A SYNCHRONOUS FRAGILE WATERMARKING SCHEME FOR ERRONEOUS Q-DCT COEFFICIENTS DETECTION*

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ABSTRACT

In video communications over error introducing channels, error concealment techniques are widely applied in video decoder for good subjective images output. However, a damaged MB could be concealed only after it is detected as erroneous. Because of the poor performance of the traditional syntax based error detection schemes, the error concealments thereafter show bad results. Our previous work explored the potential of transmission error detection by *fragile* watermarking. In this paper, a synchronous fragile watermark based transmission error detection scheme for hybrid decoder is proposed. By watermarking, we enforce a synchronization signal like correlation on Q-DCT coefficients. Thus the decoder *could* use this pre-forced information for detecting errors. The simulation results show that the erroneous Q-DCT coefficients detection capabilities are largely improved compared to syntax-based scheme.

Keywords: watermarking, fragile watermark, error detection, error resilience

1. INTRODUCTION

In video communication system, due to Motion Compensated (MC) Inter Frame Prediction and Vary Length Coding (VLC) techniques employed by many highly efficient video coding standards, such as H.26x [1] and MPEG-x[2], the compressed video streams are highly sensitive to channel errors. While in many cases, the real channels do introduce vast errors; the correct video transmission will crash if no protection against errors is applied.

There are many error resilience techniques designed for resolving that challenging problem. Other than error correction and interleaving techniques, error detection and error concealment techniques are usually employed in video decoders. When a Macro-block (MB) is damaged due to channel degradations, if the video decoder detects this erroneous MB, the content-dependent concealment actions, such as resynchronization or temporal interpolation, so as to make the decoded video look more comfortable. Clearly, the efficiency and results of the error concealment rely on the error detection performance. Typically, error concealment techniques are applied at MB level. So, in this paper, we only concern the error detection at MB level.

In a typical system that employed DCT transform, MC and VLC, following syntax checks are often applied in video decoders to detect bit stream error.

- Motion vectors is out of range
- DCT coefficients is out of range
- Invalid VLC table entry is found
- The number of DCT coefficients in an 8x8 block exceeds 64
- Quantizer scale factor is out or range

Due to the bits to represent Q-DCT coefficients is normally significantly more than the bits represented header information and motion vector (MV) information, the Q-DCT coefficients are much easier to be damaged by channel bit errors. So, the error detection scheme should have the ability to well detect erroneous Q-DCT coefficients. Error detection by these syntax checks, however, has significant disadvantages on detecting erroneous Q-DCT coefficients, namely low error detection rate (E.D.R.) and low error correctly located rate (E.C.L.R.). Those disadvantages are showed in [3]. Besides the discussions in [3], it is also difficult for syntax checks to detect shift phenomenon and thus difficult to conceal it. A shift phenomenon is shown below.

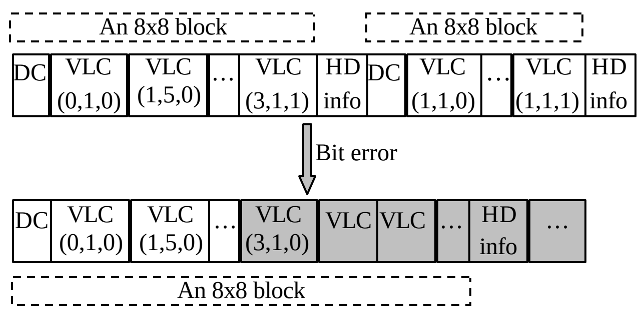


Figure 1. A *Shift phenomenon: An 8x8 block is "removed"*

When a bit error happens in a VLC code word, it may cause the code word changes to a new one with same length, run and level value but different last value. In such case, an 8x8 block is "inserted" into the bit stream if the last value changes from zero to one; an 8x8 block is "removed" if the last value changes from one to zero. This phenomenon is called shift. In the particular case that the bit error only results in combining two 8x8 blocks and keeping data in other 8x8 blocks untainted, the bit stream may be correct in syntax but will cause MB shift all over a slice. Consider the MC used in video decoder, unacceptable reconstructed images would be produced.

In summary, to detect transmission error only by syntax checks is not good enough. Recent contributions [3]-[6] explore the potential of detecting transmission error by watermarking. The idea in [5] and [6] is to employ robust watermarking into error detection. In this paper, followed the basic idea in [3] that introduce fragile watermarking into error detection, we propose a synchronous signal like fragile watermarking scheme for

* This work is supported by NSFC and Advanced Research Project of University

detecting erroneous quantized DCT (Q-DCT) coefficients, namely FZW. Analysis on the PSNR loss due to watermarking is also provided in section 2. Section 3 gives out simulation results, followed by a summary in section 4.

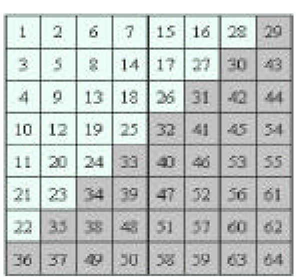
2. Force Zero Watermarking (FZW) SCHEME

2.1 Description of the technique

The scheme proposed here follows the work in[4], and it fragile watermarking the 8x8 blocks to improve error detection capabilities of video decoder. The watermarking makes a zero coefficients sequence in Q-DCT coefficients before they are passed to VLC, this zero sequence can serve as a synchronous signal when decoding the streams. Since error in VLC code words would cause the *run/last* value to change, the synchronous signal may be damaged if a non-zero coefficient exists in the sequence. Hence, by checking this signal, the video decoder could detect the error happened at 8x8 block level. The description of the scheme is:

- ***On encoder side***, a special watermark is forced into Q-DCT coefficients of any coded 8x8 blocks, before these coefficients are passed to VLC. To avoid drift, the watermarking procedure is included in MC loop.
- ***On decoder side,*** after an 8x8 block is decoded, the synchronous signal (zero sequence) is check in Q-DCT coefficients. An error is reported if the signal is damaged; otherwise, current 8x8 block is assumed to be correct. A MB is assumed to be a correct one only if all 8x8 blocks inside are detected as correct.

For the 64 Q-DCT coefficients in an 8x8 block, the watermarking procedure force zero on the coefficients from AC_{pos} to AC_{64} (Fig. 2). Clearly, the parameter *pos* control the visual quality loss due to watermarking, and it could vary due to intra-/inter- block or Y/C block. The *pos* also determine the fragility of the watermark. The decrease of the *pos* makes the zero coefficients sequence longer, thus more sensitive to VLC code word errors. It is a trade-off when select parameter *pos*, this kind of trade-off between the increase of error detection capabilities and visual quality loss has been discussed in [3].



$$\rightarrow \sum_{i=pos}^{64} |AC_i| = 0$$

Figure 2. FZW Watermarking *illustration*

In the case that most Q-DCT coefficients in an 8x8 block are zeroes, the watermarking procedure may affect no coefficient. This 8x8 block is then thought as " originally watermarked" since it fits the forced correlation the watermarking procedure want to cast on it. So not surprising, the error detection procedure works well under such situation.

Due to cutting off some coefficients, the quality of the frame under consideration is decreased a little after watermark embedding, thus the prediction for the next frame may be affected negatively, increasing the required bit rate under a given quality level. Yet, the simulation results show that the select watermark would not increase the coded bit rate to an unacceptable level, which is important in video transmission over band-limit channels. For the proposed scheme, it is a trade-off between the increase in probability of transmission error detection and the decrease of visual quality, similar to the one noted in [3].

2.2 Analysis on *PSNR* loss after watermarking

In this section, we consider the visual quality loss on the images due to watermarking as a function of system parameters. We firstly explore the relationship between the expectation of Mean Square Error of DCT coefficients, namely $E(MSE_{DCT})$ and watermarking parameters *pos* and quantization parameter QP. Then with the acknowledgement that DCT is a linear orthogonal transformation, we know the MSE_{DCT} is exactly the MSE on spatial domain. Hence, we can calculate the *PSNR* between quantized but unwatermarked images and quantized and watermarked images using $E(MSE_{DCT})$.

In [7], it is shown that the non-dc DCT coefficients in intra-blocks could follow Laplacian distribution. From section 2.1, we know after watermarking, all non-zero coefficients after zig-zag index *pos* are forced to zero. If we only concern the quantization function using in intra-block in TMN8[8], the expectation of square error between quantized coefficient AC_i and quantized-watermarked coefficient AC_i^w (i>*pos*) is:

$$\begin{aligned} E\left(\left|AC_i - AC_i^w\right|^2\right) &= E\left(AC_i^2\right) \\ &= 2\sum_{k=0}^{\infty}\int_{2kQP}^{2(k+1)QP}(k)^2 \frac{l_i}{2} e^{-l_i x}dx \qquad (1) \\ &= e^{-2QP\,l_i} + \frac{3e^{-4QP\,li}}{1-e^{-2QP\,li}} + \frac{2e^{-6QP\,li}}{\left(1-e^{-2QP\,l_i}\right)^2} \end{aligned}$$

where $l_i \quad i = pos, pos+1, \ldots 64$ are the parameters of Laplacian distributions of different index unquantized AC coefficients. Hence, the $E(MSE_{DCT})$ could be calculated as (2):

$$\begin{aligned} E\left(MSE_{DCT}\right) &= \frac{1}{64}\times \\ &\sum_{i=pos}^{64}\left[E\left(4QP^2AC_i^2\right) + 4QP^2 E\left(\left|AC_i\right|\right) + p\{AC_i \neq 0\}QP^2\right] \\ &= \frac{1}{8}QP^2\sum_{i=pos}^{64}\left[e^{-2QPli} + \frac{2e^{-4QPli}}{1-e^{-2QPli}} + \frac{e^{-6QPli}}{\left(1-e^{-2QPl_i}\right)^2}\right] + \frac{1}{64}QP^2e^{-2QPli} \end{aligned}$$

Then as mentioned above, the MSE_{DCT} is equal to MSE on spatial domain; hence, the PSNR between quantized-unwatermarked images and quantized-watermarked images due to watermarking can be calculated as below:

$$PSNR = 10\log_{10}\left[\frac{255^2}{E\left(MSE_{DCT}\right)}\right] \qquad (3)$$

To verify the correctness of formula (3), the relationship between *PSNR* and the watermark parameter *pos*, a result is given by using TMN8 codec to encode Cost Guard CIF sequence. In experiment, the *PSNR* between quantized-unwatermarked and quantized-watermarked intra frames are calculated, with watermarking parameter *pos* varies from 24 to 44. Then, with the parameters l_i $i = pos, pos + 1, ...64$ by statistics, a theoretic curve is provided using formulas (2) and (3). From Fig 3, it is shown that these curves are quite match. While for the sequence that its DCT coefficients are not strictly follow the Laplacian model, it is possible for the curves do not match well. In those case, better result could be retrieved if more sophisticated model is applied, Generalize Gaussian Distribution for example, however the method here to calculate the visual quality loss is making sense. With (2) and (3), if all the parameters in the formulas are known, we can evaluate the visual quality loss performance of the watermarking. At the same time, if the *PSNR* is pre-set, we can get the minimum value that the watermarking parameter *pos* could be set under the constrain, which is exciting when designing the watermark.

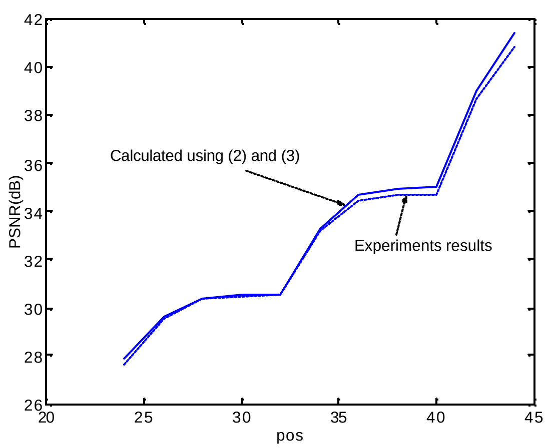


Figure 3. *Visual quality loss due to watermarking (QP=10)*

3. SIMULATION RESULTS

In simulation, we choose modified TMN8 as video codec. In encoder, watermarking module is included follow the structure shown in [3]. In decoder, the corresponding watermark-detecting module and syntax based error detection module are implemented. After video sequence is encoded, the coded stream is sent to a Binary Symmetric Channel (BSC) with a random bit rate $5e^{-4}$ and then arrived at the decoder. BSC is applied here because we assume under protection of error correction techniques and interleaving, a real channel can be equivalent to a BSC channel. We assume the remaining random bit error rate for steams is 10^{-3}~10^{-4}. We select QP as 10 for both intra-/inter-blocks; coding frame rate is 30 frames/s. For watermarking, the parameter *pos* is select as 44 for intra-Y-blocks, 29 for inter-Y-blocks, 29 for intra-C- blocks or 16 for inter-C-blocks. 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.

In order to test the robustness of the proposed scheme, three standard video test sequences with different complexity are used in simulation. These sequences are 240 frames Akiyo, Mother and Daughter and Car Phone, all in CIF format. For different schemes, E.D.R., E.C.L.R. and *encoding PSNR* without/after watermarking are listed in Table 1-3. And Fig. 4 shows the error detection rate distribution graph as the error detected relative position varies. From Fig. 4, it is shown that by detecting the forced synchronous signal, the decoder significantly improved the E.C.L.R.. So it is expected that the proposed scheme could detect the kind of bit error mention in Fig. 1 and avoid shift phenomena to exist.

From the results, it is shown the FZW scheme can improve the E.D.R. with an extra 52%~95%, the E.C.L R. with an extra 270%~700%, comparing with the syntax based error detection scheme. While *PSNR* loss is minor, complexity is low and coded bit rate does not increase. Figure 5 show the *Y-PSNR* comparison of the reconstructed images on encoder/decoder side with only different error detection schemes. For error concealment, simple copying from previous frame is applied. In simulation, no error is cast on the bits that represent the first intra-frame data. Also, a sample reconstructed frame applied different error detection scheme only is shown in Fig. 6 for subjective results comparison.

Table 1. *Akiyo*

Error detection scheme	$\overline{PSNR}$ (dB)	$\triangle\overline{PSNR}$ (dB)	Bit rate (Kbits/s)	E.D. rate (%)	E. C. L. rate (%)
Syntax based	36.45	--	92.56	28.9	11.3
FZW	35.82	0.37	87.29	55.04	42.64

Table 2. *Mother and Daughter*

Error detection scheme	$\overline{PSNR}$ (dB)	$\triangle\overline{PSNR}$ (dB)	Bit rate (Kbits/s)	E.D. rate (%)	E. C. L. rate (%)
Syntax based	34.95	--	158.14	31.1	6.0
FZW	34.62	0.31	155.20	60.62	44.02

Table 3. *Car Phone*

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
FZW	34.08	0.67	291.22	56.29	39.77

4. SUMMARY

In this paper, a synchronous fragile watermarking scheme, namely FZW, for detecting erroneous Q-DCT coefficients is proposed. We also provide analysis for visual quality loss due to watermarking under some assumptions. With the expression derived, the value range that the watermarking parameter could choose can be calculated when visual quality loss is pre-defined. The more precise result could be derived using more sophisticated model (GGD for example), thus it can be applied in wider range. The simulation results show that less than 0.7 dB loss is reported while the error detection capabilities gain are 52%~95% for the error detection rate and 270%~700% for the error correctly located rate, comparing to the syntax based scheme. Thus would improve the efficiency and results of the error concealment techniques.

Though the FZW scheme now works with Q-DCT coefficients only, future work would explore the ability of detect erroneous header information and MV information by fragile watermarking. At current time, the FZW scheme can work with syntax check for detecting all these kinds of error. Under a pre-defined visual quality loss requirement, the watermarking parameter *pos* may vary when QP changes. Hence, a look up table for these two elements should be applied in the applications that employ bit rate control scheme.

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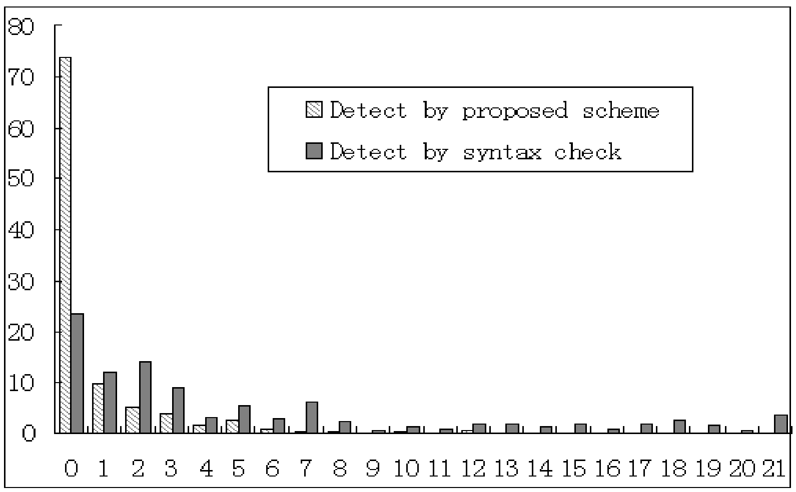

Figure 4. *Horizontal: relative position between error detected position and error occurred position. Unit: MB Vertical: ratio of error detected at current relative position divided by total error detected. Unit: %*

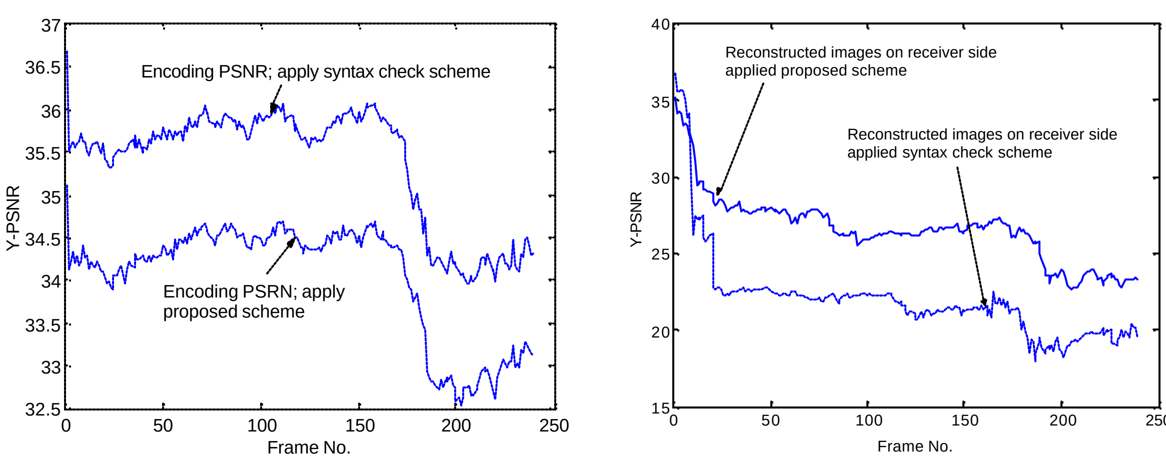

Figure 5. *Encoding/reconstructed Y-PSNR comparison under different error detection scheme only*

a) Apply syntax based scheme

b) Apply proposed scheme

Figure 6. *The 180th reconstructed frames applied different error detection scheme only*