2014 The 2nd International Conference on Information Technology and Science (ICITS 2014)
IPCSIT vol. 59 (2014) © (2014) IACSIT Press, Singapore
DOI: 10.7763/IPCSIT.2014.V59.32

Encryption System Integrated with ROI and Tracking for High Efficiency Video Coding

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Abstract. In this paper, we present a novel encryption scheme that integrates Region of Interest (ROI) tracking on the next generation High Efficiency Video Coding (HEVC) standard. With the Tracking Learning Detection (TLD) algorithm, the ROI encryption system can become more intelligent through constrained motion estimation and some constrained mode decision. The encryption system we proposed on the selected bin strings in Context Adaptive Binary Arithmetic Coding (CABAC) of the HEVC can achieve an obvious encryption performance improvement on different situations. With the RSA and key management scheme, the security of our encryption system is fully guaranteed.

Keywords: Video Encryption, HEVC, ROI, CABAC, Tracking Learning Detection

1. Introduction

In the last decades, as the development of the next generation video coding standard, video protection achieves more and more attention with the appearance of new video coding tools and new syntax elements. The coding efficiency of next generation video coding standard, High Efficiency Video Coding (HEVC) standard [1] is much better than H.264/AVC. With the boom of the video industry, a number of multimedia applications will adopt HEVC standard.

In many situations, people don’t want their video be viewed which involving privacy, or as the video has its copyright and only those who have paid for it can have the privileges to watch the high quality version of the video. So the video encryption is an urgent issue for video surveillance, transmission and so on. Video content protection on the multimedia applications is of importance in the highly developed Internet society.

Sometimes the video publisher allows others to view the video except some special parts. Maybe some moving objects in the video are valuable while the background is useless. On the other hand, as to the video copyright, the free viewers only can watch the encrypted video that the foreground is chaotic while the background is clear, the paid user can view the full content of that video. So the encryption on a Region of Interest (ROI) is significant. In most situations the objects in the ROI are not stationary, such as running cars or pedestrians, tracking ROI must be taken into consideration in a real application system. In our system what the video publishers need to do is to decide the encrypted area on the initial frame, sometimes it just means drawing a simple rectangle on his touch screen or dragging his mouse to sketch the outline of an important area, the work left will be completed by mobile devices or computers automatically.

Many selective encryption schemes on H.264/AVC have been proposed over the years including selective encryption on Context Adaptive Binary Arithmetic Coding (CABAC) or Context-based Adaptive Variable-Length coding (CAVLC), secret Discrete Cosine Transform (DCT) and so on. For details, interested reader can refer the survey of encryption on H.264/AVC and Scalable Video Coding (SVC) [2]. The ROI encryption is also analysed by some literatures, but tracking schemes for moving ROI have never been sufficiently discussed forever. In [3], the authors proposed a bitrate lossless encryption scheme with

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fully analysis on the CABAC bins, and a new key management protocol (MIKEY) is integrated with the encryption of SVC coding, but ROI encryption is not supported in that framework. In [4], a selective encryption scheme with ROI enabled for SVC is proposed, while the system attempts to encrypt some dangerous syntax elements which may cause incompatibility between the output bitstream and the standard SVC bitstream, besides, the proposed system doesn't support the moving ROI encryption. In [5], a fast protection method and full analysis on the encryption result is presented by Z. Shalid et al, but the ROI encryption has not been integrated with the proposed algorithm.

In this article, we propose an encryption system integrated with ROI tracking on the new HEVC standard. Experimental result demonstrates that our system can achieve a bitrate lossless encryption and it conquers the problems of moving ROI coding in HEVC. With RSA [6] [7] key management algorithm and Tracking Learning Detection (TLD) ROI tracking algorithm [8], the system can be easily deployed in the real application system.

The following of this paper is organized as follows. In Section II, we analyse HEVC encoder and introduce the proper syntax elements to be encrypted. The proposed ROI encryption system and the implementations details will be discussed in Section III. The experimental results are shown in Section IV; five different encryption situations are fully tested with a full analysis of the encryption security. In the last section, we make a conclusion of this paper.

2. Proposed Syntax Elements for Encryption

HEVC standard aims at reaching the highest coding efficiency which can achieve 50% bit-rate reduction for equal perceptual video quality comparing to H.264/AVC [1]. The quadtree coding structure plays a critical role in HEVC. The size of the coding tree block (CTB) which is the node of the quadtree coding structure is decided by the encoder which can be much larger than H.264/AVC standard. The coding units (CUs) specify the basic encoding blocks which may be split into prediction units (PUs) and a tree of transform units (TUs) [1] [9].

TLD is a state-of-the-art tracking system framework which provides a real-time long-term tracking system [8]. The performance of the TLD tracking method is still outstanding and robust when the object is deformed or it moves out of and back into the screen, so it is very suitable for video ROI tracking applications.

Through the entropy coding in HEVC, the video syntax elements become binary bits. After binarization, bypass bins are coded directionally without context model. There are five binarization schemes in CABAC coding for binary sequences in HEVC, unary code, truncated unary (TU) code, truncated rice (TR) code, kth Exp-Golomb (EGk) code and fixed length (FL) code [10]. Sometimes, these five basic binarization schemes can be concatenated together to form a more complex binarization scheme. We choose some syntax elements in the HEVC CABAC process to perform encryption. Due to the fact that encryption system can be used for ROI encryption, some conditions should be taken into considerations.

2.1. Format Compliance

A prerequisite to ROI encryption is to keep format compliance with HEVC standard. The encrypted area should be chaotic while the outside area should be the same with raw video. Format compliance means the encrypted stream suffices the syntax's and semantics' requirements of the HEVC standard and the stream can be decoded by a simple standard, none-modified HEVC codec decoder. Arbitrary modification of some CABAC bin strings may bring serous decoding mistakes because of the potential relationships among those bin strings. The ROI encryption system has to guarantee the format compliance.

2.2. Compression Efficiency

Among the five binarization schemes in CABAC, fixed length and Exponential Golomb codes may be the best choices to encrypt. Modification on the fixed length bins will not change the length of the overall bins because the length of those bins is fixed. Exponential Golomb code has a prefix and a suffix, and the leading zeros until the first one on prefix signals the length of the suffix. Modification on the Exponential Golomb bins cannot guarantee the fixed length on those codes, but the Exponential Golomb bins which replace the suffix with bits of the same length are legal Exponential Golomb bins, thus the length of that bins has not changed.

2.3. Bins Choosing Result

As the conditions format compliance and compression efficiency mentioned above, modification on the bins that exert no effect on the context model of CABAC is the best choice. We have two choices, one is choosing lossless encryption bins which means the encryption progress has no effect on the coding efficiency, and the other is choosing loss encryption bins which suffers a bitrate gain with better security.

From the above analysis and the real tests on HEVC encoder, we finally decide to choose several bins shown in Table 1.

Table. 1: CABAC Bins Choosing Result

Bins' Features		Syntax Element Name
Lossless	Bypass EG0	Suffix of cu_qp_delta_abs
	Bypass EG1	abs_mvd_minus2
	Bypass FL	mvd_sign_flag
	Bypass FL	cu_qp_delta_sign
	Bypass FL	coeff_sign_flag
Loss	Unary	MVP index
	TU	Merge index
	TU	Reference Frame index

2.4. DCT Coefficients Shuffling

Besides the bitstream domain, the frequency domain can also be used for encryption. DCT coefficients represent the energy distribution of the current block in the frequency domain. It is evident that DCT coefficients shuffling will cause serious chaos in the image domain. But this will bring great harm on the context model so that the coding efficiency will drop severely. As we all know DCT coefficients obey some certain distributions on the current transform block. The direct current (DC) coefficient which specifies the mean pixel value of all the current block plays a more critical role for video quality than the other DCT coefficients. So we can only choose the DC coefficients in the encrypted area and then shuffle them by Fisher–Yates shuffling algorithm [11].

3. Implementations of ROI Encryption System

For the need of the selected area encryption, we first calculate the index of the columns and rows of CUs which divide the current picture into several tiles by the given specified ROI coordinates. Then we encode the video, setting one tile identical to one slice. With tiles and slices, we can easily generate ROI areas in the picture [12] [13]. Because some objects in the ROI are not always stationary, the encrypted area should cover the moving objects all the time by tracking algorithm to avoid those objects moving out of the ROI region. Some further constrained conditions should be applied in the HEVC encoder in order to prevent the potential error spreading.

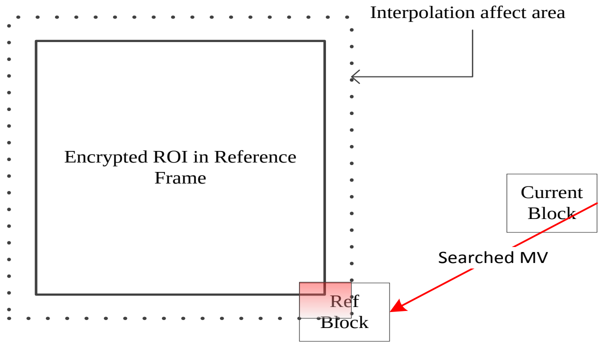

Fig. 1: None Constrained Motion Estimation on the Boundary of the Encrypted ROI, the red rectangle is the Mistaken Intersection Rectangle area.

3.1. Repacking Picture Parameter Sets (PPS)

The specified configurations of tiles and slices can keep a stationary ROI in the video coding and encryption procedure. A moving ROI should be supported if we want to get tracking with the encrypted ROI area.

Once the tiles configurations have been changed, repacking PPS is necessary as the tiles information is packed in the PPS. Repacking PPS tells the decoder that the tiles area in current processing frame has just been changed.

3.2. Interpolation on the ROI Boundary

Before the encoder deals with the motion estimation, up-sampling on the reference frame is required. To generate the half-pel and quarter-pel pixels, a six tap finite impulse response filter (FIR) is performed. As we know 1/4 pixel motion vector is utilized in HEVC, the mistaken area after interpolation in the reference frame will expand a little around the edge of certain encrypted ROI, just as shown in the dashed rectangle in the Fig. 1. So we need to constrain the motion estimation, skip and merge mode on the ROI Boundary.

3.3. Constrained Motion Estimation

Motion Vectors (MVs) obtained from the motion estimation (ME) indicate the shift of the blocks in the reference frame. Because the reference frame contains a mistaken decoded ROI, if the searched MV is located in this ROI, the motion compensations of the current blocks will suffer some serious quality degradation. As shown in Fig. 1, the red block is the intersection rectangle of the reference block and the encrypted ROI area due to interpolation effect. We call that area Mistaken Intersection Rectangle (MIR). Obviously, the pixels in MIR are in mistake.

So, constrained motion estimation is the basic principle of the ROI coding which the reference blocks and the encrypted ROI with interpolation effect area should not have intersected area when searching MV outside the encrypted ROI, i.e. the MIR should not appear in the motion estimation.

3.4. Constrained Skip and Merge Mode

Skip mode and Merge Mode which uses index information to select one of several available candidates allows the MV of the current block inherits MV from neighboring prediction blocks. Sometimes, although the MVs in the candidate list are constrained as mentioned above, putting the selected MV in the current Skip or Merge Mode block around the ROI boundary will probably generate MIR which will cause error in the none-encrypted area.

So when calculating the rate-distortion (RD) cost in the Skip or Merge Mode outside the ROI, once MIR appears, the RD cost on the current PU should be set as the maximum RD cost value, which means the encoder have no choice to select the mode that may cause decoding error.

3.5. Encryption System

Using the TLD Algorithm, we first give the encoder a single bounding box to indicate which area is to be encrypted in the initial frame, and then the encoder will track the object in the next frame automatically.

The encryption on CABAC bins should first generate a pseudo random sequence using a secret key, then perform XOR operation with the selected syntax elements and the pseudo random sequence to get a random mistaken syntax element, As analysed before, changing on a selected syntax element in Table 1 into another feasible value ought not to violate the format compliance condition. DC coefficients shuffling of the DCT also needs a seed key to generate the random id number. So the key for encryption CABAC bins and the key for DC coefficients shuffling can be combined together into a binary sequence as a secret key for video encryption.

We use RSA algorithm to encrypt the secret key. Video encoders encrypt the secret key using the public key, users then use their private key to decrypt the secret key.

4. Experimental Results

We implement our system on HEVC Test Model (HM 10.0) software [14]. Then we test several sequences of with different resolutions from 416x240 to 2560×1600. We encode 100 frames for each sequence in random access mode; the quantization parameter (QP) is set to be 32. The Group of Pictures (GOP) size is 8.

The experiments can be divided into two major categories with five subclasses. The five subclasses represent five different test cases, which are the bitrate lossless encryption (case 1), all selected CABAC bins encryption (case 2), DC coefficients shuffling (case 3), stationary ROI encryption (case 4), and moving ROI encryption with tracking (case 5). The five different test conditions are discussed below. All test results are shown in Table 2-4 and Fig. 2 - 3.

Table 2: The Bitrate Addition After Encryption

Sequence	Case 2	Case 3	Case 4	Case 5
BlowingBubbles	+0.36%	+1.28%	+50.39%	+69.79%
BQMall	+0.10%	+0.99%	+23.95%	+50.34%
ChinaSpeed	-0.15%	+0.70%	+2.32%	+11.41%
Johnny	+2.89%	+4.12%	+60.70%	+60.70%
vidyo	+2.81%	+4.25%	+35.77%	+27.06%
ParkScene	+0.90%	+1.99%	+3.47%	+6.73%
SteamLocomotive	+0.54%	+1.55%	+2.07%	+2.58%
Average	+1.06%	+2.13%	+25.52%	+32.66%

Table. 3: The PSNR Results Between Encryption and Decryption

Sequence	Case 1 PSNR (dB)		Case 2 PSNR (dB)		Case 3 PSNR (dB)		Case 4 PSNR (dB)		Case 5 PSNR (dB)	
	Decrypt	Encrypt	Decrypt	Encrypt	Decrypt	Encrypt	Decrypt	Encrypt	Decrypt	Encrypt
BlowingBubbles	32.26	8.76	32.25	8.72	32.25	8.57	32.65	12.28	32.61	12.31
BQMall	34.02	10.02	34.02	10.20	34.02	9.67	33.68	8.17	32.95	9.12
ChinaSpeed	35.20	3.67	35.20	3.72	35.20	6.30	34.27	3.62	34.30	3.85
Johnny	39.60	7.58	39.60	7.58	39.60	8.84	37.59	7.08	37.60	7.13
vidyo	39.66	9.07	39.65	9.07	39.65	9.24	37.34	9.94	34.83	15.07
ParkScene	35.02	5.15	35.02	5.10	35.02	8.81	35.15	14.01	33.84	13.56
SteamLocomotive	35.97	6.93	35.97	6.84	35.97	6.76	38.35	4.40	38.58	6.48
Average	35.96	7.31	35.96	7.32	35.96	8.31	35.58	8.50	34.96	9.65

Table. 4: The SSIM Results Between Encryption and Decryption

Sequence	Case 1 SSIM		Case 2 SSIM		Case 3 SSIM		Case 4 SSIM		Case 5 SSIM	
	Decrypt	Encrypt	Decrypt	Encrypt	Decrypt	Encrypt	Decrypt	Encrypt	Decrypt	Encrypt
BlowingBubbles	0.9896	0.0177	0.9896	0.0067	0.9896	-0.1894	0.9853	0.1092	0.9852	0.1088
BQMall	0.9944	-0.1753	0.9944	-0.1703	0.9944	-0.1061	0.9950	-0.2116	0.9935	-0.0017
ChinaSpeed	0.9968	-0.2077	0.9968	-0.1839	0.9968	-0.2697	0.9922	-0.0731	0.9925	-0.0748
Johnny	0.9989	-0.4812	0.9989	-0.4756	0.9989	-0.4452	0.9981	-0.3622	0.9981	-0.3558
vidyo	0.9988	-0.2805	0.9988	-0.2671	0.9988	-0.3139	0.9976	0.2185	0.9933	0.4045
ParkScene	0.9922	-0.0849	0.9922	-0.1126	0.9922	-0.2138	0.9927	0.2037	0.9893	0.3034
SteamLocomotive	0.9940	-0.2351	0.9940	-0.2446	0.9940	-0.2441	0.9865	-0.0017	0.9945	-0.0312
Average	0.9950	-0.2067	0.9950	-0.2068	0.9950	-0.2546	0.9925	-0.0167	0.9924	0.0505

4.1. Bitrate Lossless Encryption

Only encrypting the bypass mode syntax elements on the CABAC bins will achieve a bitrate lossless encryption. In this situation, no tiles or slices are allowed to exist in the encoding, i.e. there is no ROI coding in the frame, and the encryption is processed on the whole contents of the video.

4.2. Encryption on the all selected CABAC bins

The encryption on the all selected CABAC bins is the same as the bitrate lossless encryption, as all selected CABAC bins contains the none-bypass mode syntax elements; bitrate would be increased after encryption.

4.3. DC Coefficients Shuffling

In this situation, DC coefficients shuffling is tested with encryption which is performed with all selected CABAC bins. Meanwhile there are no tiles and slices coding, and the full video is encrypted.

4.4. Stationary ROI Encryption

Not all applications need to enable the ROI automatic tracking, such as the news report, the TV announcer in the video is almost stationary, so there is no need to track the announcer, avoiding the complex TLD tracking.

The original bitrate in this situation is tested with the configuration of the same slice in the corresponding encrypted video sequence. The encryption is performed on all selected CABAC bins with the DC coefficients shuffling enabled.

As the encryption is only performed in the ROI, only the Mean Square Error (MSE) of the ROI is used to represent the encryption quality.

4.5. ROI Encryption with Tracking

In this case, we enable the TLD ROI tracking with ROI video coding in the encoding progress. The test condition is the same as that in case 4, the stationary ROI encryption, except tracking the moving object in the initial frame. Every change in the position of the ROI will lead to a different slice and tile configurations. We only calculate the MSE in the ROI area, which is the same to the stationary ROI encryption test case, but the ROI sometimes is moving in this situation.

4.6. Coding Performance for Encryption

Fig. 2 shows a typical encryption result for the sequence "ParkScene". (a) ~ (c) (case1 ~ case3) represent the full content encryption without ROI, (e) (case 4) shows the result of the stationary ROI encryption, (f) ~ (h) (case 5) show the ROI tracking result in our system.

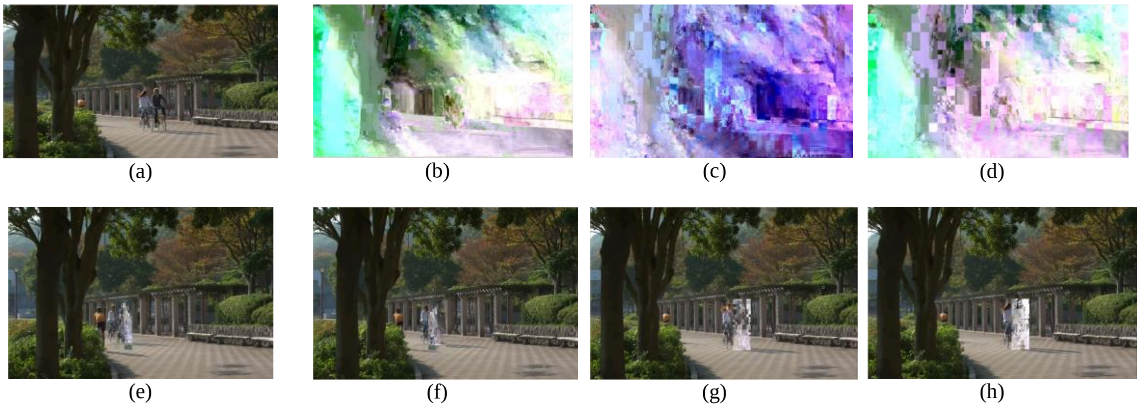

Fig. 2: Visual patterns comparisons, (a) shows the raw picture without video encryption, (b) shows the picture of the bitrate lossless encryption (case 1), (c) shows the picture of all selected CABAC bins encryption (case 2), (d) shows the picture of DC coefficients shuffling (case 3), (e) shows the picture of the stationary ROI encryption (case 4), (f) ~ (h) show pictures of the ROI encryption with tracking (case 5).

Table 2 demonstrates the bitrate increase after encryption. As there is no bitrate increase in case 1, the bitrate of case 1 is not provided in Table 2. Case 2 and case 3 are encoded without considering ROI, so the bitrate increase is all caused by the CABAC bins encryption overhead. The bitrate increase in case 4 and case 5 is mostly accounted for the constrained ME, constrained special modes and the modifications of some other coding tools to get a correct encryption result.

Table 3 shows the Peak Signal to Noise Ratio (PSNR) value changes between encryption and decryption video. For cases 4 and 5, we only calculate the PSNR value in the ROI rectangle area, not the full video content. The PSNR value of the encrypted video is very low; the PSNR of the luminance component is near 10dB which means that the image of the encrypted video is chaotic enough.

4.7. Structural Similarity for Encryption

As the new structural similarity (SSIM) index [15] can get a better view of the similarity between two images, we also provide the results using the evaluation of SSIM.

SSIM value ranges from -1 to 1. If two images are exactly the same, the SSIM value between the two images is 1; otherwise the value is less than 1. A lower value represents that there is more difference between the two images.

The SSIM test results are shown in Table 4, and from the table, we can easily get the encryption quality from case 1 to case 5. The SSIM value of case 1 is very similar to the value of case 2 while the SSIM value of the case 3 is smaller than the value in the case 1 or case 2 which indicates that more encryption tools result in better quality of encrypted videos. The SSIM value in case 4 and case 5 is very small, indicating quite good encryption results.

Fig. 3 shows the SSIM value changes within 100 frames. From the curves it is obvious that the SSIM of original video, which is encoded with the same configuration as the encrypted videos, is near to 1, but the SSIM of the encrypted videos are very small. The SSIMs of most of the encrypted frames are below zero indicating bad image visual quality. The curve of the bypass mode (case 1) is very close to the curve of the all selective CABAC mode (case 2). Obviously, in most time the curve of the DC coefficients shuffling mode (case 3) is lower than the curves of case 1 and case 2 that revealing case 3 obtains the best encryption among these three cases.

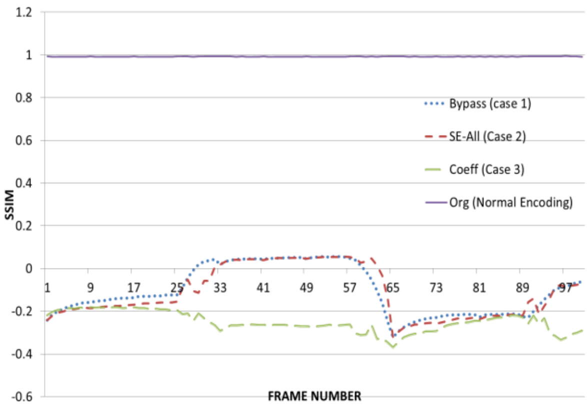

Fig. 3: SSIM curves from case1 to case3 compare with cure of the original encoded picture.

4.8. Encryption Attacks Analysis

Considering all three different encryption tools together (case 1 ~ case 3), eight different CABAC bins in Table 1 and one shuffling algorithm are performed.

For case 1 and case 2, each CABAC bin in Table 1 has n_i ($1 \leqslant i \leqslant 8$) different syntax values and the encryption is performed on m_i ($1 \leqslant i \leqslant 8$) valid blocks. The probability of cracking the correct value of one block is P_i ($1 \leqslant i \leqslant 8$) while the probability of cracking one entire frame is P_1.

$$P_1 = \prod_{i=1}^{8} (P_i)^{m_i} = \prod_{i=1}^{8} (\frac{1}{n_i})^{m_i}$$

For the random DC coefficients shuffling, if the number of none-zero DC coefficients in the encrypted area is n^*, the probability of cracking one entire frame is P_2.

$$P_2 = \frac{1}{n^*!}$$

Finally, the probability to get a decrypted frame of video without a valid secret key is P.

$$P = P_1 \times P_2$$

In most cases, mi and n^* are very large values as a result the P_1 and P_2 are very small. So the value of P is close to zero which means it is hard to attack the encrypted video stream without a valid key.

5. Conclusion

In this paper, we propose an encryption system integrated with ROI and Tracking for HEVC. In our proposed system, we perform encryption on selected CABAC syntax elements and DC coefficients shuffling. We integrate the TLD algorithm with the HEVC encoder to provide the ROI encryption with tracking scheme under constrained motion estimation and some constrained modes. Experimental results indicate that our proposed system can give the effective protection for the video content in different situations.

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