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# Robust watermarking of video objects for MPEG-4 applications

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## ABSTRACT

This paper presents two different watermarking schemes devoted to protect video objects.

The first presented scheme performs embedding and detection in the uncompressed domain. It has been developed to enable signature detection after object manipulations such as rotations, translations and VOL modifications. To achieve these requirements, the first scheme exploits the shape of the object using CPA analysis: a random sequence is transformed to fit the scale and the orientation of the object. The detection of the mark is performed applying an inverse transform and calculating a correlation between the random sequence and the transformed object.

The second scheme is based on compressed-domain processing of video objects. Two different signals are embedded, one for synchronization recovery and another for copyright protection. Both signals are embedded and detected in the compressed domain. During detection, first synchronization recovery is performed and then the copyright watermark is extracted.

## 1. INTRODUCTION

With the emergence of new multimedia standards such as MPEG-4 and JPEG2000, the notion of video-object (VO) is more and more widespread.<sup>1</sup> VOs are widely used in special effects creation, web-cam applications and digital video composition.

Consequently, a need to protect the different objects of an image or a video appeared. The watermarking technologies enable the embedding of an *unnoticeable* and *indelible* mark inside multimedia contents such as images, video or audio.<sup>2</sup> Consequently new multimedia standards are more and more bounded with watermarking methods: the MPEG-4 group designed an IPMP (*Intellectual Property Management & Protection*) layer presenting a watermarking structure to permit monitoring, copy control and fingerprinting MPEG-4 contents.<sup>3</sup>

One part of the European IST-1999-12554 ASPIS project is devoted to the development of watermarking schemes for Video Objects. This paper presents two different video-object watermarking techniques developed for this project: one in the uncompressed domain and the other one in the compressed domain.

### 1.1. VO watermarking context

Object watermarking is quite different from bit-stream or compressed watermarking of image or video. In the field of object watermarking, the embedded mark has to be bound with the video object. Moreover it has to be detected after object manipulations such as:

- The insertion of a marked Video Object (VO) in a set of other VO (named VOL in the MPEG-4 context to denote Video Object Layer).
- A shifting operation applied to the marked VO inside the VOL.
- A rotation or a scaling of the VO.
- The conversion of the object-based format to a raw format. In this case the mark has to be detected after a new object segmentation step.

All these constraints are essential but it is also important to perform the detection of the mark and the decoding of the hidden message for a wide range of bit-rates and in real-time conditions. Using a CIF video for example, the signature had to be detected for bit-rate of few Mbit/sec to several hundred of Kbit/sec.

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## 1.2. Previous Approaches

The objective of this section is to give an overview of different approaches that have been designed to enable MPEG-4 sequence watermarking. The embedding process relies on the modification of animation parameters or of coded frames coefficients.

Watermarking of MPEG-4 facial animation parameter (FAP) have been studied by Hartung *et al.*<sup>4</sup> The mark is additively embedded into the parameters values and the detection and message retrieval is performed by correlation using the original FAP. The detection step can be achieved using FAP or by an estimation of their values on MPEG-2 sequence.

Barni *et al* presented a method to mark Video Object Plans (VOP).<sup>5</sup> In this scheme, the embedding of the mark is performed modifying selected pairs of DCT quantized coefficients in each VOP. This scheme belongs to the class of substitutive schemes<sup>6</sup>: the balance between the absolute value of the selected pair ( $|c_1|; |c_2|$ ) is modified to insert the mark. Signature detection is performed after calculating the sum:

$$S = \sum_{pair} |c_i| - |c_j|$$

The sign of  $S$  gives the embedded bit value. The localization of the marked macro-blocks inside the VO is performed using a pseudo-random sequence and consequently the detection of the mark is depending of the MPEG-4 format.

Piva *et al* developed an additive embedding scheme in the wavelet domain for MPEG-4 video streams.<sup>7</sup> The proposed method belongs to the additive schemes class (addition of a random sequence on an image's transform). The detection of the mark is done by correlation and requires the decompression of the video. This operation is consequently independent of the video format and this scheme provides robustness to video object translation and background modification, nevertheless the mark cannot be detected after other object manipulations such as rotation or scaling operations.

## 2. VO WATERMARKING IN THE UNCOMPRESSED DOMAIN

The first method has been designed to enable the mark detection after object manipulation such as translation, scaling and/or rotations. These classes of manipulations occur a lost of synchronisation that eliminate the detection of the signature with classical watermarking schemes. Such requirements need a synchronization stage that cannot be easily performed in the compressed domain.

### 2.1. Proposed Scheme

The first presented method embeds a signature using the shape of the VOP to permit synchronization of the mark after geometrical manipulations. The mark is bounded with the content of the object and consequently belongs to the category of second generation watermarking schemes<sup>8,9</sup>

Basically we use two main features to enable the synchronization of the mark during the detection process: the object orientation and the object scale.

#### 2.1.1. Signature orientation

To detect the signature and decode the embedded message after VO rotations, we propose to orientate the signature according the principal directions of the object shape. Principal Component Analysis is used to estimate the principal directions  $\vec{U}$  and  $\vec{V}$  of the VOP<sup>10</sup> (vectors  $\vec{U}$  and  $\vec{V}$  denotes directions providing maximal variance of the data). In this context, the set of data is represented by a set of 2-D random variables  $m_i(x_i, y_i)$  that belong to the object mask  $M$ .  $\vec{U}$  and  $\vec{V}$  represent consequently the eigenvectors of the  $2 \times 2$  covariance matrix  $C(O)$ .

The main direction of the VOP, denoted  $\alpha_{CPA}$ , represents the angle between the eigenvector  $\vec{U}$  and the horizontal direction of the object plan, denoted  $\vec{i}$ :

$$\alpha_{CPA} = (\vec{i}; \vec{U}) \text{mod}(\pi)$$

Such a process permits to obtain a sharp orientation of the video object. Table 1 illustrates angle variation in degrees for different object rotations of 20 degree multiples on the "Bream" VO. Results indicate the fact that the presented estimator is extremely accurate (mean precision is over  $10^{-2}$  degree).

|                         |         |         |         |         |         |         |         |         |         |
|-------------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| angle (degree)          | 0       | 20      | 40      | 60      | 80      | 100     | 120     | 140     | 160     |
| $\alpha_{CPA}$ (degree) | 354.755 | 334.778 | 314.750 | 294.789 | 274.763 | 254.316 | 234.735 | 214.744 | 194.762 |
| error (degree)          | 0       | 0.022   | 0.005   | 0.033   | 0.007   | 0.439   | 0.020   | 0.010   | 0.007   |

**Table 1.** Orientation evaluations of VO “Bream” using PCA.

### 2.1.2. Signature scaling

To enable the detection of the mark after a VOP scaling operation, we extract a specific value of the VOP scale from the PCA analysis.

Supposing that the VOP, denoted  $O$ , has been scaled by a factor  $s$ , the value  $\Gamma(O)$  represents a real proportional to the VOP scale. Given:

$$\Gamma(O) = (\lambda_1(O) + \lambda_2(O))^{\frac{1}{4}}$$

We obtain:

$$\frac{\Gamma(sO)}{\Gamma(O)} = \frac{(\lambda_1(sO) + \lambda_2(sO))^{\frac{1}{4}}}{(\lambda_1(O) + \lambda_2(O))^{\frac{1}{4}}} = s$$

Table 2 illustrates the capacity of the proposed method to estimate the specific scale of the VOP. Our tests were applied on the “Akiyo” VO for scale factors varying from 1 to 0.2. In all configurations, the estimation error is under  $10^{-2}$  and consequently this scale estimator is reliable.

|              |       |       |       |       |       |       |       |       |       |       |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $s$ (%)      | 1     | 0.9   | 0.8   | 0.7   | 0.6   | 0.5   | 0.4   | 0.3   | 0.2   | 0.1   |
| $\Gamma(sO)$ | 2.616 | 2.352 | 2.089 | 1.833 | 1.569 | 1.305 | 1.041 | 0.778 | 0.522 | 0.260 |
| error        | 0     | 0.002 | 0.003 | 0.002 | 0.000 | 0.003 | 0.005 | 0.006 | 0.001 | 0.001 |

**Table 2.** Scaling evaluation of “Akiyo” VO using PCA.

## 2.2. Embedding scheme

Our embedding scheme can be considered as an additive scheme with the particularity that the signature is inserted in an appropriate referential depending on the object shape. This scheme can be decomposed in six different step illustrated on Figure 1:

1. As presented in the previous section, a Principal Component Analysis is performed on the VO binary mask  $O$ . Values of  $\alpha_{CPA}$  and  $\Gamma$  are extracted.
2. A random sequence (denoted  $S$ ), composed of a set of  $\{+1, -1\}$  spread on  $2 \times 2$  blocs, is generated from a secret key  $K$ .
3.  $S$  is thereafter scaled and rotated using  $\alpha_{CPA}$  and  $\Gamma$  to obtain a sequence  $S'$ . Each coordinate  $(x', y')$  are given by:

$$\begin{aligned} \begin{bmatrix} x' \\ y' \end{bmatrix} &= \Gamma \begin{bmatrix} \cos \alpha & -\sin \alpha \\ \sin \alpha & \cos \alpha \end{bmatrix} \begin{bmatrix} x - x_c \\ y - y_c \end{bmatrix} \\ + \Gamma \begin{bmatrix} x_c \\ y_c \end{bmatrix} &= \Gamma \left( \mathbf{R}(\alpha) \begin{bmatrix} x - x_c \\ y - y_c \end{bmatrix} + \begin{bmatrix} x_c \\ y_c \end{bmatrix} \right) \end{aligned} \quad (1)$$

where  $(x_c; y_c)$  are the coordinate of the center of the VOP shape.

An interpolation process based on a spline-cubic convolution kernel is performed to preserve the high frequencies of  $S$ .

4.  $S'$  is thereafter weighted by a visual mask depending of VOP luminance to obtain the sequence  $S'_v$ . We exploit the fact the distortion in an image is most noticeable in the mid-gray region.<sup>11</sup>
5.  $S'_v$  is finally added to the object texture to create the marked object.

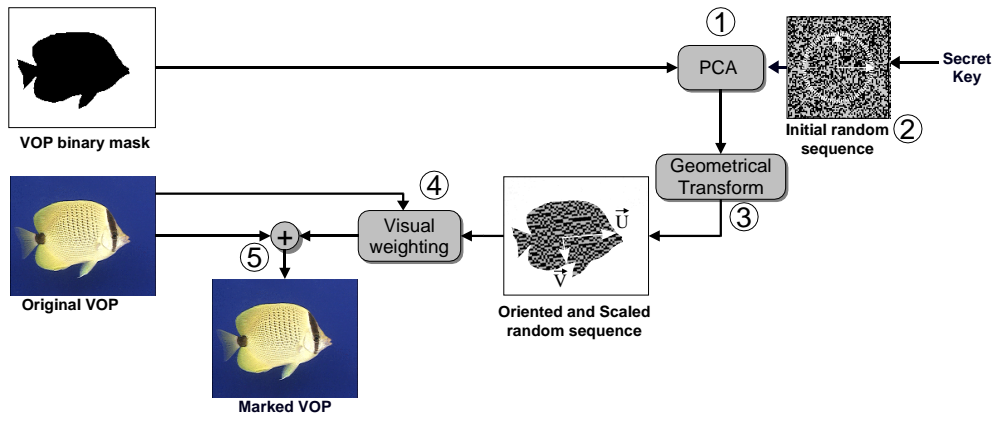


Figure 1. Signature embedding scheme.

### 2.3. Detection scheme

As in classical additive schemes, the detection of the mark is performed using a correlation criterion. The detection process can be divided in five steps illustrated on figure 2.

1. As in the embedding scheme, one sequence  $S$  is generated using a secret key  $K$ .
2. We transform the object texture to obtain an object  $O_m$  in such a way that  $O_m$  orientation is null and  $O_m$  scale is equal to 1. This operation is equivalent to invert equation 1:

$$\begin{bmatrix} x \\ y \end{bmatrix} = \Gamma^{-1} \left( \mathbf{R}(-\alpha) \begin{bmatrix} x' - x'_c \\ y' - y'_c \end{bmatrix} + \begin{bmatrix} x'_c \\ y'_c \end{bmatrix} \right) \quad (2)$$

3. A Wiener prediction is applied on  $O_m$  to minimize the texture contribution of the original object before the correlation computation.<sup>12</sup>
4. The correlation value  $corr$  between  $\hat{W}$  and the random sequence  $W$  is evaluated::

$$corr = \sum_{(i,j) \in O} \hat{W}(i,j)W(i,j)$$

5. The correlation value is stored in an accumulation variable  $corr_A$  initialised to 0.  $corr_A$  is thereafter compared with a threshold depending on a false-alarm probability  $\lambda(p_{fa})$ . In the case of  $corr_A > \lambda(p_{fa})$ , the signature is consequently detected inside the VOP.

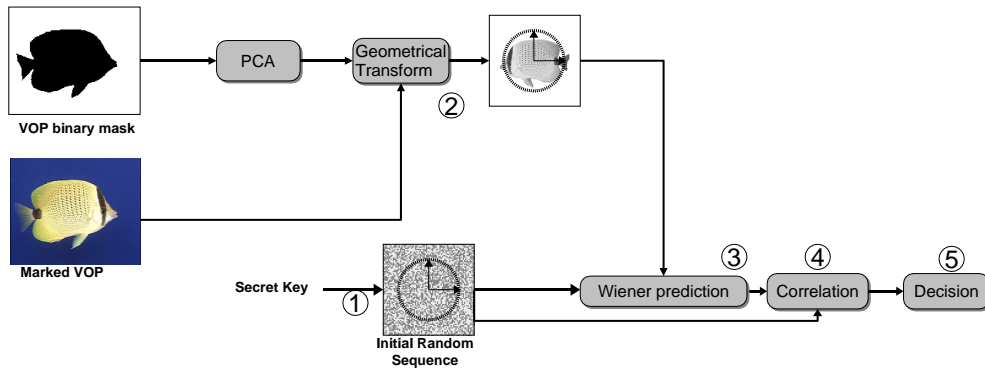
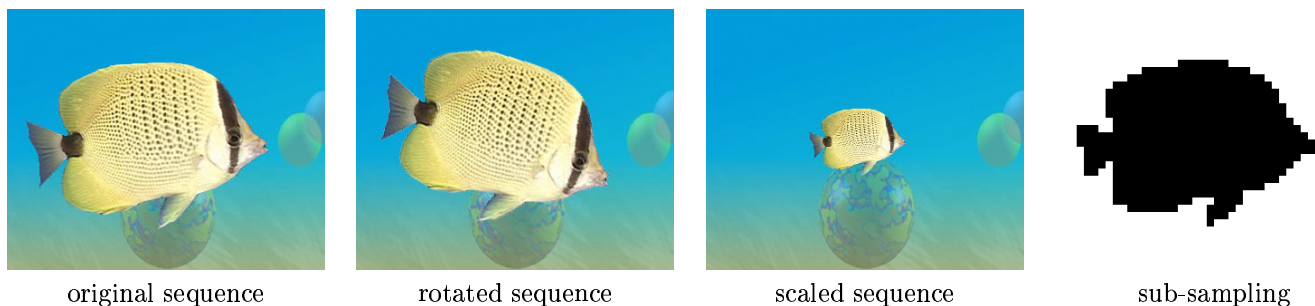


Figure 2. Signature detection and decoding scheme.

## 2.4. Results

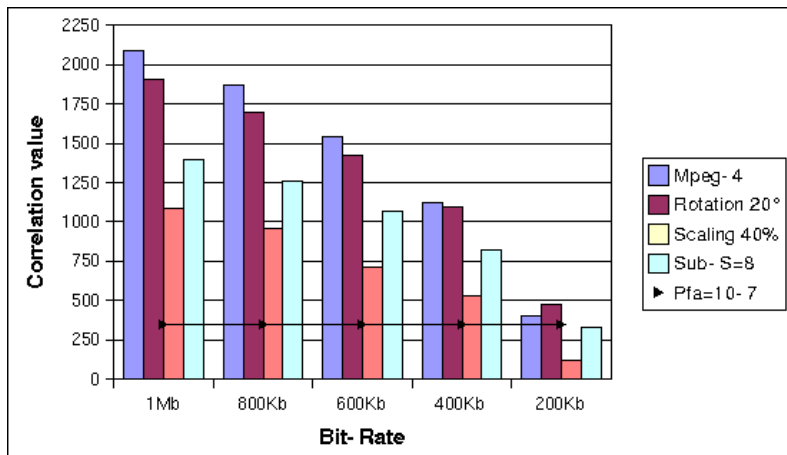
We have tested the presented method on the *Bream* sequence, composed of 300 frames in a CIF format ( $352 \times 288$ ) using a 4:2:0 sampling. Only the luminance components of the different frames are marked. The *Bream* sequence is composed of two video objects, a fish denoted  $VO_{11}$  delimited by a  $272 \times 185$  bounding box and a background representing the aquarium denoted  $VO_{12}$ . Only  $VO_{12}$  is marked in these tests. The final decision is determined by the sum of correlations obtained for each sequence VOP. The evaluation of the proposed scheme was performed for different VO manipulations and different bite-rates. The bite-rates have been chosen to represent a wide variety of multimedia applications. 1Mb/sec, 800Kb/sec, 600 Kb/sec, 400 Kb/sec and 200 Kb/sec have been used. The marked sequence does not have noticeable differences from the original one, even in its uncompressed version. The VO manipulations that have been tested are:

- VO scaling of 40%
- VO rotation of 20 degrees
- VO mask sub-sampling with a factor equal to 8 pixels, this is commonly used to perform lossy compression of the VO shape.



**Figure 3.** Evaluated configurations.

We have performed a statistical analysis of  $corr_A$  to determine a false-alarm threshold. In these tests the false-alarm probability was fixed to  $10^{-7}$ . The different correlation values are sum-up on Fig. 4. Theses results illustrate the fact that our detection scheme is robust to bit-rate reduction for very low bit-rates. But the most important property of the presented method refers to its robustness to scaling and rotation operations for different bit-rates. Finally the mask sub-sampling operation by a factor equal to 8 seems to not affect the detection process in an important way. In our futur works we will concentrate the tests on real new segmentation conditions



**Figure 4.** Signature detection results for different bit-rates.

### 3. VO WATERMARKING IN THE COMPRESSED DOMAIN

#### 3.1. Compressed-domain processing

Compressed-domain watermarking algorithms are in general less flexible in comparison to those operating in the uncompressed domain. This is due to the requirement for compressed processing which imposes additional limitations, such as fast embedding/detection, file size preservation etc. Although compressed-domain methods may not be as efficient as uncompressed-domain ones, they can be more easily used in practical applications.

In this section a framework for the watermarking of MPEG-4 bitstreams is presented. The block diagram of the embedding process is depicted in Fig. 5. Video objects (VOs) reside into an MPEG-4 bitstream.<sup>13</sup> MPEG-4 video objects are coded macroblock-wise, as in MPEG-2 and MPEG-1. Shape and texture information is coded separately for each macroblock. Texture coding is DCT-based and shape coding is achieved using Context-based Arithmetic Encoding (CAE).<sup>14</sup> The multiplexing mechanism is out of the scope of MPEG-4, so a generic method is assumed (e.g. the FlexMux method provided by MPEG-4 systems<sup>13</sup>). In effect, the demultiplexing process used by the system depicted in Fig. 5 is equivalent to the extraction of each video object bitstream from the multiplexed stream. After the VO bitstream extraction, inverse CAE is performed, yielding the binary alpha mask of the object. This mask is used during the watermark embedding process. Inverse VLC is also applied to the texture DCT coefficients, which are then dequantized. When the embedding of synchronization and copyright signal is complete, the watermarked DCT texture coefficients are quantized, VLC coded and the resulting stream is placed in the appropriate position in the MPEG-4 stream. An important characteristic of the scheme is that the binary mask does not need to be reencoded, since it is only used for the calculation of the object center and the insertion of the synchronization pattern.

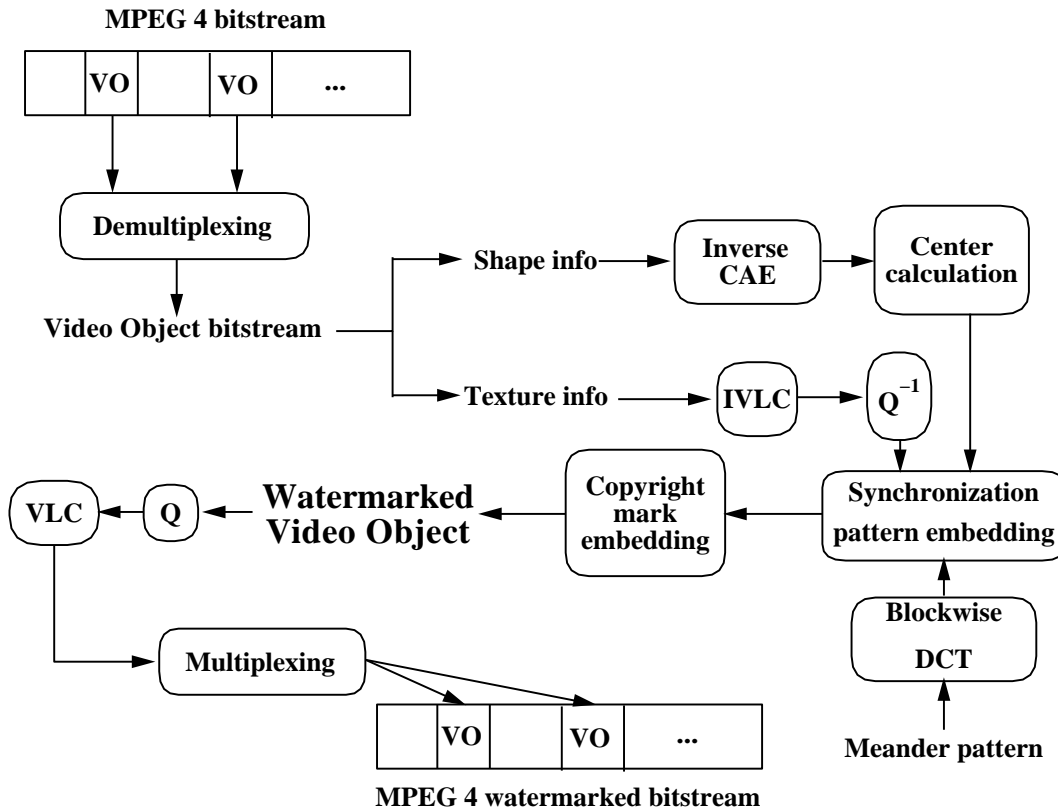


Figure 5. Block diagram of the watermark embedder.

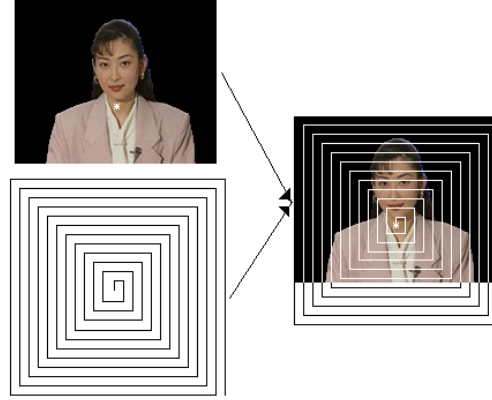
#### 3.2. Embedding synchronization information in MPEG-4 objects

Undoubtedly, synchronization is a major issue for the watermarking of MPEG-4 objects. Although spatial domain methods are very suitable for robust schemes against synchronization attacks, they require source frame processing,

thus making their use impossible for most compressed-domain applications. In the proposed compressed-domain framework, the binary alpha mask of the MPEG-4 objects is the only information that is fully decompressed. Using this mask, the center of the object is calculated as the mean of the coordinates of all non-zero pixels of the mask along the horizontal and vertical direction. Let  $\mathbf{c}$  denote the center of the object:

$$\mathbf{c} = \mathcal{R}(m_x, m_y) = \mathcal{R}\left(\frac{1}{N} \sum_{(x_i, y_i) \in \mathcal{A}} (x_i, y_i)\right) \quad (3)$$

where  $\mathcal{A}$  is the set of the coordinates of all non-zero pixels of the object,  $N$  is the number of pixels it includes and  $\mathcal{R}(\cdot)$  denotes the rounding operation. The center of the object, computed as above, is the starting point of the embedded synchronization signal. The synchronization signal, a meander in our case, is blockwise DCT transformed and inserted in the partially decoded stream, using the center as reference point, as shown in Fig. 6.



**Figure 6.** Watermark embedding in object using meander pattern.

### 3.3. Embedding watermarks for copyright protection

The copyright watermark is a random sequence of zero-mean normally distributed numbers which is added to middle frequency DCT coefficients. Such coefficients are ideal for robust embedding without introducing visible artifacts. The watermark sequence is the same for every frame, but different for every block. The embedding is done as follows:

$$c'(i, j) = c(i, j) + aw(i, j) \quad (4)$$

where  $c'(i, j)$ ,  $c(i, j)$  are the watermarked and the original block coefficients respectively,  $w(i, j)$  are the watermark coefficients and  $a$  is the factor which controls the strength of the watermark. This factor can be either the same or different for each block. To control the strength of the watermark even further, embedding takes place only if the energy of the AC coefficients in a block exceeds a predefined threshold, i.e. if

$$E = \frac{1}{63} \left( \sum_{i=0}^7 \sum_{j=0}^7 c^2(i, j) - c^2(0, 0) \right) > T \quad (5)$$

This threshold is derived using heuristic techniques.<sup>15</sup>

### 3.4. Synchronization recovery and watermark detection

The MPEG-4 Terminal Architecture<sup>13</sup> defines *Object Composition Memories*. These are buffers in which decoded objects are stored prior to their presentation in the scene. Since, during decoding objects are easily accessible in the spatial domain, synchronization recovery and copyright watermark extraction can take place in the spatial domain. The center of the object is initially calculated from the binary alpha mask using (3). Supposing there has been no modification of the object boundary, the calculated center is the same as in the embedding process. First the synchronization signal is detected to verify the presence of the watermark. Then the detection of the copyright

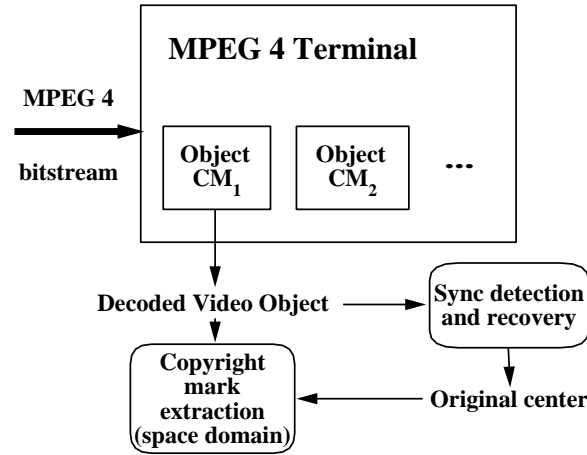


watermark takes place. If there have been modifications, the process is as follows : for the calculated center, the synchronization signal is detected, yielding a correlator metric  $q$ .

The correlator metric  $q$  is computed as

$$\begin{aligned}
 q &= \frac{1}{N} \sum_{i=1}^N c'_{si} w_{si} = \frac{1}{N} \sum_{i=1}^N (c_{si} + a w_{si}) w_{si} = \\
 &= \frac{1}{N} \sum_{i=1}^N c_{si} w_{si} + \frac{a}{N} \sum_{i=1}^N w_{si}^2 = a \frac{1}{N} \sum_{i=1}^N w_{si}^2
 \end{aligned} \tag{6}$$

where  $c'_{si}$  are the test pixels,  $c_{si}$  are the original pixels and  $w_{si}$  are the space-domain watermark coefficients obtained by applying IDCT to the coefficients embedded in the DCT domain. The first term on the right side of (6) limits to zero, since the pixel sequence and the watermark signal are statistically independent and the watermark signal is zero-mean. Equation (6) is applicable to the detection of both the synchronization signal and the copyright watermark. The block diagram of the detection process is depicted in Fig. 7.



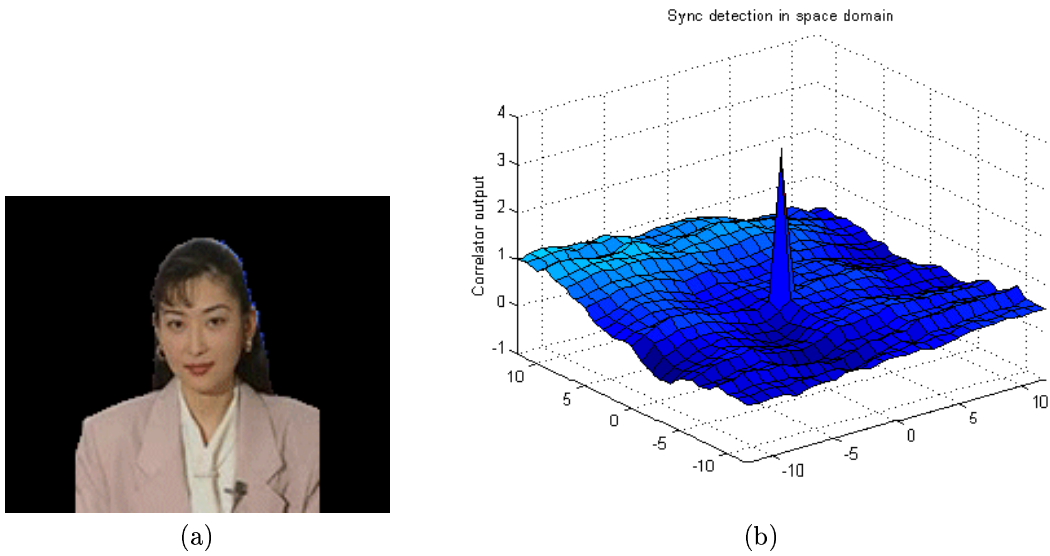
**Figure 7.** Block diagram of the detection process. Both synchronization recovery and copyright watermark detection are performed entirely in the space-domain.

The synchronization signal detection process is repeated for all adjacent pixels of the center, yielding a correlator metric  $q$  for every candidate center. The search radius varies according to the anticipated modifications of the boundary. Minor, and therefore imperceptible, modifications will result in calculating the same center as the original or very close to the original. Finally, the candidate center, for which the correlator output is maximum, is considered the original embedding starting point.

It is quite obvious that the above scheme reduces drastically the search space for synchronization recovery and it is far more efficient than classical methods that employ brute force search techniques. Such techniques are computationally intensive and extremely time consuming, rendering them useless for most real-time applications. The proposed system is very effective against cropping and translation attacks, which are frequently present in MPEG-4 object manipulation scenarios. Furthermore, it is possible to make the system robust against scaling attacks by using a "prototype meander" and adapting it to the size of the object's bounding box. After synchronization is recovered, copyright watermark extraction can proceed immediately.

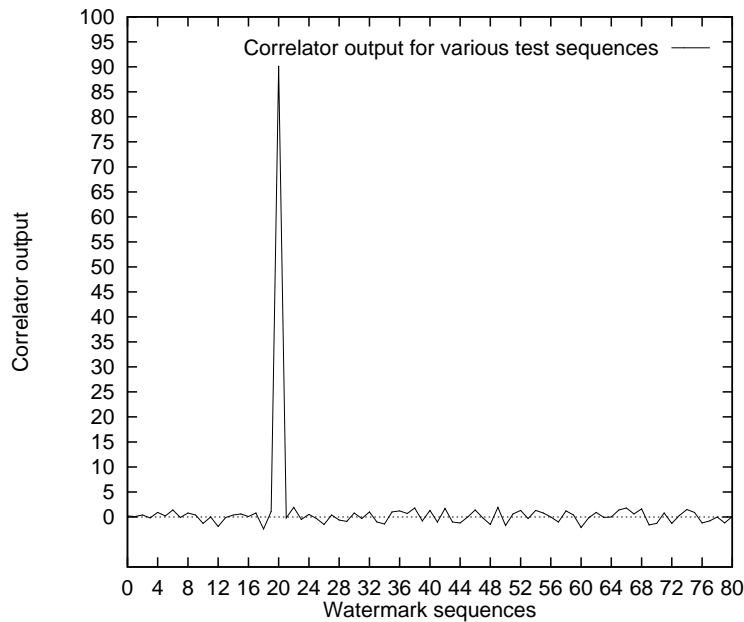
### 3.5. Experimental results

For the experimental evaluation of the proposed scheme, the synchronization procedure described in the previous section was applied to the standard MPEG sequence "Akiyo". Fig. 8a shows a cropped test frame, which was used for evaluating the efficiency of the proposed technique in cases of severe object cropping. In Fig. 8b the correlator output for various candidate centers is shown, using spatial domain synchronization recovery.



**Figure 8.** a) Cropped “Akiyo” frame. b) Correlator output for candidate centers (spatial domain).

For the copyright watermarking of coefficients, experimental results show that any strength factor valued between 9 and 10 yields strong watermarks without introducing visible artifacts. Experiments also show that for the above strength factor, the corresponding threshold should be between 280 and 310 for best results. The results for the “Akiyo” sequence are shown in Fig. 9. The results vary slightly from frame to frame. In Fig. 9, the correlator output is plotted for various test watermark sequences. As expected, the correlator output magnitude is much larger when the actual watermark sequence is used for the detection.



**Figure 9.** AC watermark detection for various test sequences.

## 4. CONCLUDING REMARKS

This paper illustrates the advantages of uncompressed-domain and compressed-domain watermarking of MPEG-4 video objects. Uncompressed-domain approaches (cf section 2) are more flexible than compressed-domain techniques. Uncompressed-domain processing enables signature orientation using CPA and enable watermark detection after rotation or scaling operations. Compressed-domain watermark embedding and detection (cf section 3) is less flexible since it should be performed in the DCT domain in order to have substantial advantage, in terms of computational complexity, over uncompressed-domain techniques. Although compressed-domain techniques are not so robust as uncompressed-domain ones, they enable real-time embedding and detection which is very desirable in most practical applications. An area of future research is the application of the techniques currently applied on uncompressed data to the compressed domain so that the resulting watermarking schemes enjoy the best from both worlds.

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