Error Drift Compensation for Data Hiding of the H.264/AVC

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Abstract: The error propagation problem is one of the most attractive issues in the field of data hiding of compressed video because the achievement of several data hiding characteristics remains dependent on it. In this paper, a solution to compensate the error propagation is proposed for data hiding of the H.264/AVC. The error compensation is performed by a prior measurement of the introduced error in the watermarked block or in the neighbouring blocks. Two schemes are proposed: The first algorithm exploits the method of watermarking paired-coefficients in each block in order to bring the error to the middle of the block matrix. The distortion caused by each paired-coefficient is calculated in order to give a watermarking priority to the pairs which introduce the minimum error. In the second scheme, the error estimated in the neighbouring blocks is reduced from the residuals during the encoding process. In both schemes, results show that an important improvement of the video quality can be achieved and a good compromise is provided between the video distortion, the bitrate and the embedding capacity.

Keywords: H.264/AVC, data hiding, drift distortion, drift compensation, real-time broadcasting.

1. INTRODUCTION

With the spread of the video servers on the internet, it becomes important to develop and adapt the data hiding techniques to this medium in order to promote the different applications exploiting data hiding, such as copyright protection, authentication and covert communication.

The technical efficiency of the video codec H.264/AVC has led to an orientation of the data hiding research to this support. Several data hiding methods have been proposed to the H.264/AVC. Secret data can be embedded during the encoding process, exploiting one of the three main encoding steps: Prediction, transformation and quantization, and entropy coding, or in the bitstream as depicted in Fig. 1.

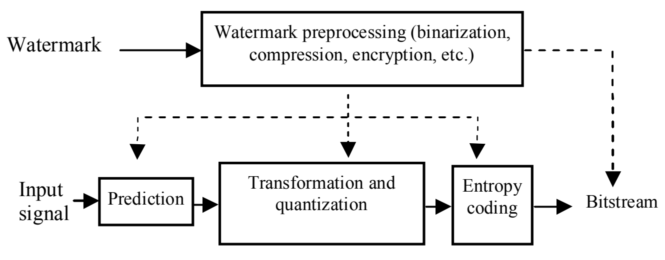


Fig. 1. General data hiding scheme of H.264/AVC

Most of the proposed methods are based on the Discrete Cosine Transform (DCT) coefficients. In (Noorkami *et al.*, 2007), the authors propose a human visual model based on 4×4 DCT block to embed the secret data into quantized AC (Alternating Current) coefficients of intra-frames (I-frames). (Chen *et al.*, 2009) present a watermarking method based on two algorithms for low and high energy blocks of I-frame in order to consider the high frequency noise attack and the low-pass filter attack. Security and robustness are ensured respectively by a Torus Automorphism algorithm and a secret image sharing technology.

In (Kim *et al.*, 2007), the authors propose to use the entropy coding stage to embed the secret data. The bit is embedded in the sign bit of the trailing ones in context adaptive variable length coding (CAVLC).

(Kuo *et al.*, 2008) propose the use of motion vectors to embed the watermark. This is done by restricting the search range of the best matching in the watermark embedding process. However, motion vectors provide fragile watermarking and increase considerably the bitrate.

Recently, data hiding methods based on intra prediction have been proposed (Yang *et al.*, 2010). To embed secret data, the optimal intra prediction modes are modified to the suboptimal ones. These methods have shown outperforming results comparing to the previous methods and a relatively high embedding capacity is achieved for a negligible decrease in the peak signal-to-noise ratio (PSNR).

However, data hiding methods based on DCT coefficients still interest the research community because of the various characteristics that can be achieved such as reversibility, robustness and security. Though, the drift distortion is a problem which hinders the data hiding efficiency and causes the propagation of the introduced error to the entire video through the intra and inter-prediction at the decoding stage.

Today, there exist few papers that address the propagation error problem for the H.264/AVC codec. In (Gong *et al.*, 2008), the authors propose a scheme that targets fastness and robustness. The watermark is embedded by modifying the quantized DC (Direct Current) coefficients in luma residual blocks. A texture masking based on perceptual model is used to adaptively choose the watermark strength for each block, the aim is to ensure robustness and maintain the perceptual video quality. To eliminate the effect of the drift error, a compensation signal is estimated for each block before embedding the watermark. However in this scheme, the secret message is modulated by a bipolar sequence which reduces the amount of the secret embedded message. The watermark is needed in the detection step (detectable scheme) and it is embedded directly in the bitstream which implies additional operations (entropy decoding and encoding), thus it cannot be used for real time broadcasting.

In (Ma *et al.*, 2010), the authors propose a readable data hiding scheme that overcomes I-frame distortion drift issue. The secret data are embedded in the I-frames, in the 4x4 luma DCT quantized coefficients. Paired-coefficients are defined in the luma blocks to prevent the distortion propagation. Embedding the data in the two coefficients allows bringing the introduced error to the middle of the block matrix. The main drawback of this method is the fact that it acts on the video stream and needs prior knowledge of the prediction modes of the neighbouring blocks. Thus, it cannot be used for real-time broadcasting either.

In (Zhang *et al.*, 2010), the authors propose to eliminate the error propagation by obtaining the difference between the original and watermarked reconstructed samples and compensating for all the integer DCT coefficients. This method was improved in (Huo *et al.*, 2011), by presenting three algorithms that compensate only the watermarked blocks according to the position of the affected coefficient. The main objective was to reduce the computational burden of this approach. However, this algorithm is detectable, it needs the watermark for the detection of the secret data, and thus its possible applications are limited.

In this paper, new methods are explored to compensate the error propagation. These methods are based on estimating the error introduced in the watermarked block or propagated in the neighbouring blocks. In the first scheme, the method in (Ma *et al.*, 2010) is adapted to be used during the encoding process. The distortion caused by each paired-coefficient is calculated in order to give a watermarking priority to the pairs which introduce the minimum error. In the second scheme, the error estimated in the neighbouring blocks is reduced from the residuals during the encoding process. In both schemes, the adopted embedding process plays a crucial role in maintaining the bitrate.

In the next section, the error propagation problem and the error estimation are presented. In section 3, the data hiding method based on watermarking paired-coefficients is explained. Then, the first data hiding scheme is presented. In the fourth section, the second scheme based on compensating the error in the neighbouring blocks is proposed. Finally, the results are presented and discussed in section 5 and conclusions are drawn in section 6.

2. THE ERROR PROPAGATION

2.1 The H.264 encoding and decoding processes

The video encoding process is summarised in three steps: Prediction, transformation and quantization, and entropy coding. In the H.264/video standard, the first image of a scene is intra predicted: a macroblock (16x16 samples) or a block (4x4 samples) of interest is predicted from macroblocks already encoded and located to the left or above. The difference between the original macroblock and the predicted one represents a residual data R. Besides the intra prediction, an inter-frame prediction is exploited between adjacent images to reduce temporal redundancies.

At the decoding stage, a macroblock in the intra frame is deduced form the residual data and the prediction. The quantized coefficients L (levels) are recovered at this stage after the entropy decoding. After the scaling and inverse transformation operation, the residual data R' are deduced. The encoding and decoding operations are roughly represented in Fig. 2. (a) and (b). More details about the encoding and decoding processes can be found in (Richardson *et al.*, 2005).

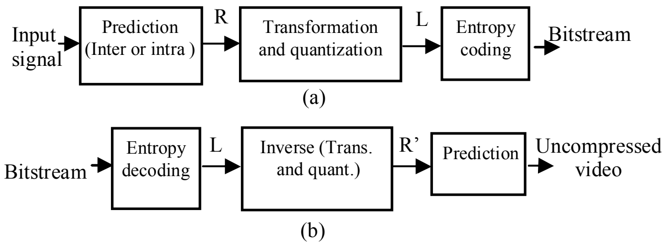
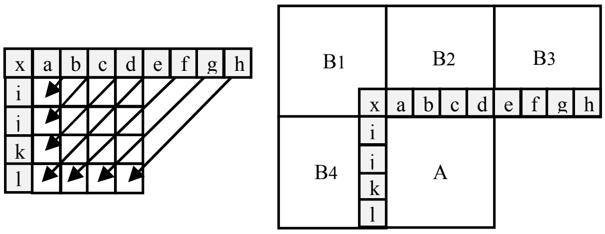


Fig. 2. (a) and (b) represent a general scheme of encoding and decoding video processes respectively.

2.2 The drift distortion

At the encoding stage, a 4x4 luminance block A can be predicted according to nine modes using the neighbouring samples already encoded, and the best mode is deduced from rate distortion optimization technique (Richardson et al.(2005)). The third mode (Diagonal down left) is shown as an example in Fig. 3 (a). For this mode, the sixteen predicted samples of the block are deduced from the samples a to h as explained in (ITU (2005)).

At the decoding stage, the blocks are reconstructed from the predicted ones and the residuals R_A'. If a secret bit is added to one of the blocks B1, B2, B3 or B4 (Fig. 3.(b)) by modifying one of the sixteen coefficients, the residual data R_{Bi}' (i=1, ..,4) and the prediction of A (deduced from a...x) would be modified. This way, an error introduced in one block can be propagated to the whole image through the intra prediction and to the whole sequence through the inter prediction.



(a) (b)

Fig. 3. (a) Prediction mode 3, (b) Neighbouring blocks and prediction samples.

2.3 The error estimation

At the encoder, the forward integer DCT of a residual block X is given in (Richardson *et al.*, 2005):

$$Y = C_f X C_f^T \otimes E_f \tag{1}$$

$$W_{ij} = C_f X C_f^T \tag{2}$$

The symbol $\otimes$ is a scalar multiplication between W_{ij} and the matrix of scaling factors E_f.

$$\boldsymbol{C_f} = \begin{bmatrix} \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} \\ \mathbf{2} & \mathbf{1} & \mathbf{-1} & \mathbf{-2} \\ \mathbf{1} & \mathbf{-1} & \mathbf{-1} & \mathbf{1} \\ \mathbf{1} & \mathbf{-2} & \mathbf{-1} & \mathbf{2} \end{bmatrix}$$

The quantized coefficients are obtained by (3) which performed the quantization and scaling in a single operation:

$$Z_{ij} = round\left(\frac{W_{ij}\, PF}{Qstep}\right) \tag{3}$$

Qstep is the quantizer step size and *PF* is equal to a^2, $ab/2$ or $b^2/4$ (a=1/2, b= $\sqrt{2/5}$) depending on the position of (i,j).

At the decoder, the residual coefficients X_{ij}' are obtained by (4) and (5) which represent the rescaling step and the inverse integer DCT transform respectively. A block of pixels is reconstructed by adding a block of residuals to the predicted block.

$$W_{ij}' = Z_{ij}\ Qstep\,.PF'.64 \tag{4}$$

$$X_{ij}' = round\left[\left(C_i^T W_{ij}' C_i\right)/\,64\right] \tag{5}$$

$$\boldsymbol{C_i} = \begin{bmatrix} \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} \\ \mathbf{1} & \mathbf{1/2} & \mathbf{-1/2} & \mathbf{-1} \\ \mathbf{1} & \mathbf{-1} & \mathbf{-1} & \mathbf{1} \\ \mathbf{1/2} & \mathbf{-1} & \mathbf{1} & \mathbf{-1/2} \end{bmatrix}$$

PF' is equal to a^2, ab or b^2 depending on the position of (i,j). In data hiding algorithms based on DCT coefficients, the secret data are embedded by adding a matrix error Δ (composed of the coefficients Δ_{ij}) to the quantized coefficients. The new rescaled coefficients become:

$$W_{ij}'' = (Z_{ij} + \Delta_{ij})\ Qstep\ PF'\ 64 \tag{6}$$

The residual coefficients are obtained by:

$$X_{ij}'' = round\left[\,((C_i^T (Z_{ij}\ Qstep\ PF'\ 64\,)\ C_i) + (C_i^T (\Delta_{ij}\ .Qstep\ PF'\ 64\,)\ C_i))/64\right] \tag{7}$$

3. ERROR DRIFT LIMITATION BASED ON WATERMARKING PAIRED COEFFICIENTS

3.1 Error drift elimination

Ma et al.(2010) proposed a method based on watermarking paired-coefficients. The authors investigate the prescaling and inverse quantizer and transformation operations and identify paired-coefficients that bring the distortion to the middle of the matrix. The paired-coefficients are gathered in horizontal and vertical sets as follows:

The horizontal set (HS): {(Z_{01}, Z_{21}), (Z_{21}, Z_{01}), (Z_{02}, Z_{22}), (Z_{22}, Z_{02}), (Z_{03}, Z_{23}), (Z_{23}, Z_{03})}

The vertical set (VS): {(Z_{10}, Z_{12}), (Z_{12}, Z_{10}), (Z_{20}, Z_{22}), (Z_{22}, Z_{20}), (Z_{30}, Z_{32}), (Z_{32}, Z_{30})}

All the paired-coefficients of HS and VS accumulate the distortion to the rows and columns respectively in the middle of the matrix. An example is given in Table 1, where Δ' is the matrix error composed of Δ'_{ij}, deduced from (7):

$$\Delta_{ij}' = \ (C_i^T (\Delta_{ij}\ .Qstep\ PF'\ 64\,)\ C_i))/64 \tag{8}$$

Based on this idea, a watermark bit embedded in a paired-coefficient from HS would prevent the error propagation to the neighbouring blocks B, C and D if they use the samples m, n, o and p (Fig. 4) in their intra prediction. Similarly, a watermark bit embedded in a paired-coefficient from VS would prevent the error propagation to the blocks A and D if they use the samples d, h, l and p in their prediction.

To embed the watermark bit, the authors proposed the selection of the paired-coefficient according to the conditions which avoid the drift distortion. A prior knowledge of the prediction modes of A, B, C and D (Fig. 4) is then necessary to apply this method. Thus, it can be applied only to the H.264 stream and not during encoding process. Besides, if the two coefficients of one pair are equal to zero, the embedding is not applied which would reduce the embedding capacity. Moreover, if only one coefficient of the pair is equal to zero, the embedding can be performed which could increase considerably the bitrate. To overcome these drawbacks, this method is adapted as presented in the next section.

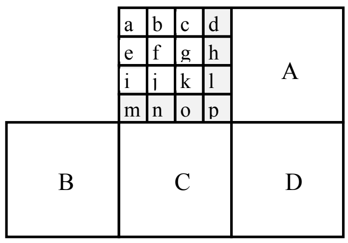


Fig. 4. Neighbouring blocks

Table 1. Example of the matrix error.

Embedded data Δ	Matrix error Δ' at the decoder
$\begin{bmatrix} 0 & 0 & t & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} a^2tQ_{step} & -a^2tQ_{step} & -a^2tQ_{step} & a^2tQ_{step} \\ a^2tQ_{step} & -a^2tQ_{step} & -a^2tQ_{step} & a^2tQ_{step} \\ a^2tQ_{step} & -a^2tQ_{step} & -a^2tQ_{step} & a^2tQ_{step} \\ a^2tQ_{step} & -a^2tQ_{step} & -a^2tQ_{step} & a^2tQ_{step} \end{bmatrix}$
$\begin{bmatrix} 0 & 0 & t & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & -t & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 & 0 & 0 \\ 2a^2tQ_{step} & -2a^2tQ_{step} & -2a^2tQ_{step} & 2a^2tQ_{step} \\ 2a^2tQ_{step} & -2a^2tQ_{step} & -2a^2tQ_{step} & 2a^2tQ_{step} \\ 0 & 0 & 0 & 0 \end{bmatrix}$
$\begin{bmatrix} 0 & 0 & 0 & 0 \\ t & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} \mathrm{abtQ_{step}} & \mathrm{abtQ_{step}} & \mathrm{abtQ_{step}} & \mathrm{abtQ_{step}} \\ \mathrm{abtQ_{step}}/2 & \mathrm{abtQ_{step}}/2 & \mathrm{abtQ_{step}}/2 & \mathrm{abtQ_{step}}/2 \\ -\mathrm{abtQ_{step}}/2 & -\mathrm{abtQ_{step}}/2 & -\mathrm{abtQ_{step}}/2 & -\mathrm{abtQ_{step}}/2 \\ -\mathrm{abtQ_{step}} & -\mathrm{abtQ_{step}} & -\mathrm{abtQ_{step}} & -\mathrm{abtQ_{step}} \end{bmatrix}$
$\begin{bmatrix} 0 & 0 & 0 & 0 \\ t & 0 & -t & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 0 & 2abtQ_{step} & 2abtQ_{step} & 0 \\ 0 & abtQ_{step} & abtQ_{step} & 0 \\ 0 & -abtQ_{step} & -abtQ_{step} & 0 \\ 0 & -2abtQ_{step} & -2abtQ_{step} & 0 \end{bmatrix}$

3.2 Proposed approach: First scheme

In the proposed approach, embedding the secret bits is performed in I-frames during the encoding process of the H.264/AVC codec.

The candidate blocks for data hiding are the 4x4 luma DCT blocks with relatively a large number of residuals. The security of the secret data is based on encryption.

The embedding is performed in paired-coefficients in order to bring the error to the middle of the block matrix as mentioned previously. Six paired-coefficients may be used: (Z_{01}, Z_{21}), (Z_{02}, Z_{22}), (Z_{03}, Z_{23}), (Z_{10}, Z_{12}), (Z_{20}, Z_{22}), (Z_{30}, Z_{32}), corresponding to the following positions in the zigzag scan: (P_1, P_8), (P_5, P_{11}), (P_6, P_{13}), (P_2, P_7), (P_3, P_{11}), (P_9, P_{14}) as illustrated in Fig. 5 (a).

From (7), it is possible to estimate in advance the error introduced in each block. Indeed, if embedding secret data is based on adding or subtracting 1, the error can be estimated by calculating Δ'_{ij} as indicated in the previous subsection.

Fig. 5 (from (b) to (d)) presents the results obtained by embedding one bit to the paired-coefficients (adding 1 to one coefficients and subtracting 1 from the second) of the positions: (P_1, P_8), (P_2, P_7), (P_3, P_{11}), (P_5, P_{11}), (P_6, P_{13}) and (P_9, P_{14}). Only samples that play a role in propagating the error are mentioned.

Based on this estimation, it is possible to give a watermarking priority to the pairs which introduce the minimum error propagation to the neighbouring block (Bouchama et al. (2012)). The paired- coefficients are ranked as follows: (P_9, P_{14}) introduces the minimum error then follow respectively (P_6, P_{13}), then ((P_5, P_{11}) or (P_3, P_{11})), and finally ((P_2, P_7) or (P_1, P_8)).

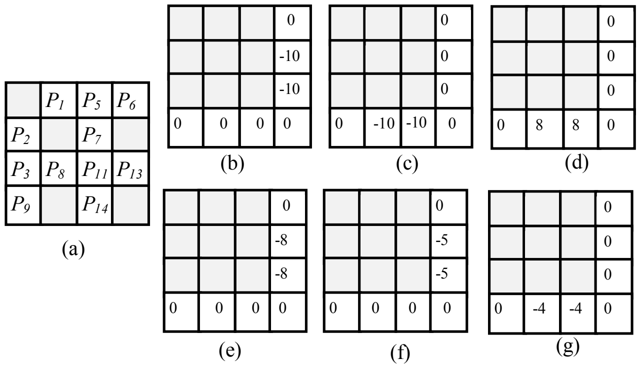


Fig. 5. (a) Representation of the paired-coefficient positions, (b), (c), (d), (e), (f) and (g) The estimated error, introduced in the block samples by embedding one bit in (P_1, P_8), (P_2, P_7), (P_3, P_{11}), (P_5, P_{11}), (P_6, P_{13}) and (P_9, P_{14}) respectively.

For the embedding process, a candidate block is first selected according to the number N of residuals (in our experiments, three cases are considered: N>5, N > 7 and N>9).

For each block, the nonzero paired-coefficients are identified then the secret bit is embedded in the appropriate pair according to the priority and to the availability.

It is necessary to choose the coefficients values that don't affect the video quality and the bitrate such as the quantized coefficients 0 and 1 which play an important role in the entropy coding step. The modification of the zero coefficient increases considerably the bitrate and the modification of the bits 1 to 0 affects considerably the video quality. Thus, to embed a watermark bit W, the applied modulation is presented in Table 2, where (C_1, C_2) is a paired-coefficient, $C_1 \neq 0$ and $C_2 \neq 0$.

If both C_1 and C_2 are equal to 1 or -1, this pair is not used for the embedding in order not to modify the coefficient to 0. In addition, if the paired-coefficient (P_5, P_{11}) is not used for this reason, the pair (P_3, P_{11}) is not used either, because the detection result may be erroneous due to the common position P_{11}.

Table 2. Embedding process.

Conditions			Instructions
(C_1mod 2 =0 and W=1) or (C_1mod 2 =1 and W=0)	$C_1 > 0$	$C_2 \neq 1$	$C_1 = C_1 + 1$, $C_2 = C_2 - 1$
		$C_2 = 1$, $C_1 \neq 1$	$C_1 = C_1 - 1$, $C_2 = C_2 + 1$
	$C_1 < 0$	$C_2 \neq -1$	$C_1 = C_1 - 1$, $C_2 = C_2 + 1$
		$C_2 = -1$, $C_1 \neq -1$	$C_1 = C_1 + 1$, $C_2 = C_2 - 1$
(C_1mod 2 =0 and W=0) or (C_1mod 2 =1 and W=1)	C_1 and C_2 are not modified.		

The extraction step doesn't need a complete decoding of the video stream. The steps below are applied.

After the entropy decoding, the quantized Integer DCT blocks with N coefficients are selected, the availability of the quantized nonzero coefficients (C_1, C_2) of the positions (P_9, P_{14}) is checked. If at least abs(C_1) ≠ 1 or abs(C_2) ≠ 1, a bit W is extracted from a block as follows:

If C_1mod 2 =1, W =1; otherwise, W=0.

abs is the absolute value and mod is the modulo operation.

If a paired-coefficient is not available (C_1=0 or C_2=0) or doesn't fulfill the embedding conditions (abs(C_1) =1 and abs(C_2) = 1), the same verification is performed for the next one according to the priority. The extracted data are decrypted to obtain the secret information.

4. ERROR DRIFT LIMITATION BASED ON COMPENSATING THE ERROR IN THE NEIGHBOURING BLOCKS

4.1 Error compensation

As indicated in the previous section, it is possible to calculate the error Δ' introduced in one watermarked block, and estimate the propagated error in a neighbouring block for each of the nine possible modes (see section 2.2).

At the decoding step, the samples matrix of the block A (Samp.A) are deduced from the residual data of A (Resid.A) and the prediction of A (Pred.A) as follows:

Samp.A = Pred.A + Resid.A (9)

When a secret bit is embedded in a block and propagated to A, the prediction is affected and the samples of A become:

Samp'.A = Pred'.A + Resid.A

Samp'.A = (Pred.A + Δ'A) + Resid.A

Samp'.A = Pred.A + (Resid.A + Δ'A) (10)

It is possible to preserve the initial samples of A if the residual data are modified at the encoding process such that the new residual data of A become:

Resid'.A = Resid.A - Δ'A (11)

At the decoder, the new samples become:

Samp''.A = Pred'.A + Resid'.A

Samp''.A = (Pred.A + Δ'A) + (Resid.A - Δ'A)

Samp''.A = Samp.A (12)

Thus, by subtracting the error from the residual data (R in Fig.2.(a)) at the encoding process it is possible to reduce the error propagation. However, the error cannot be eliminated as the quantization is an irreversible operation.

4.2 Proposed approach: Second scheme

The secret data are supposed beforehand encrypted to ensure their security. The embedding is performed in the quantized 4x4 luma DCT blocks. The proposed approach can be described in three parts: The embedding process, the compensating process and the extraction process.

In the embedding process, only one nonzero coefficient per block is watermarked as follows:

Let C be a quantized coefficient, C ≠ 0.

Case the embedded bit is 1:

If Cmod 2 =0 , if C > 0, C= C + 1 , else C = C -1 ,
M[Mb][Block]= 1 ,
If Cmod 2 =1 , C is not modified.

Case the embedded bit is 0:
If Cmod 2 =1, if C > 0, C= C + 1, else C = C -1,
M[Mb][Block]= 1,
If Cmod 2 =0 , C is not modified.

To apply the error compensation, a matrix M is defined. It is initially a matrix of zeros. Its role is to save all the macroblocks and the related blocks positions that may be concerned by the error compensation (the neighbouring blocks resented in Fig. 3 (b)).

For the compensating process, the following steps are applied.

Step 1:

The error is calculated for a watermarked block and the propagated error (Δ'A) is estimated for each possible prediction mode. For instance, if the block B2 is watermarked by adding 1 to DC coefficient, four samples from the matrix error and the error propagated to A are represented in Fig. 6 in case the best mode of A is the diagonal down left (see subsection 2.2).

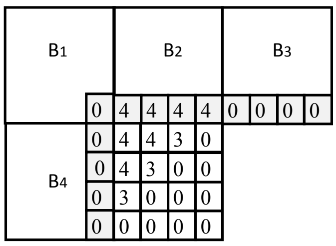


Fig. 6. Error samples (B2 watermarked in DC coefficient) and the error propagated to A by mode 3.

Step 2:

For a current block A, if M[Mb][Block] = 1, the block is concerned by the error compensation.

The error is subtracted from the residual matrix R (Fig. 2) obtained for the best mode, and new quantized coefficients are obtained after the transformation and the quantization.

At the decoder, the secret data are extracted easily from the watermarked blocks as indicated in the following expression:
If Cmod 2 =1, W =1; otherwise, W=0.

C is the nonzero watermarked coefficient.

5. RESULTS AND ANALYSIS

Tests have been performed on eight video sequences: Foreman, Silent, Mobile, Carphone, Salesman, Hall, Mother and Claire. The secret data are embedded in I frames, in the 4x4 DCT blocks. The codec configuration is shown in Table 3.

Table 3. H.264/AVC configuration.

Profile	Main profile
GOP	IBPBPBPBPBPBPBPBPBP BPBPBPBPBPB
Intra period	15
Frame rate	30 picture / second
QP	28
Source size	176 x 144 (QCIF)
Coded frame	299
Number of I Frames	10

A pseudo random binary sequence has been used as secret data which were inserted in I-frame according to the methods described previously, by integrating the algorithm in the H.264/AVC codec. The secret data are supposed to be encrypted before embedding to ensure security.

5.1 First Scheme

To embed secret data, the candidate blocks should contain a relatively large number N of nonzero coefficients. Three cases are considered: N>5, N>7 and N >9.

The objective quality is measured by the PSNR of the sequences as presented in Fig. 7. The increase of N implies a decrease of candidate blocks for watermarking which leads to an improvement of the video quality. It is clear that Hall sequence presents the highest PSNR degradation because of its large homogeneous areas. Subjectively, the degradation may be seen in some P frames, for N>5. Fig. 8 presents the unwatermarked and watermarked P frame (number 33) of Hall sequence.

Results show that the bitrate is maintained for all the sequences and for all the N values as represented in Fig. 9.

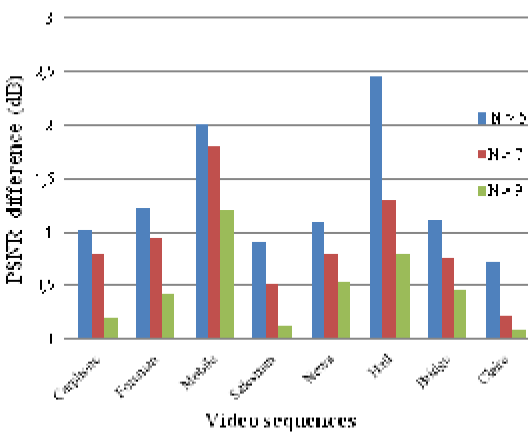
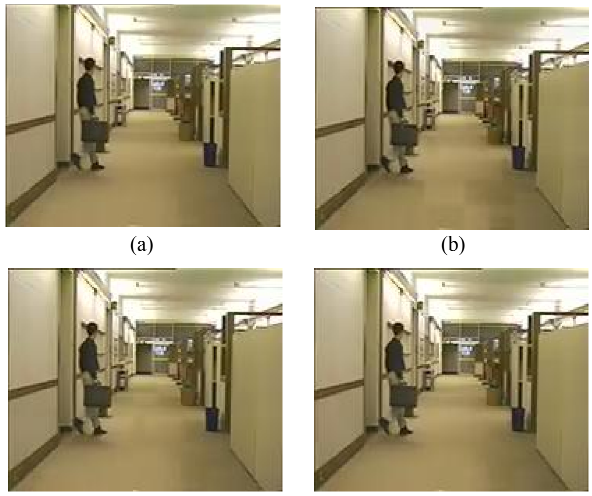


Fig. 7. PSNR differences measured for the eight sequences for N>5, N>7 and N>9.



(a) (b) (c) (d)

Fig. 8. Hall sequence, P-frame number 33 (a) unwatermarked frame, (b) watermarked frame (N>5), (c) watermarked frame (N>7), (d) watermarked frame (N>9).

Fig. 10 shows that the embedding capacity is obviously decreasing with the increase of N. However the sequence Mobile maintains a relatively high embedding capacity, this is due to its highly detailed texture.

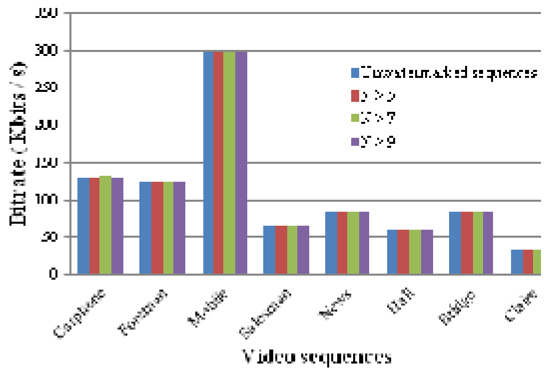


Fig. 9. The bitrate of the eight unwatermarked and watermarked sequences for N>5, N>7 and N>9.

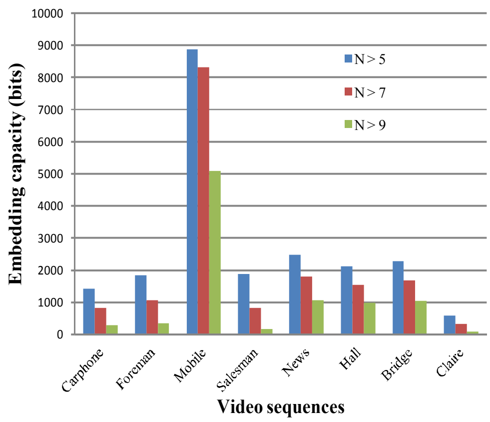


Fig. 10. The embedding capacity of eight watermarked sequences for N>5, N>7 and N>9.

5.2 Second Scheme

In order to choose the coefficient which would contain the watermark bit, tests have been performed for different positions of nonzero coefficients (for each test the same coefficient position is used in each block). Results have shown that it is possible to achieve an important improvement if the neighbouring blocks of a current watermarked block are not watermarked. In Fig. 11 and Table 4, results are presented for watermarking the first nonzero DC coefficients of each 8x8 block of the macroblock, which means four coefficients are watermarked in a macroblock.

The proposed approach provides a good video quality improvement as represented in Fig. 11. An example is given in Fig. 12 for the first frame of Mother sequence (the correction of the degradation can be seen in particular on the mother's cheek). The bitrate is maintained and sometimes reduced as presented for Mother sequence which gives also the highest embedding capacity. Indeed, in our experiments the embedding capacity doesn't depend on the video texture because the embedding is performed in DC coefficients.

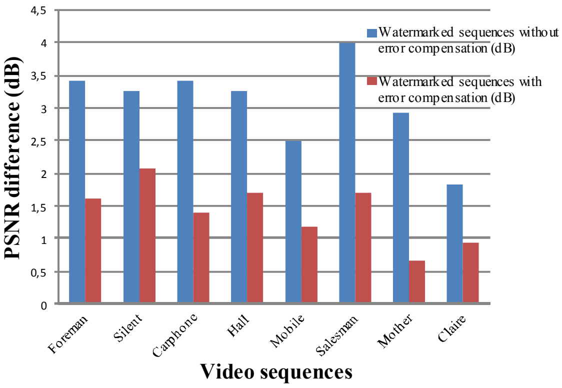


Fig. 11. PSNR differences measured for the eight sequences.

Table 4. Increase in bitrate and embedding capacity for eight video sequences.

Video sequences	Increase in bitrate (%)	Embedding Capacity (bits)
Foreman	0.06	1815
Silent	0.15	2315
Carphone	0.41	1663
Hall	0,32	1676
Mobile	-0.03	2852
Salesman	0.79	2234
Mother	-0.12	2913
Claire	0.26	782

5.3 Comparison with other methods

In Table 5, a comparison is presented between the proposed approaches and results presented in (Ma *et al.*, 2010) for four sequences, implemented in the same conditions.

(a) Unwatermarked frame.

(b) Watermarked frame without error compensation.

(c) Watermarked frame with error compensation.

Fig. 12. First watermarked I-frame of Mother sequence with and without error compensation.

In the first scheme, results are obtained for N equal to 7, and in the second scheme, they are obtained by watermarking only two bits per macroblock.

We notice, for both schemes that the proposed approaches present better results in terms of video quality, embedding capacity and especially maintaining the bitrate. This is mainly due to the fact that the zero coefficients are not used for embedding secret data. At the contrary, the algorithm proposed in (Ma *et al.*, 2010) may use the zero coefficients, otherwise, the embedding capacity would be very low since it won't be obvious to meet frequently the embedding conditions as explained in section 3.1.

In Table 6, a comparison is presented between the proposed approaches and results presented in (Huo *et al.*, 2011), implemented in the same conditions. For the first scheme, increasing the embedding capacity is linked to the availability of the paired coefficients; however it is possible to use more coefficients per macroblock in the second scheme. We notice that the second scheme gives better results than the first one in terms of embedding capacity. However, comparing to (Huo *et al.*, 2011) both of the proposed approaches seems to be more adaptable for the highly detailed sequences (such as mobile) for which the trade-off between the different data hiding characteristics is better reached. Indeed, for this sequence the embedding capacity can be increased while relatively maintaining the video quality. The bitrate is higher but remains less than 1 %. Besides, the proposed methods present the advantages to be readable and can be implemented during the encoding process for real time broadcasting.

Table 5. Comparison between the proposed approaches and (Ma *et al.*, 2010).

Sequences		Algorithm of Ma	Proposed approach	
			scheme 1	scheme 2
Carphone	Avg. capacity in I frame (bits)	806	816	844
	PSNR (dB)	42.9	43.03	43.07
	Bitrate increase (%)	3.24	0.35	0.35
Mobile	Avg. capacity in I frame (bits)	910	8311	1490
	PSNR (dB)	41.12	40.04	40.92
	Bitrate increase (%)	0.88	0.16	-0.04
Foreman	Avg. capacity in I frame (bits)	737	1059	904
	PSNR (dB)	42.72	42.69	42.89
	Bitrate increase (%)	3.16	-0.24	0.28
Salesman	Avg. capacity in I frame (bits)	936	833	1155
	PSNR (dB)	38.58	39.86	39.65
	Bitrate increase (%)	7.17	0.2	0.28

Table 6. Comparison between the proposed approaches and (Huo et al.(2011)).

Sequences		Algorithm of Huo	Proposed approach	
			scheme 1	scheme 2
		Detectable	Readable	
Mobile	Avg. capacity in I frame (bits)	672	700	870
	PSNR (dB)	38.61	37.65	37.25
	Bitrate increase (%)	0.40	0.80	0.84
Foreman	Avg. capacity in I frame (bits)	428	218	400
	PSNR (dB)	40.58	42.43	36.83
	Bitrate increase (%)	1.28	1.26	1.29

6. CONCLUSION

In this paper, new approaches aiming to limit the distortion drift were proposed for the H.264/ AVC. These methods are based on a prior measurement of the error signal in a paired-coefficient watermarked block or in the neighbouring blocks.

Both schemes are applied during the encoding process, they are convenient for real-time video broadcasting and they achieve a relatively high embedding capacity for negligible PSNR decrease and a maintained bitrate, particularly for highly detailed sequences.

As perspectives for the first scheme, it would be interesting to investigate the possibility of collecting information on blocks that have not been yet coded for a better choice of the paired-coefficients to be marked during the encoding process.

For the second scheme, the texture-based visual models may improve considerably the results. This scheme leads also to interesting perspectives related to correcting the drift distortion when the secret data are embedded in DC coefficients which could enhance the robustness of watermarking methods based on embedding data in low frequencies.

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