DCT AND ICA VIDEO WATERMARKING SCHEMES BASED ON AN INFORMED TRELLIS

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ABSTRACT

In this paper, we aim to study the performance of a video watermarking scheme, using an informed coding technique, in different transformed domains. Therefore, an informed trellis scheme is applied on transformed video data obtained using two transforms: the Discret Cosine Transform (DCT) and an Independent Component Analysis (ICA) coding technique. We show the interest of applying such an approach in each domain, and we present a comparison between method performances in both domains. Finally, we show that, for both of them, the scheme offers a good robustness against MPEG-2 compression, as well as an acceptable capacity level. We consider in this paper data hiding in digital TV channels (data are compressed using MPEG-2).

1. INTRODUCTION

Techniques for hiding watermarks in still images have grown steadily more sophisticated and increasingly robust to lossy image compression and standard image processing operations. In this paper, we are interested in data hiding in digital TV channels, where data are compressed using MPEG-2. In the case of video watermarking, the challenge is to mark a group of images which are strongly intercorrelated and often manipulated in a compressed form. A first group of watermarking methods therefore directly operates on MPEG-2 data to avoid full decompression [1] [2]. In order for the watermark to be less dependent on the way the video compression was done, another approach is to mark the uncompressed video sequence in spite of the increased computational cost. In the case of uncompressed video, a possibility is to individually mark all the frames of the video using still image watermarking techniques. We have adopted this approach in our scheme, furthermore we have taken into account the temporal dimension of the video, by using two different ways : firstly by embedding the same message on a group of frames and secondly by watermarking the error prediction frames. We have adapted an informed trellis scheme [3] for our approach. Two transform domains were used to study the scheme performance: the DCT (Discret Cosinus Transform) domain and the domain obtained by applying Independent Component Analysis (ICA) [4].

This paper is organized as follows: in section 2, we present the informed trellis scheme. In section 3, the application of the algorithm in the DCT domain is detailed. In section 4, we present the method using an ICA coding technique. In section 5, experimental results and discussion are presented. Finally, conclusions are drawn in section 6.

2. WATERMARKING USING INFORMED TRELLIS

In this section, we present the watermarking technique used in our scheme, proposed by Miller et al. [3]. It is an informed spread spectrum technique where each message is represented by a subset of coding vectors. The union of all subsets constitutes the codebook. Error correcting codes, and trellis of convolutional codes in particular, provide a practical way to construct and organize such a codebook [5].

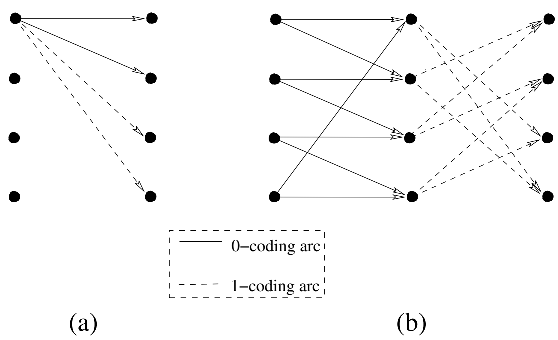

Fig. 1. A 4-state full connected trellis: in figure (a), we represent only the arcs issued from the first state. Each bit can be coded by 2 different ways. In figure (b), we show the sub-trellis T_{01} corresponding to the message 01.

In the following, we present in details the informed scheme proposed by Miller et al. [3].

Starting from a simple modification of a trellis code, we can produce an efficient code used for watermarking. In a traditional trellis code, each possible l length message corresponds to a path through the trellis from a state at time 0 to one of the nodes at time l. We refer to the transition from one column of nodes to the next as a step, and each such step corresponds to one bit in the coded message. Each arc in the trellis is labelled with a randomly-generated vector of length n_b. Each path, and thus each message, is coded with a length $l \times n_b$ vector that is the concatenation of the labels for the arcs it contains. This vector can be used as a watermark pattern. The trellis is modified so that multiple alternative code vectors can be obtained for each message. The basic idea is to have more than two arcs enter and exit each state, but still use each step of the trellis to encode a single bit. Thus, a given message $\mathbf{m}$ can be represented by a number of different paths (a sub-trellis $T_{\mathbf{m}}$), and hence a number of different length $l \times n_b$ code vectors. In this case, trellis is termed as informed trellis.

Our trellis has 64 states and 64 arcs per state. Each arc is labelled with a vector of length $n_b = 128$. The label for each 1-arc is drawn from an independent, identically distributed Gaussian distribution. The label for each 0-arc is the negation of one of the 1-arc labels from the same node. The labels are scaled so that the mean squared error (MSE) between marked and unmarked frames would equal the embedding strength, α.

In Figure 1, we present an example of a fully connected 4-state trellis, as well as the case when the trellis corresponds to a message of 2 bits.

3. WATERMARKING IN DCT

In this part, we present the implementation of the algorithm on a video sequence, using the DCT transform.

With this approach, we have decided to apply the watermarking algorithm described in the previous section to Intra-coded video frames (I frames): each frame is coded separately using the DCT transform. According to our experimental results, this choice provides a good performance in a DCT video watermarking scheme. In order to exploit the temporal information present in the video, a message is embedded in a group of frames. It is necessary to separate frames carrying the same message by a distance fixed according to the application. An example of a message embedded in a group of 7 frames is presented on the figure 2.

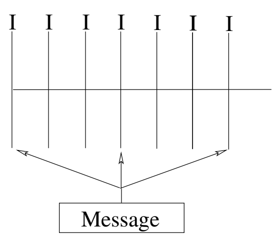

Fig. 2. Message embedded in a group of 7 Intra-coded video frames (termed in the figure as I frames). The frames carrying the message are separated by a distance of 2.

We present now the structure used to watermark each frame. A frame is first divided into 8×8 blocks, and the DCT transform is calculated for each block. We extract from each block n_1 coefficients, in order to obtain a length $k \times n_b$ host signal $\mathbf{x}$ ($n_1 \ll n_b$), necessary to insert k bits in a group of frames (Section 2).
We use a Viterbi decoder to find the vector $\mathbf{w}$ (coding a path in the sub-trellis $T_{\mathbf{m}}$) that yields the highest correlation with the host signal.
$\mathbf{w}$ is multiplied by an adjustable factor α, then added to the host signal $\mathbf{x}$, yielding the watermarked vector: $\mathbf{s} = \mathbf{x} + \alpha\mathbf{w}$.

During the detection process, the decoder applies the Viterbi algorithm to the entire trellis T. This identifies the vector having the highest correlation with the watermark. The hidden message is then decoded by looking at bits represented by the arcs in the path coded by the identified vector.

4. WATERMARKING USING ICA

In this section, we present the approach using an ICA coding technique. Before presenting our approach, we begin by introducing the ICA method and the principal watermarking schemes we have noticed in literature that use ICA.

4.1. ICA and watermarking

ICA is a statistical technique that consists of obtaining from a set of components another set as statistically independent as possible [4]. ICA enables therefore the data to be represented by statistically independant components unlike Principal Component Analysis (PCA) which leads to uncorrelated components. The statistical independance takes into consideration higher order moments and is so a stronger statistical property than decorrelation (the second order statistic used in PCA).
In a practical way, ICA defines a change of data basis. We consider a vector $\mathbf{x}_t$ projected into a space of independent components (ICs), using a mixing matrix B, resulting in $\mathbf{y}_t$. The change of basis is thus represented as following :

$$\mathbf{y}_t = B\mathbf{x}_t \quad t = 1, 2, \ldots$$

The demixing relation is described as following :

$$\mathbf{x}_t = W\mathbf{y}_t \quad t = 1, 2, \ldots$$

W is the demixing matrix, which can be deduced from the mixing matrix B.

In this paper, we are interested in ICA as an image coding tool. $\mathbf{x}_t$ is obtained by reshaping size $k \times k$ image patches into length k^2 vectors. By applying ICA to $\mathbf{x}_t$, we obtain the ICs of the image. The coding approach is based on the idea that images with similar features may be restored from a common set of components, called the coding dictionary. It can be estimated using the FastICA algorithm [4] which is a fixed-point algorithm providing good decomposition results efficiently.

The main motivation to use ICA in watermarking is that embedding information in one of the statistically independent sources provided by ICA minimizes the emerging cross-channel interference [6]. Thus, it has been shown in [6] that distortion is minimized when the message is embedded in statistically independent sources. ICA has been applied in watermarking schemes by different authors, in particular by González-Serrano et al. [7], Bounkong et al. [6] and Sun et al. [8]. González-Serrano et al. have used a least significant components technique for a fragile watermarking application. Bounkong et al. have proposed a robust watermarking scheme based on a scalar quantization technique. Sun et al. have proposed a video watermarking scheme, in which ICA is applied to extract video ICs, and a watermark is embedded into the wavelet domain of the video ICs using a 4-neighboring-mean-based method.

4.2. Watermarking scheme using ICA

We have adapted the watermarking scheme proposed by Bounkong et al. [6] to be adequate for a video watermarking application, using the informed trellis technique as for the DCT Domain. However, with this approach, we have decided to apply the informed technique on the video error prediction frames (Figure 3). This choice was made in order to exploit the video temporal dimension. Another motivation for our choice is that, according to our experimental tests, an ICA watermarking scheme provides a poor performance in Intra-coded frames.

In order to use the ICA coding scheme, it is necessary to construct a coding dictionary well adapted to the host data. This step is carried out using the FastICA algorithm applied on size 16×16 image patches, selected from the test video sequences employed in our experiments (Section 5). The obtained data are centered and their dimensionality is reduced using principal component analysis.

As mentioned above, we have chosen to insert the watermark in prediction error frames P (Predicted frames). These frames are coded using the ICA coding technique presented previously (Section 4.1).

We present now the way we watermark each prediction frame P.
P is divided into patches of size 16×16, representing a set of mixed signals. Each patch p_i is then demixed, using the demixing matrix W, resulting in a vector $\mathbf{x}_{p_i}$. A set of coefficients s_i is then randomly selected from $\mathbf{x}_{p_i}$, and watermarked in order to hide the message.
The insertion and detection processes applied on $\mathbf{x}_{p_i}$ are performed in the same way as for the DCT based scheme (Section 3).

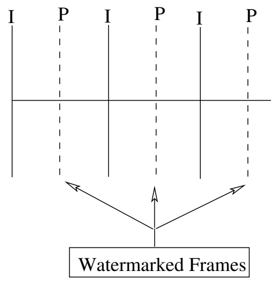

Fig. 3. In the ICA based scheme, watermarking is applied on error prediction frames (termed in the figure as P frames), separated by Intra coded frames (termed in the figure as I frames)

5. RESULTS AND DISCUSSION

In this section, we present results obtained for both methods. Their performance was tested under MPEG-2 lossy compression [9].

We tested the methods on five 4:2:0 video sequences (Susie, News, Mother Daughter, Hall monitor, Container) composed of 150 frames in a QCIF format (176×144). The watermarking distortion, determined by the mean PSNR value, was maintained at a level of 42 dB.

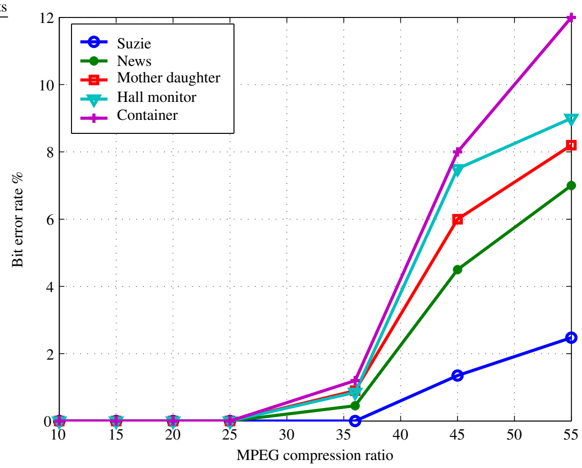

Fig. 4. Robustness of the method applied in the DCT domain, against MPEG-2 lossy compression

We state now parameters used in the algorithm applied on the DCT domain. We extracted 12 coefficients from a 8×8 block (Section 3, $n_1 = 12$). This allowed us to embed 37 bits in a group of frames (the frame size is 176×144). The performance of this method after a MPEG-2 lossy compression is presented in figure 4 showing the percent of decoding bit errors as a function of the MPEG-2 compression ratio. We can see that for a compression ration of 35, we were able to correctly decode most of bits (BER $< 2\%$).

PSfrag replacements

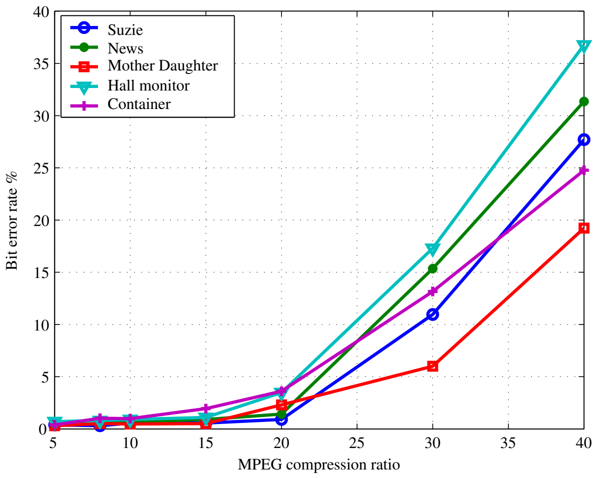

Fig. 5. Robustness of the method applied using an ICA transform coding, against MPEG-2 lossy compression

In the second approach, we extracted 41 coefficients from each patch. This allowed us to embed 31 bits in a frame of size 176×144. The embedding strength α is equal to 1.5.

The robustness of this approach against MPEG-2 lossy compression is presented in figure 5. We retrieved most of embedded bits, after a compression ratio of 20.

Spread-spectrum watermarking methods are generally robust against lossy compression. However, the first method, applied in the DCT domain, is more robust than the second one applied in the ICA domain, against this kind of degradation.

In the DCT domain, we can identify the coefficient range that might be degraded by a compression process. This allows us to choose coefficients that are probably robust, against compression. However, it is not the case for the domain resulting from an ICA coding technique. On the other hand, it is necessary to mention that, in the ICA domain, we have chosen to watermark coefficients corresponding to a fixed range of basis vectors, regardless of their module level. This may result in watermarking some coefficients having poor energy, which might be set to zero after an efficient compression. This choice was made to overcome a problem related to ordering video ICs according to their module: the order may change in the decoding stage, leading to a desynchronisation of a decoding process based on the relative module level.

6. CONCLUSION

In this paper, a video watermarking scheme is proposed. The insertion is performed in two transform domains: DCT and a set of statistically independent sources. A trellis based technique is used in this scheme: this allows us to construct a structured codebook, applying hence the principles of watermarking with side information.

Experimental results, in both domains, claim the invisibility and the robustness of the proposed approach: the scheme offers a good robustness against MPEG-2 lossy compression, as well as an important capacity level. Comparaison between method performances in each domain shows that the DCT domain is more adequate for our scheme: it is more adapted for an MPEG-2 lossy compression using the DCT domain. The relative instability of coefficients module in ICA domain limits our possibility to choose a set of robust coefficients.

7. REFERENCES

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