A Reversible Watermarking Algorithm in the Lossless Mode of HEVC

KwangHyok Jo, Weimin Lei, Zhaozheng Li, and Xiaoshi Song
(Corresponding author: Weimin Lei)

School of Computer Science and Engineering, Northeastern University
Shenyang 110169, China
(Email: leiweimin@ise.neu.edu.cn)
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Abstract

Reversible watermarking is considered to be an effective approach for copyright protection. However, it requires much more embedding capacity. To solve the problem, we consider reversible watermarking in the HEVC lossless mode which bypasses all nonreversible operations to improve the embedding capacity. Further, to prevent the performance loss of compression efficiency, the residual sample-based prediction method is applied together with the reversible watermarking. It is shown that the proposed algorithm not only provides enough space for embedding but also has the controlling capability. In addition, it does not degrade the performance of compression efficiency.
Keywords: HEVC; Information Hiding; Reversible Watermarking; Watermarking

1 Introduction

With advances in digital video service and digital video processing technology, legitimate video propagation is at great risk due to the ease of manipulation, tampering, redistribution and illegal copying of digital media. As such, the protection and enforcement of intellectual property rights for digital media has become an important issue. Watermarking technology plays an important role in securing multimedia data against illegal recording and retransmission [14]. Particularly, over recent years, a special kind of digital watermarking, namely the reversible watermarking, has been extensively studied, which not only provides the protection of copyright by embedding the assigned watermark into the original media but also enables the recovery of the original media from the suspected media [8, 12]. Therefore, the reversible watermark can be used to determine the ownership of the digital media by comparing the retrieved watermark with the assigned one. It is worth noting that despite its advantages, the reversible watermarking schemes may suffer certain performance loss due to the fact that additional recovery information has to be embedded into the original media. As such, how to guarantee the accuracy of the retrieved watermark under the constrained embedding capacity is considered to be the main challenge in the design of reversible watermarking.

High efficiency video coding (HEVC) [15], also known as H.265 and MPEG-H Part 2, is a loss video compression standard developed by Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T Video Coding Experts Group (VCEG) and ISO/IEC Moving Picture Experts Group (MPEG). Particularly, with almost twice the compression efficiency of the previous standard, *i.e.* H.264/AVC, HEVC has been widely applied in recording, compression, and distribution of high-resolution video contents [4, 9, 10]. It is worth noting that for applications such as medical imaging, preservation of artwork, image archiving, remote sensing, and image analysis, lossless compression is required. As such, with growing demand for these applications, the HEVC standard has specified the HEVC lossless mode to enable the lossless compression. It is also worth noting that HEVC lossless mode is achieved by skipping the transform, quantization, and in-loop filtering operations [1, 11].

In this paper, under the lossless mode, we propose a reversible watermarking algorithm for HEVC in lossless mode. It is worth noting that HEVC lossless mode bypasses all nonreversible procedures such as transform, quantization, the inverse operations, and all in-loop filtering operations including de-blocking filter, sample adaptive offset (SAO), and adaptive loop filter (ALF) in the encoder and decode. As such, under the HEVC lossless mode, the original video can be successfully retrieved from the watermarked video without any loss. It is shown that the proposed algorithm not only provides enough space for embedding of desired payload but also has the capability of controlling embedding capacity. In addition, compared with the HEVC lossless mode, the proposed algorithm does not degrade the performance of compression efficiency.

The remainder of this paper is organized as follows. In

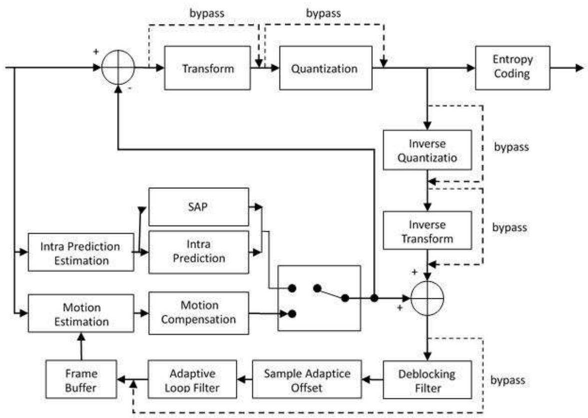

Figure 1: The framework of the HEVC lossless mode

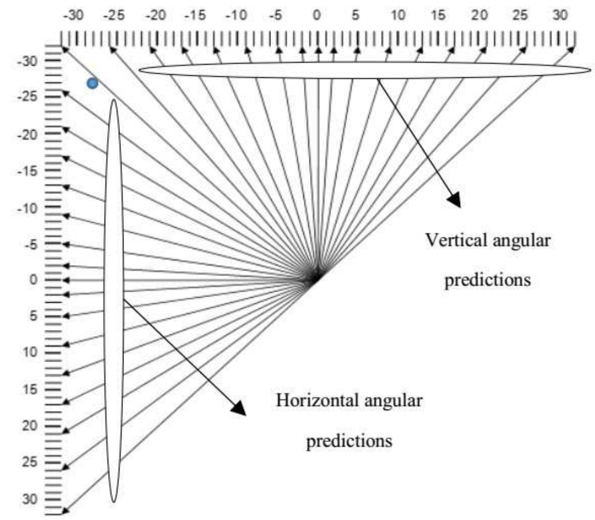

Figure 2: Angular intra prediction angle definition in HEVC

Section 2, a briefly overview of the HEVC lossless mode including its structure and base coding modules is presented. In Section 3, we analyze the distribution characteristics of prediction residual in the HEVC loss-less mode and the reversible watermarking algorithms for spatial domain. In Section 4, a reversible watermarking algorithm in the HEVC lossless mode is proposed. In Section 5, the feasibility and the performance of the proposed algorithm are verified through experiments. Finally, conclusions are presented in Section 6.

2 HEVC Lossless Coding Mode

2.1 Overview of the HEVC Lossless Mode

The overall structure of the HEVC lossless mode is shown in Figure 1. In Figure 1, dashed lines represent the bypass. It is assumed that all bypass operations are activated in the HEVC lossless mode [2].

In lossless coding, no distortion is allowed in reconstructed frames. Therefore, to achieve lossless coding, transform, quantization, their inverse operations, and all in-loop filtering operations including de-blocking filter, sample adaptive offset (SAO), and adaptive loop filter (ALF) are bypassed in the encoder and decoder since they are not reversible in general. Also, sample-based angular prediction (SAP) is applied to re-place the existing intra prediction method.

The design principle of HEVC lossless mode is to leverage the existing HEVC loss coding structure and to maximize logic sharing with the existing HEVC coding tools. As such, the implementation of HEVC lossless coding are subject to this special constraint in addition to common complexity and coding efficiency tradeoff consideration. The main coding modules of the HEVC lossless mode is described in detail in the following subsection.

2.2 Main Coding Modules of the HEVC Lossless Mode

2.2.1 SAP: Sample-Based Angular Prediction

As was noted previously, the transform and quantization operations are bypassed in lossless coding. Thus, for a pixel sample within a prediction unit (PU), the samples in its neighboring blocks as well as the immediate neighboring samples within the PU can be utilized for prediction. In order to explore spatial sample redundancy in intra-coded frame, SAP is employed instead of general HEVC intra prediction. As shown in Figure 2, 33 angles are defined and these angles are categorized into two classes: vertical and horizontal angular prediction.

The main idea of SAP is to use two neighboring samples in its top row as its reference samples to predict the current pixel when the prediction direction is vertical angular prediction and use two neighboring samples in its left column as its reference samples to predict the current pixel when the prediction angle is horizontal angular prediction. The SAP method can improve coding performance significantly.

2.2.2 Residual Sample-Based Prediction

The residual sample-based prediction was proposed as a method for enhancement of compression performance of HEVC lossless mode [3]. The flowchart of the residual sample-based prediction is shown Figure 3.

As shown in Figure 3, the residual sample-based prediction is implemented as a separate module. In this method, sample-based prediction is performed on the prediction residues without any modification to the existing intra prediction process. Also, the sample-based prediction process does not depend on the intra prediction mode and color component, the same prediction process is applied to all intra residual samples.

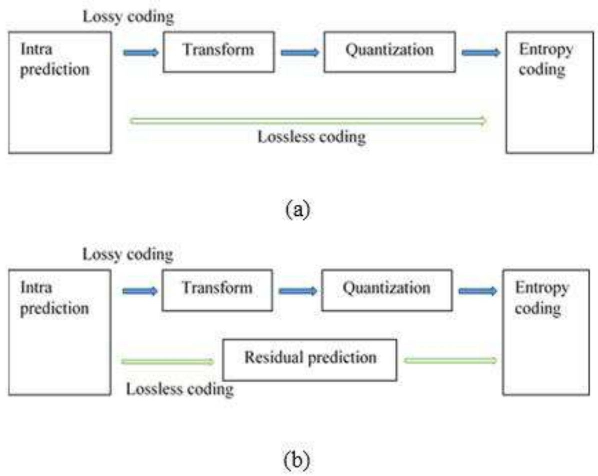

Figure 3: The framework of the residual sample-based prediction

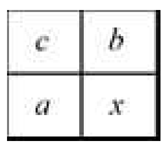

Figure 4: Residual pixel and its neighbors

Figure 4 illustrates the neighboring residuals used in predictor. The prediction of the residual x is denoted as P(x) and is computed as Equation (1).

$$P(x) = \left\{ \begin{array}{l} \min(\mathrm{a,b}) \text{ if } c \geq \max(\mathrm{a,b}) \\ \max(\mathrm{a,b}) \text{ if } c \leq \min(\mathrm{a,b}) \\ a+b-c \text{ otherwise} \end{array} \right\} \quad (1)$$

where min (a,b) and max (a,b) represent the larger and smaller function in calculating a and b, respectively.

If any neighboring samples are not available due to x being in the first row or column of a block, the same process is carried out with the missing values set to zero. It is reported that the proposed scheme improves the lossless intra coding performance by average 6.5%.

3 Analysis of Reversible Watermarking Algorithm

3.1 Distribution Characteristics of Residual Data in the HEVC Lossless Mode

In lossless coding, the residual data is not quantized transform coefficients but differential pixel after pre-diction. As a result, the residual data in lossless coding has different characteristics than that in the loss coding. Considering the Slide Editing test sequence as an example, the histogram of its intra luma prediction residuals in lossless coding and the histogram of its quantized transform coefficients when coded using QP=27 are shown in Figure 5 and Figure 6, respectively [6]. From these results,

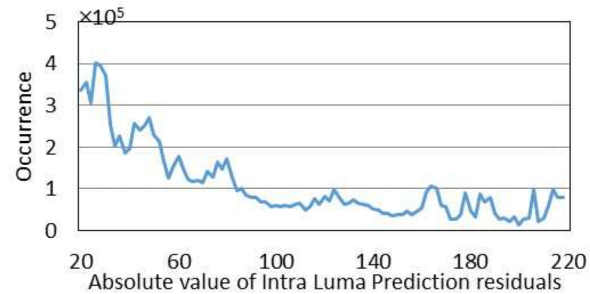

Figure 5: The histogram of intra luma prediction residuals

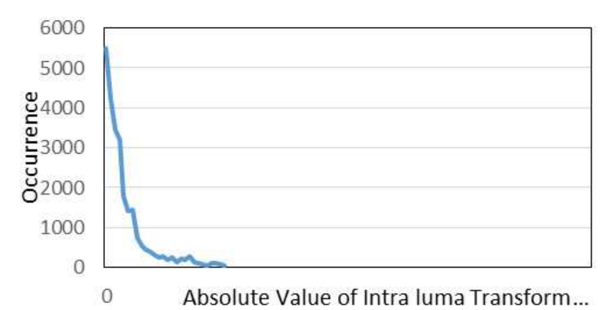

Figure 6: The histogram of intra coded luma transform coefficient levels

we observe that large luma prediction residuals appear with relatively higher frequency in the lossless case, with respect to the transform coefficients. In lossless coding, transform coefficients are usually concentrated at the upper left corner of the transform unit (TU) while it is not the case for quantized residuals. Prediction residuals may often appear in the bottom of a residual block. And it is observed that for relatively small TU, *e.g.* an 8×8 or a 4×4 TU, when intra prediction is in vertical direction, the residual will often appear in vertical direction. Thus, a vertical scan will often result in better performance. Similarly, when the intra prediction is in horizontal direction, a horizontal scan will often be better. The energy distribution of prediction residuals is often the inverse of the transform coefficients. For example, when diagonal scan is used, the energy in transform coefficients often decreases from the top-left corner to the bottom-right corner while the energy in the prediction residuals often increase from the top-left corner to the bottom-right corner.

3.2 Analysis of Reversible Watermarking Algorithms

Prediction residuals are spatial domain data. For data over spatial domain three classic methods, the difference-expansion (DE) method, the histogram shifting method, and the prediction error based method, are widely studied for typical reversible watermarking algorithms, which are specified as follows.

A common feature of DE methods [13, 18] is using a decorrelation operator to create features with small magnitudes. Data can be embedded by expanding these features to create vacant space into which message bits are embedded. DE methods usually suffer from undesirable distortion when the values of features are large. It is worth noting that HEVC lossless mode is designed to support high video quality. Thus, DE method might not be suitable for applications where higher image quality is demanded.

In histogram-shifting based techniques [16, 17], a histogram of feature elements is created. As such, the data can be embedded by shifting histogram bins. Unfortunately, the capacity of histogram-shifting based techniques is low and highly depends on the histogram distribution of the cover image. In general, the higher the peak of image histogram, the more the embedding capacity is. But, as observed from Figure 5 and Figure 6, compared with H.264/AVC, the HEVC lossless mode does not concentrate on certain values and instead has several peak points in histogram distribution of prediction residual. This fact indicates that the histogram-shifting based techniques is not suitable for the prediction residual of HEVC.

The prediction error based method is considered as another type of reversible watermarking method [7, 19]. Particularly, Hong *et al.* has proposed a reversible data hiding technique based on modification of prediction errors (MPE). In MPE, since the histograms in the domain of prediction errors are sharply distributed, the embedding capacity is higher than that of traditional histogram-shifting method for the same image quality. The embedding process of modification of prediction errors (MPE) involves calculating the prediction errors from the neighborhood of a given pixel and then embedding the message bits in the modified prediction errors. The median edge detection (MED) predictor is used in MPE to predict pixel values, which is same as that used in the prediction residual. Particularly, based on the values of context pixels a, b, and c, MED predicator is able to predict current pixel x by applying raster scan order and edge rule, which is as shown in Figure 4. The output of the predicted value $\hat{x}$ is given by Equation (1). Assuming that the predicted result of pixel x is , the prediction error e can be then obtained by subtracting the prediction from x, *i.e.*, $e = x - \hat{x}$.

MPE not only has the capability to control the capacity-PSNR, where fewer data bits need less error modification, but also can be applied to images with flat histogram, which is in accordance with the distribution characteristics of prediction residual of HEVC. Also, the calculation method in the prediction errors is consistent with the prediction residual method for improvement of performance in HEVC lossless mode, which means that MPE algorithm can be as an efficient solution for implement of reversible watermarking in HEVC lossless mode.

4 Proposed Algorithm

4.1 Embedding Algorithm

According to the structure of HEVC encoder, it can be classified into in-feedback loop and out-feedback loop for information embedding position. It is worth noting that if the watermarking is performed in the in-feedback loop, it is difficult to retrieve original video. This is because that the embed information of the current block can only be used for reconstruction and prediction of next block. Therefore, in order to implement reversible watermarking, it is favorable to embed information in out-feedback loop.

In this paper, the MPE reversible watermarking algorithm is implemented during the residual prediction progress in HEVC lossless mode. As mentioned above, if the residual sample-based prediction is applied after intra prediction in HEVC lossless mode, the compression efficiency can be improved by 6.5% on average. The residual sample-based prediction operation in HEVC lossless mode is same as the calculation operation of prediction error in MPE. Thus, to implement MPE during the residual sample-based prediction progress in HEVC lossless mode, we need to add the watermark embedding operation into the residual sample-based prediction progress.

In HEVC, there are four effective intra prediction block, in which the sizes of samples ranges from 4×4 to 32×32. Due to the characteristics of human visual system, the video visual quality distortion caused by watermarking embedding is more visible in smooth regions than that in complex regions. As such, it is more beneficial to use relatively large size blocks for prediction in smooth regions. While, in complex regions, the small size blocks are more preferable. It is worth noting that for small size blocks, the change of the block size may have only trivial impact on visual quality of the video. Therefore, we selected 4×4 luma block of intra predicted I frame as embedding region.

The proposed algorithm is performed independently in each transform block such that the change of the currant block due to the watermarking does not impact other blocks. Also, since we select block of size 4×4 as the watermark embedding block, the value of M and N is 3 in MPE.

In addition, the proposed algorithm is implemented in a manner which is independent of intra prediction modes and color components, the proposed algorithm is applied to all 4×4 intra residual samples. The frame-work of the proposed algorithm is shown in Figure 7, in which the prediction residual block in Figure 3 (b) is substituted to watermarking block.

The detailed embedding steps are listed as (Algorithm 1).

4.2 Extraction Algorithm

Through entropy decoding, the PU residual of size 4×4 can be obtained. For all PU of size 4×4, we use the same

Algorithm 1 The Embedding algorithm

Input: An intra predicted residual block I, and the watermark bit stream W.

Output: Watermarked block I' of size 4×4, the end of embedding position L and the auxiliary information A.

1: **if** block size is 4×4 **then**
2: go to STEP 6,
3: **else**
4: sent the residual sample-based prediction block
5: **end if**
6: Prepare an empty matrix I'. Then, initialize the pixel values in the first row and first column of I', respectively, to the pixel values in the corresponding position of I.
7: **for** $1 \le i \le 3$, $1 \le j \le 3$ **do**
8: scan each pixel $I'_{i.j}$ by using raster scan order.
9: **end for**
10: **if** $I'_{i,j} = 0$ or $I'_{i,j} = 255$ **then**
11: set $I'_{i,j} = I_{i,j}$ and record the position (i, j) in array A as the auxiliary information for recovering, then proceed to next pixel.
12: **end if**
13: Use Equation (1) to predict the value of $I'_{i.j}$ by setting $a = I'_{i,j-1}$, $b = I'_{i-1,j}$ and $c = I'_{i-1,j-1}$. Let the predicted result to be $\hat{I}'_{i,j}$.
14: Calculate prediction error e. Prediction error e is the difference between pixel $I_{i,j}$ and its predicted result $\hat{I}'_{i,j}$, *i.e.*, $e = I_{i,j} - \hat{I}_{i,j}$.
15: **if** all the watermark bits in W have been embedded **then**
16: set L = (i, j), and go to STEP 33.
17: **end if**
18: **if** e = 0 or e = -1 **then**
19: go to STEP 23 for data embedding.
20: **else**
21: go to Step 30.
22: **end if**
23: **if** the to-be-embedded bit is 0 **then**
24: the prediction error e remains unchanged.
25: **else if** the to-be-embedded bit is 1 and e = 0 **then**
26: modify the value of e to e+ 1
27: **else if** if e = -1 **then**
28: modify the value of e to e - 1. After embedding, go to Step 33.
29: **end if**
30: **if** e ¿ 0 **then**
31: modify the value of e to e + 1, if e ¡ -1, then modify the value of e to e-1.
32: **end if**
33: Set $I'_{i,j} = \hat{I}'_{i,j} + e$.
34: **if** $i \neq M-1$ or $j \neq N-1$ **then**
35: update the index i and j, go to STEP 7.
36: **else**
37: the embedding procedure is completed.
38: **end if**
39: End

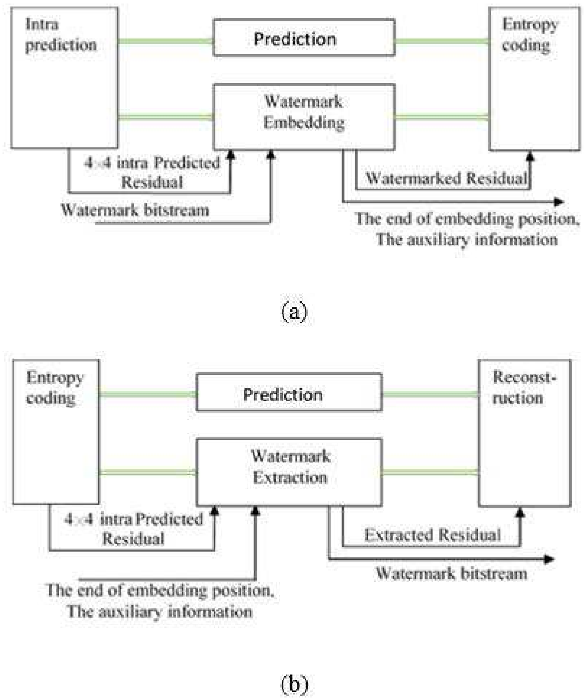

Figure 7: The framework of proposed algorithm within the HEVC codec

scan order as in the embedding phase to predict pixel values, and then calculate the prediction error e. It is worth noting that, if the value e is 0 or -1, the embedded watermark bit is 0, while if the value e is 1 or -2, the embedded watermark bit is 1, else if the value e is not one of the four numbers -2, -1, 0 and 1, then there is no bit embedded. Since we have modified the prediction errors during embedding, the original video can be restored by modifying the prediction errors back to their original value. The detailed steps for extracting watermark and recovering the original video are listed as (Algorithm 2).

5 Experimental Results and Analysis

In this section, we evaluate the feasibility and the performance of the proposed algorithm in terms of the embedding capacity and the peak signal to noise ratio (PSNR) difference. We also compare the compression performance of the proposed algorithm with the HEVC lossless mode and the residual sample-based prediction mode, respectively.

The proposed algorithm is simulated in the HM-16.9 model of the HEVC reference software, and the experiments are performed by embedding and extracting random generated bit streams. In the experiments, RDOQ, de-blocking filter, SAO and ALF are disabled. Also, for HE configurations, InternalBitDepth is set to equal to InputBitDepth in the configuration files. HEVC lossless mode is useful in coding video sequences with mixed contents, *e.g.* natural video with overlaid text and graph-

Algorithm 2 The Extraction algorithm

Input: Stego frame I', the end of embedding position L and auxiliary information A.

Output: The bit stream W and the original frame I''.

1: Prepare a matrix I'' to store the recovered block. The size of I'' is the same as stego frame I'. Initialize the pixel values in the first row and the first column of I'' to the pixel values in the corresponding positions of I'.
2: **for** $1 \leq i \leq 3$; $1 \leq j \leq 3$ **do**
3:     scan each pixel $I'_{i,j}$ in the stego frame by using the raster scan order.
4: **end for**
5: **if** (i, j) was recorded as the auxiliary information in A **then**
6:     set $I''_{i,j} = I'_{i,j}$ and proceed to next pixel.
7: **end if**
8: Predict the value $\hat{I}'_{i,j}$ using Equation (1), by setting $a = I'_{i,j-1}$, $b = I'_{i-1,j}$ and $c = I'_{i-1,j-1}$. Suppose the predicted value is $\hat{I}'_{i,j}$.
9: Calculate the prediction error $e = I_{i,j} - \hat{I}_{i,j}$.
10: According to the parameter L, decide whether all the embedded information has been extracted or not. If they are, then go to STEP 24.
11: **if** e = 0 **then**
12:     the embedded watermark bit is 0, and the prediction error e remains unchanged.
13: **else if** e = 1 **then**
14:     the embedded watermark bit is 1, and the prediction error e is modified to e - 1.
15: **else if** e = -1 **then**
16:     the embedded watermark bit is 0, and the prediction error e remains unchanged.
17: **else if** e = -2 **then**
18:     the embedded watermark bit is 1, and the prediction error e is modified to e + 1.
19: **else if** e ¿ 1 **then**
20:     prediction error e is modified to e - 1.
21: **else if** e ¡ -2 **then**
22:     the prediction error e is modified to e + 1.
23: **end if**
24: Set $I''_{i,j} = \hat{I}'_{i,j} + e$.
25: **if** $i \neq 3$ or $j \neq 3$ **then**
26:     update the value of i and j. After that, we first go to the next pixel, and then go to STEP 5.
27: **else**
28:     we have finished the watermark extraction and original video recovery. It is worth not-ing that the obtained result I'' is same as original block I.
29: **end if**
30: End

ics, thus we selected F class sequences (BasketballDrillText, ChinaSpeed, SlideEditing, SlideShow) for testing and each sequence is shown in Figure 8. Parameters of test sequences are shown in Table 1 [5].

First, we evaluate the embedding capacity of the proposed algorithm. Table 2 shows distribution of 4×4 residual in all size of residual for HEVC lossless mode. As shown in Table 2, 4×4 prediction residual occupies most among all prediction blocks.

Table 3 shows the embedding capacity of proposed algorithm in compared with DE method. As shown in Table 3, our algorithm is 2.03 times in embedding capacity over DE method. Therefore, the prediction residual has more changeable elements for embedding of watermark. Intuitively, this is because that the prediction residual has more non-zero coefficients than transform coefficients or quantized coefficients.

We also calculate the objective video coding quality variation (PSNR) difference in experiments. Peak Signal-to-Noise Ratio (PSNR) measure has been used to analyze the quality of watermarked video with respect to original video, which is given as Equation (2) shown.

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE}\right) \quad (2)$$

The difference of the value of PSNR before embedding watermark and after embedding watermark $\Delta PSNR$ is defined by:

$$\Delta PSNR = PSNR' - PSNR.$$

Where $PSNR'$ and PSNR are the video coding quality before and after embedded watermark, respectively, and MSE (mean square error) is a measure which is used to quantify the difference between the initial video frame I and the stego video frame I'.

If the video frame has a size of $M \times N$ then:

$$MSE = \frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left(I\left(i.j\right) - I'\left(i,j\right)\right)$$

Figure 9 shows the performance evaluation curve between the embedding capacity and PSNR degradation. The proposed algorithm is only 1.2dB in PSNR degradation when embedding capacity is 100000 bit. This means that proposed algorithm efficiently performs the watermarking.

Finally, we compare compression performance of proposed algorithm with that of the standard HEVC lossless mode and residual sample-based prediction mode. Table 4 lists the comparison result for compression performance in case of embedding of 100000 bit watermarks.

Table 4 lists coding performance comparison results among the proposed algorithm, the standard HEVC lossless mode and the residual sample-based prediction.

Where kbps % [1] compare with the standard HEVC loss-less mode, and kbps % [2] compare with the residual sample-based prediction.

Table 1: Parameters of test sequences

Class	Sequence name	Resolution	Frame count	Frame rate
F	BaskeballDrillText	480×480	500	50fps
F	ChinaSpeed	1024×768	500	30fps
F	SlideEditing	1280×720	300	30fps
F	SlideShow	1280×720	500	20fps

Table 2: Distribution of 4×4 residual in all size of residual for HEVC lossless mode

Sequence name	Distribution of 4×4 residual (%)
BaskeballDrillText	93.09
ChinaSpeed	92.15
SlideEditing	84.13
SlideShow	78.34

Table 3: Average embedding capacity per frame

Sequence name	DE	Proposed	Increased capacity (%)
BaskeballDrillText	39856	86 248	2.16
ChinaSpeed	62700	163 002	2.60
SlideEditing	45328	90 624	2.00
SlideShow	32082	43 828	1.37

Table 4: The coding performance comparison results

Sequence name	kbps % [1]	kbps % [2]
BaskeballDrillText	-0.3	1.1
ChinaSpeed	-7.2	0.6
SlideEditing	-1.2	0.9
SlideShow	-12.0	1.4

It can be observed that our proposed algorithm outperforms the standard HEVC lossless mode by 5.2% on average in terms of the compression efficiency. Such observation indicates that, compared with the HEVC lossless mode, the proposed algorithm does not degrade the performance of compression efficiency. It is also observed that compared with the residual sample based prediction, our proposed algorithm has a performance loss of 1% with respect to the compression efficiency.

6 Conclusions

In this paper, an efficient reversible watermarking algorithm in HEVC lossless mode is proposed. HEVC lossless mode is suitable for the implement of reversible watermarking since it bypasses all nonreversible operations such as transform, quantization and in-loop filtering operations. In this paper, we have analyzed the distribution characteristics of prediction residual of HEVC and reversible watermarking algorithms in spatial domain, and selected the reversible algorithm suitable for prediction residual. The proposed algorithm not only provides enough space for embedding of desired payload but also has the capability of controlling embedding capacity. In addition, compared with the HEVC lossless mode, the proposed algorithm does not degrade the performance of compression efficiency. Our experiment results indicate that the averaged embedding capacity of this algorithm is at least two times more than that of DE technique. It is also shown that the compression efficiency of the proposed algorithm outperforms the standard HEVC lossless mode by 5.2%.

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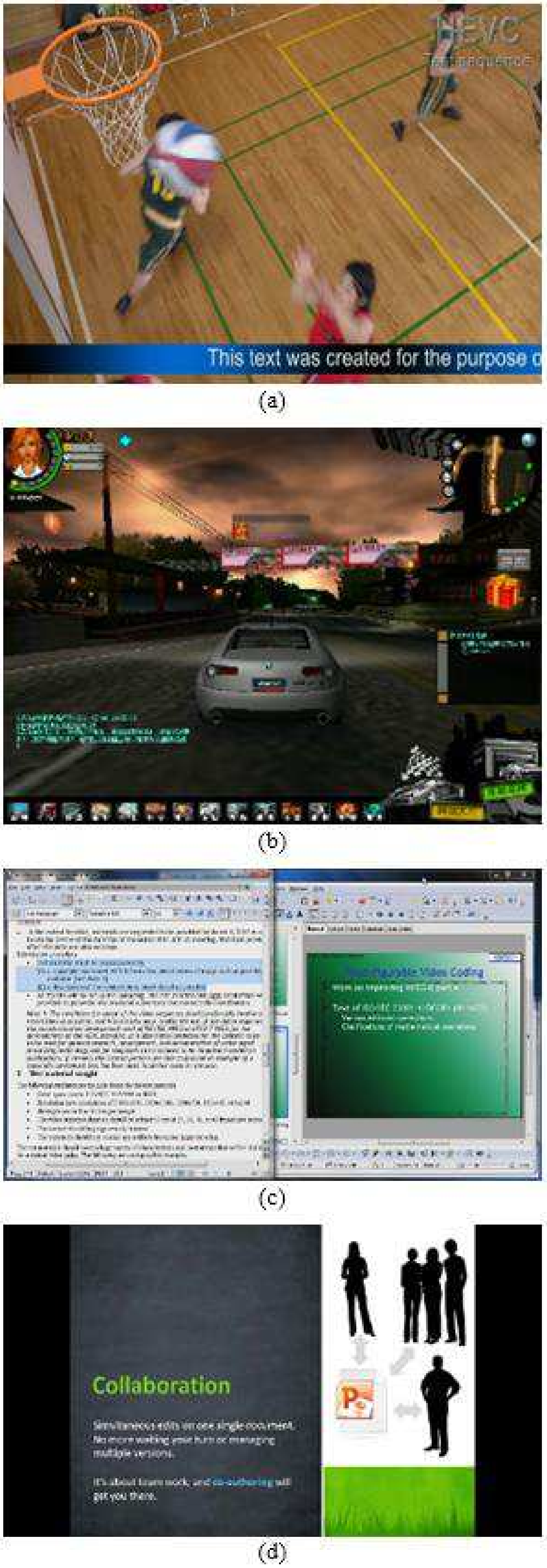

Figure 8: Test sequence: (a) BaskeballDrillText, (b) ChinaSpeed, (c) SlideEditing, (d) SlideShow

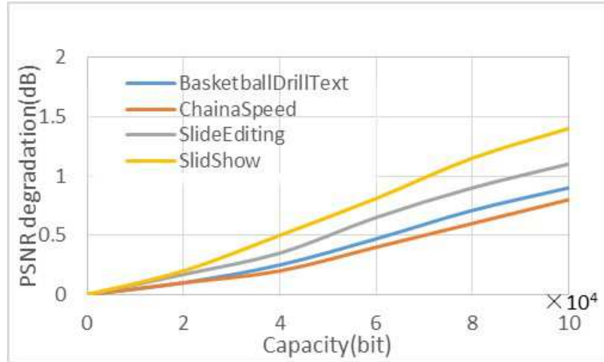

Figure 9: Performance evaluation curve between the embedding capacity and PSNR difference

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Biography

KwangHyok Jo is a Ph.D. candidate with School of Computer Science and Engineering, Northeastern University, China. His current research interests include DRM technology, information hiding, network security.

Weimin Lei is a professor and Ph.D supervisor with School of Computer Science and Engineering, Northeastern University, China. His current research interests include protocols and services in IP multimedia system, multipath transport, overlay network, SDN and adhoc network.

Zhaozheng Li is a Ph.D. candidate with School of Computer Science and Engineering, Northeastern University, China. His current research interests include IP communication, trusted technology, network security.

Xiaoshi Song is a lecturer and doctor with School of Computer Science and Engineering, Northeastern University, China. His current research interests include Computer networks, optical networks.