Error detection by fragile watermarking*

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Abstract Error concealment techniques are useful in video transmission over channels that introduce bit errors. The efficiency and result of error concealment technique, however, rely on the error detection capabilities of video decoders. A novel error detection technique employing fragile watermarking is proposed in this paper. By embedding a fragile watermark on the quantized DCT coefficients and examining its integrity on the decoder side, the error detection capability of video decoders is significantly increased compared to widely used syntax-based error detection schemes.

Keyword fragile watermark, watermarking, error detection, error resilience

1. INTRODUCTION

In video communication over error-prone transmission channels, various random bits and burst errors are introduced, impeding the correct transmission of compressed video streams. There are many approaches to make video streaming more resilient to channel degradations, such as (i) error correction and data interleaving [1], typically Forward Error Correction (FEC), (ii) error detection and localization at channel coding level [1] and (iii) resynchronization and data partitioning [2]. These approaches are designed to detect and correct the errors before streams are passed to video decoder, without interpreting the syntax of data.

However, undetected (transmission) errors remain to exist in the compressed bit stream that is offered to the decoder. For that reason, also the video decoder itself has to be prepared to detect and conceal any remaining errors. Since normally error concealment techniques are applied at macro block (MB) level, we are concerned with error detection and localization at macro block level in this paper.

In a typical motion-compensated DCT-based compression system, the following *syntax based* bit stream error detection techniques are commonly employed: (a) motion vectors are out of range; (b) invalid VLC table entry is found;(c) DCT coefficient is out of range;(d) number of DCT coefficients in an 8x8 DCT-block exceeds 64; (e) quantizer scale factor is out of range.

Unfortunately, syntax-based error detection in decoder has two significant disadvantages, namely:

(1) The error detection rate is low typically between 15 and 40 percent; in this paper, we define
error detection rate = detected error slices (MB line) / total error slices

(2) The rate at which errors are correctly located is very low, typically between 5 and 15 percent. As a consequence, many MBs that have not been found to be incorrect, as still decoded incorrectly and cannot be concealed (See figure 1). This phenomenon is called detection lagging, causing visually very significant degradations. In this paper, we define
error correctly located rate = non-lagging detected error slices / total error slices

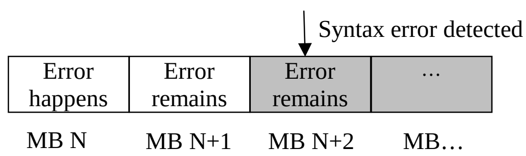

Figure 1. *Detection lagging demonstration*

In a recent proposal [3], it was shown that the error detection capabilities of video decoder can be

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increased by embedding additional data (in the form of a watermark) into compressed video stream. However, a 2 dB encoding PSNR loss was reported for Akiyo sequence after employing the "DEMVRC" technique. In section 2, we first describe the idea of video decoder-based transmission error detection and localization using *fragile watermarking.* A scheme employing a special watermark is proposed. In section 3, we will consider the performance of the fragile watermark on error detection ability and the increase in mean squared error (MSE_{DCT}) due to the watermark embedding. Then section 4 provides simulation results.

2. PROPOSED TECHNIQUE

2.1. General approach

In the proposed technique, the encoder puts a fragile watermark on the Q-DCT coefficients before these are passed to the Variable Length Coding (VLC) encoder. The watermark embedding is carried out within the motion-compensation loop as so to avoid degradations due to drift. The structure of a MC-DCT-VLC based encoder using the proposed fragile watermarking technique is shown in figure 2. On the decoder side, the watermark is detected directly on the Q-DCT coefficients. Since the watermark is fragile, any remaining transmission errors in the compressed video bit stream will corrupt the watermark, in this way enabling the decoder to perform the precise detection and localization of the erroneous MBs.

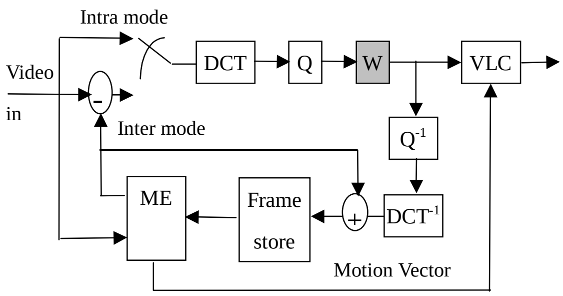

Figure 2. *Structure of the MC-DCT-VLC based encoder employing proposed technique*

Irrespective of the watermarking technique used, a trade-off has to be made between the increase in the probability of transmission error detection and the decrease of the visual quality. In particular case, the quality of the frame under consideration is decreased somewhat after watermark embedding, thus the prediction for the next frame may be affected negatively, increasing the required bit rate for a given quality level. In band-limit application case, the watermark embedding should not result in an unacceptable increase on the bit rate.

2.2. Proposed scheme

This proposed scheme embeds and detects fragile watermark on Q-DCT coefficients of 8x8 blocks. On encoder side, a watermark is embedded onto Q-DCT coefficients of every *coded* 8x8 blocks. Then these watermarked data continue their way towards motion compensation and VLC. On decoder side, the integrity of the watermark is examined on Q-DCT coefficients of decoded 8x8 blocks. If the watermark is corrupted, the 8x8 block under consideration is detected as erroneous. Otherwise the block is assumed to be correct.

The fragile watermark used in this scheme is shown below; all Q-DCT coefficients in an 8x8 block after a defined zig-zag scan position pos are modified to nearby *smaller* even numbers. The predefined value pos may be different according to intra/inter coding mode, Y/C block or the quantization parameter in encoder. Hence the watermarking procedure is given as:

for i = pos to 64

$$AC_i^w = AC_i - sign(AC_i) \times W(AC_i)$$

end

$$Watermarking: W(x) = \begin{cases} 0 & if\ |x|\ is\ even \\ 1 & if\ |x|\ is\ odd \end{cases}$$

Watermark sequence $\overline{w}(i), i = pos, \ldots 64$ is detected on the watermarked Q-DCT coefficients of 8x8 block on decoder side. To assess the extent of error, the error assessment function (EAF) is calculated. An error is reported to the decoder if EAF is bigger than a pre-defined threshold *T*, otherwise it is defined that those data with embedded watermark is free of error. In this paper, we only concern the case that *T* = 0.

$$EAF(\overline{w}) = \frac{1}{L}\sum_{pos}^{64}\overline{w}(i) \le T \qquad L = 64 - pos$$

3. PERFORMANCE ANALYSIS

In this section we consider the performance of the watermark, i.e. the trade-off between the error detection rate and the loss in image quality denoted by MSE_{DCT}. Firstly we assess the performance of the proposed scheme as a function of the system parameters. We model the distortion on the Q-DCT coefficients after transmission as a zero mean additive Gaussian noise (AGN) with variance σ_n^2 for the worst case. Thus the effects of the damage on a given coefficient could be seen as

$$\overline{AC_i}^w = AC_i^w + sign(n_i)\times\lfloor |n_i| + 0.5\rfloor$$

where AC_i^w is the undistorted watermarked Q-DCT coefficient and $\overline{AC_i}^w$ is the distorted one. n_i is a zero mean AGN with variance σ_n^2. Hence, the probability that watermark is not damaged on this coefficient is:

$$P\{w(i)=0\} = P\left\{\left(\overline{AC_i}^w + AC_i^w\right) \bmod 2 = 0\right\}$$

$$= erf\left(\frac{1}{2\sqrt{2}\sigma_n}\right) + \sum_{k=1}^{\infty}\left[erf\left(\frac{2k+0.5}{\sqrt{2}\sigma_n}\right) - erf\left(\frac{2k-0.5}{\sqrt{2}\sigma_n}\right)\right]$$

Hence with some derivations, we can have error detection probability of a watermarked MB as (1):

$$P_{ed\_MB} = P\left\{EAF\left(\overline{w}\right) > 0 \mid \overline{AC}^w \neq AC^w\right\}$$

$$= \frac{1 - \left\{erf\left(\frac{1}{2\sqrt{2}\sigma_n}\right) + \sum_{k=1}^{\infty}\left[erf\left(\frac{2k+0.5}{\sqrt{2}\sigma_n}\right) - erf\left(\frac{2k-0.5}{\sqrt{2}\sigma_n}\right)\right]\right\}^{6L}}{1 - \left[erf\left(\frac{1}{2\sqrt{2}\sigma_n}\right)\right]^{384}}$$

We apply the Expectation of Mean Square Error of DDCT coefficients, namely $E(MSE_{DCT})$, when studying the image visual quality loss between *unwatermarked but quantized* images and *watermarked and quantized* image. Here, we only consider the loss on intra-block; the loss on inter-block could be derived in similar way. In [4], it is shown the original non-dc DCT coefficients could follow Laplacian distribution. This knowledge, joint with the known quantization function and watermarking function, lead to the result of $E(MSE_{DCT})$ (see formula (2)). If visual weighted factors are included in the expression, a better result could be achieved.

$$E\left(MSE_{DCT}\right) = \sum_{i=pos}^{64} E\left(\left|2QP\left(AC_i - AC_i^w\right)\right|^2\right)$$

$$= 4QP^2 \sum_{i=pos}^{64}\left(2\sum_{k=1}^{\infty}\int_{(2k-1)2QP}^{4kQP}\frac{\lambda_i}{2}e^{-\lambda_i x}dx\right) \qquad (2)$$

$$= 4QP^2 \sum_{i=64-L}^{64}\frac{e^{-\lambda_i 2QP}}{1+e^{-\lambda_i 2QP}}$$

From (1) and (2), we can have the relationships between L and watermark's sensitivity to channel error (namely fragility), L and loss in $E(MSE_{DCT})$. In additional, figure 4 shows the tradeoff between $E(MSE_{DCT})$ and P_{ed_MB}, and the QP's influence on the performances.

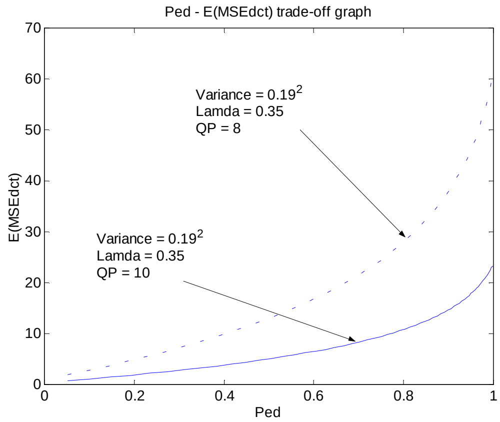

Figure 4. *Tradeoff between $E(MSE_{DCT})$ and P_{ed_MB}*

4. SIMULATION RESULT

In simulation, a 240 frames Car Phone sequence in CIF format is passed into the TMN8[5] H.263 encoder (one example of hybrid coders) employing watermarking module following the structure in figure 2. The coded stream is then sent to a BSC (Binary Symmetric Channel) with a random bit error rate 5×10^{-4}. Finally, the stream arrived at a H.263 decoder. We apply watermark detection scheme, and error concealment scheme in the decoder. For comparison, the simulation result for the syntax-based scheme is also given. The reason that BSC is applied here is that, we assume that under protection of FEC and interleaving, a real channel can be equivalent to a BSC channel. We assume the remaining random bit error rate for video steams is 10^{-3}~10^{-4}.

We select QP as 10 for both intra-/inter-frames, coding frame rate is 30 frames/s. For watermarking, pos is select as 37 or 22. To focus on erroneous Q-DCT coefficients detection ability, we only cast bit error on those bits that represent Q-DCT coefficients, and leave motion vectors and header information untainted. The frames are coded in IPPPP… format.

For different schemes, error detection rate (E.D. rate), error correctly located rate (E.C.L. rate) and *encoding* $\overline{PSNR}$ without/after watermark embedding are listed in table. Also, the 180th reconstructed frames applying different error detection schemes only are shown in figure 5, simple copying from the previous frame is serving as the error concealment technique here.

From the results, it is shown the proposed scheme can improve the E.D. rate with an extra 28%~62%, the E.C.L rate with an extra 400%~700%, comparing with the syntax based error detection scheme. While $\overline{PSNR}$ loss is within 0.5 dB, complexity is low and coded bit rate does not increase. For the proposed scheme, when pos decrease, the coding $\triangle\overline{PSNR}$ go increasing, while the E.D. rate and E.C.L. rate go up. This result provides a cross check for the statement that it is a trade-off between the increase in probability of transmission error detection and the decrease of visual quality, noted in section 2.1 and sectio n 3.

Table 1. *Simulation results comparison*

Error detection scheme	$\overline{PSNR}$ (dB)	$\triangle\overline{PSNR}$ (dB)	Bit rate (Kbits/s)	E.D. rate (%)	E. C. L. rate (%)
Syntax based	35.36	--	333.76	37.0	4.9
P. S. (*pos=37*)	34.78	0.28	313.71	47.45	28.31
P. S. (*pos*=22)	34.51	0.46	306.62	63.12	40.35

5. CONCLUSION

In this paper, a watermark based transmission error detection technique is proposed, performance analysis for watermarking under some assumptions is provided and simulation results are listed. In the proposed technique, it is a good trade-off between the watermark's fragility and the loss in visual quality due to watermark embedding, less than 0.5 dB loss is reported while the detection gain are 28%~62% for the error detection rate and 400%~700% for the error correctly located rate, comparing to the syntax based scheme. The simulation results show that proposed scheme has good performance and low cost. In addition, the technique has good enough compatibility, which means the corresponding watermark detection module is not required for decoding watermarked video streams. And it can be applied combining with other techniques for better error resilience performance, FEC for example, or be used independently.

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a) Apply syntax-base error detection scheme (Y/Cb/Cr PSNR =19.97/27.85/32.21dB)

b) Apply proposed scheme ($pos = 22$) (Y/Cb/Cr PSNR =27.69/36.22/38.45dB)

Figure 5: *Reconstructed frame applying different error detection schemes only*