion, cross-fade, level adjustment etc.

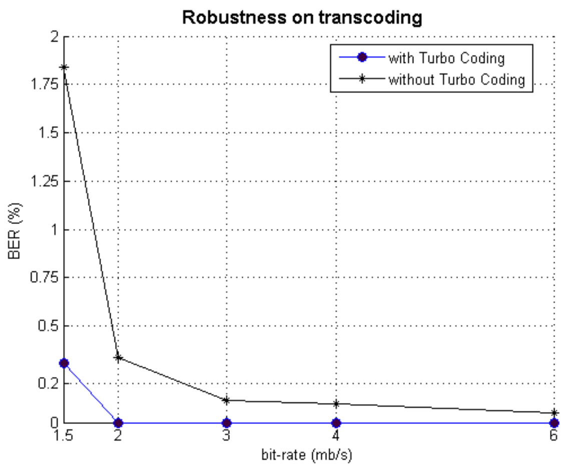

Figure 5. Robustness on MPEG2 transcoding

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