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A Cover Selection HEVC Video Steganography Based on Intra Prediction Mode

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ABSTRACT Existing video steganography puts much emphasis on the design of algorithms such as mapping rules or distortion functions, thereby ignoring the selection of cover to embed secret information. However, this is just one of the major differences between image steganography and video steganography. In addition, since HEVC is the latest standard in the video codec field, it is of important academic significance and applied value to study HEVC-based steganography. This paper proposes a novel video steganography in HEVC, based on intra-prediction mode (IPM). Firstly, this paper analyzes the probability distribution of 4×4 IPMs. Then a cover selection rule combined with the Coding Unit (CU) and Prediction Unit (PU) coding information is proposed, which can improve the security performance of a stego video stream. In addition, matrix coding is used as a coding example to implement the steganography on HEVC video streams. Experimental results show that the proposed algorithm can not only maintain the video quality and the security performance but is also easy to implement. Furthermore, the proposed cover selection rule can also be integrated into other HEVC IPM based steganography.

INDEX TERMS Video steganography, HEVC, IPM, cover selection rule.

I. INTRODUCTION

As one of the branches of information hiding [1], steganography is designed for covert communication, embedding secret information into an innocent-looking cover medium (such as image, audio, and video) [2]–[7]. Over the last few years, image steganography has drawn extensive interest, whereas only a few studies have focussed on video steganography. However, driven by rapid advances in computers, multimedia, as well as networking, video coding technologies have been vigorously developed and video applications are also becoming popular gradually, which has laid a solid foundation for video steganography. In addition video stream is becoming the most popular and reliable cover in the field of steganography, due to its large embedding capacity and negligible quality loss. Existing video steganography falls into four major categories, based on different cover types: intra-prediction mode (IPM), DCT coefficients, motion vector (MV), and entropy coding coefficient [8]–[10].

As the latest video coding standard, HEVC [11] provides a 2x bit rate reduction with the same perceptual quality compared to H.264/AVC [12], and is expected to take the place of H.264/AVC as the most widely deployed standard. This creates an urgent need to explore the algorithms for hiding data in HEVC video streams. Therefore, this paper mainly focusses on the IPM-based steganography in HEVC. Since steganography in HEVC is still in its infancy, a review covers related research on IPM based steganography in both H.264 and HEVC video streams.

In [13], Hu *et al.* firstly presents a video steganography which uses IPMs as the cover to embed information. In this algorithm, the qualified 4×4 IPMs are modified based on the mapping rules obtained by sampling more than 100,000 4×4 IPMs from ten testing sequences. However, the mapping rules need to be transmitted to the decoder, which may cause an increase in the number of bits.

Thus, an algorithm that is an improvement of that of [13] is proposed by Yang *et al.* [14]. They divide the qualified 4×4 IPMs into groups, and use matrix coding to implement a map between the embedding information and 4×4 IPMs. Therefore, every three 4×4 IPMs can embed two bits almost without sacrificing quality. In addition, to enhance the security of the embedded information, an embedding position template is used to select the candidate 4×4 IPMs.

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Xu *et al.* present a key-dependent algorithm in [15] to increase security performance against malicious attacks. A chaotic sequence is used to encrypt the secret information and then another chaotic sequence is used to select the qualified 4×4 IPMs for randomly embedding information. Experimental results demonstrate that the proposed algorithm can achieve high data capacity with little increase in the bit rate and almost no quality degradation.

Zhang *et al.* propose an adaptive IPM-based video steganography algorithm in H.264/AVC based on cost assignments [16] with Syndrome-Trellis Code (STC). Here, a texture feature based cost assignment scheme is introduced to perform adaptive embedding perturbations, and then STC is used to choose I4×4 blocks (4×4 blocks in I frames) whose IPM needs to be changed. Experimental results show that the security performance can be maintained with the proposed method.

The following are some studies of IPM-based steganography in HEVC video streams. Wang *et al.* propose a high-capacity information hiding algorithm for HEVC [17]. A mapping rule between the IPMs and the embedding information is first established based on the probability distribution of the statistical optimal prediction mode and suboptimal prediction mode. But this method has high complexity when compared with other algorithms.

Hence, another mapping rule based on angle differences of IPMs is proposed in [18], and the corresponding IPM is modified to embed the secret information. However, the proposed algorithm is fragile with excessive changing of intra-prediction modes.

In [19], an adaptive IPM-based steganography of HEVC is proposed to maintain the rate-distortion optimization. Three-layer isolated channels are established to separate the neighboring IPMs which may mutually affect each other. Then a two-layered STC based on a novel distortion function describing multilevel embedding impacts (intra-PU and inter-PU embedding impacts) is applied to execute the specific embedding operation. Experimental results demonstrate that the proposed method outperforms other algorithms.

The review above shows that the existing literature on IPM-based steganography in HEVC is mainly based on steganographic algorithms for images. They mostly focus on the design of an algorithm including mapping rules or distortion functions for STC but ignore the selection of the cover for embedding secret information, which is one of the significant differences between image steganography and video steganography and is vital for the security performance of steganography. Hence, the IPM-based steganography of HEVC in this paper mainly focusses on making use of the new features in HEVC. The key contributions of this paper include:

1). The probability distribution of the coding information is first analyzed, which is the basis of the proposed cover selection rule;

2). A cover selection rule based on the unique CU depth information and PU partition types of HEVC is constructed, which is a preliminary screening of the covers without any calculation;

3). Matrix coding is used as a coding example to implement the steganography in HEVC video streams to demonstrate the feasibility and effectiveness of the proposed method. Experimental results show that the proposed algorithm can maintain the steganographic capacity and high security. In addition, the proposed method can also be integrated into other HEVC IPM based steganography.

The rest of this paper is organized as follows. In Section II, the intra coding scheme in HEVC is briefly introduced. Then, the details of the cover selection rule and proposed steganography are presented in Section III. Next, Section IV gives a detailed summary of the proposed information embedding algorithm and extraction procedure. Experimental results and analysis are presented in Section V. Finally, the conclusions of this paper are given in Section VI.

II. INTRA-CODING SCHEME IN HEVC

HEVC adopts the same hybrid coding framework used in H.264/AVC. Figure 1 depicts a block diagram of the typical hybrid video encoder of HEVC [11]. We can see that big changes have been made in the details of the technologies in HEVC, and many innovative technologies have been introduced as well when compared with H.264/AVC. For instance, instead of the concept of the macroblock in H.264/AVC, HEVC defines a set of brand new syntax elements for picture partitioning, including CU, PU and Transform Unit (TU). These three concepts make operations such as transform, prediction, and entropy coding in HEVC much more flexible, and can also optimize the performance of video coding.

A. CODING UNIT AND PREDICTION UNIT

CU is the basic unit of intra- and inter-coding in HEVC. A frame in HEVC is first split into several 64×64 coding tree units (CTUs) without any overlap. Then every CTU can contain only one CU or can be further partitioned into multiple CUs with sizes of 32×32, 16×16, or 8×8. Here, the partitioning is achieved by the quad-tree structure, which is depicted in Figure 2. With this structure, HEVC can select various sizes of CU to encode blocks based on the signal characteristics, which enables achieving a higher compression efficiency. In addition, CUs can be further split into PUs and TUs.

That is to say, the CU is the root of the PU partitioning structure. At the CU level, it can only make a decision about whether to code the unit using intra-prediction or inter-prediction. The specific operation of intra-prediction or inter-prediction is carried out at the PU level. For intra-prediction, there are only two types of PU partition modes: $2N \times 2N$ and $N \times N$. But there are eight types of PU partition modes prepared for inter-prediction, as depicted in Fig. 3 [11]. HEVC supports variable PU size: from 4×4 up to 64×64.

B. THE INTRA-PREDICTION SCHEME IN HEVC

Intra-prediction can effectively remove the spatial redundancies between the current block and its neighbors by using the

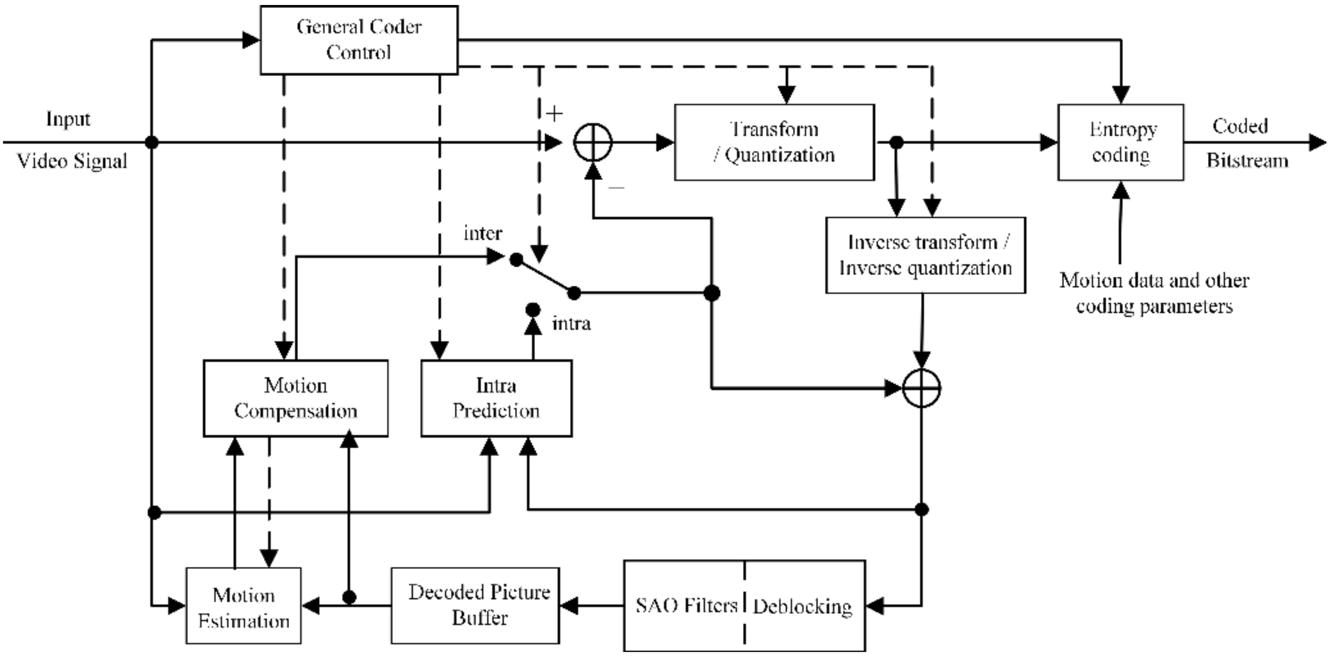

FIGURE 1. Typical HEVC hybrid video encoder.

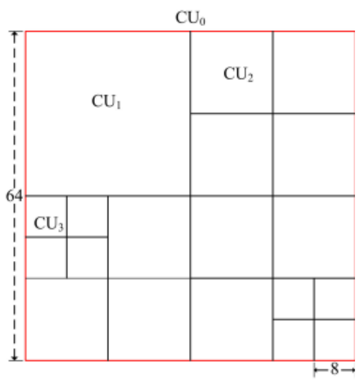

FIGURE 2. Quad-tree partition of CTU into CUs in HEVC.

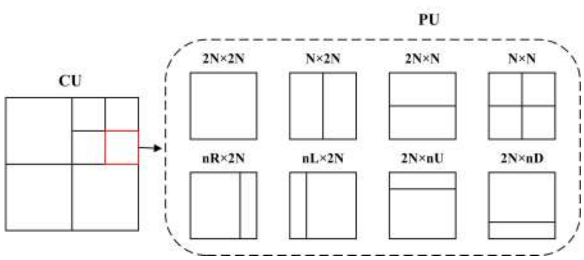

FIGURE 3. Partitioning modes of PUs in HEVC.

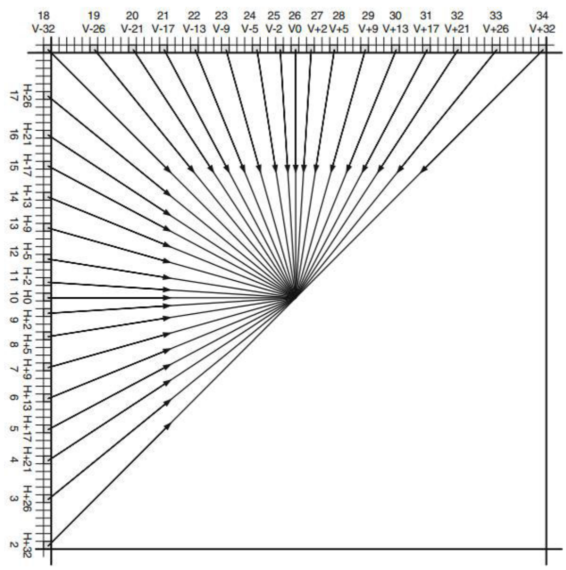

FIGURE 4. Intra-prediction mode in HEVC.

coding information of the neighbors to predict the samples of the current block. Compared with H.264/AVC, the number of IPMs increases from 9 to 35 in HEVC, which can significantly improve the accuracy of the intra-prediction. The 35 prediction modes include DC mode, planar mode, and 33 angular modes, as depicted in Figure 4 [20].

The basic flow of the intra-prediction scheme in HEVC is depicted in Figure 5, and can be summarized in the following three steps:

Firstly, HEVC adopts Rough Mode Decision (RMD) to select N candidate modes from the 35 modes, to reduce the computational complexity. The number of candidate modes is N, which is determined by the size of the PU which is illustrated in Table 1. RMD considers both the Sum of Absolute Transformed Difference (*SATD*) and the bits used for representing the coding information of each mode.

Then, the most probable modes (MPMs) derived from the neighboring blocks are added to the above candidate set.

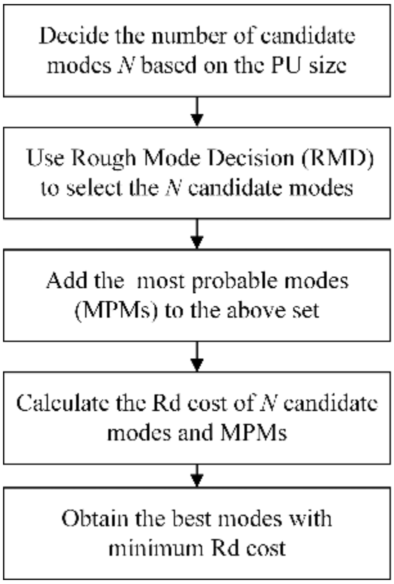

FIGURE 5. The basic flow of intra-prediction scheme in HEVC.

TABLE 1. Number of candidate modes (N) for each PU size.

PU size	N
4×4	8
8×8	8
16×16	3
32×32	3
64×64	3

Note that instead of the one MPM that there is in H.264/AVC, HEVC increases the number of MPMs to three. In HEVC, if the current IPM is one of the three MPMs, only the MPM index needs to be encoded with one or two bits; otherwise, the index of the current IPM needs to be encoded by using a 5-bit fixed length code. The adoption of this technology can dramatically improve the coding efficiency of HEVC.

Finally, the Rate Distortion Optimization (RDO) technique is used to calculate the RD cost of the candidate modes selected by the above two steps. Therefore, the mode which has a minimum RD cost is chosen as the optimal mode of the current PU. The RD cost of a mode can be formulated as

$$J = D_m + \lambda_m R_{all}. \tag{1}$$

Here, D_m represents the distortion between the original signal and the reconstructed signal, R_{all} stands for the total number of bits used for encoding with mode m, while λ_m is the Lagrange multiplier.

III. THE PROPOSED STEGANOGRAPHY IN HEVC

In this section, we first analyse the cover selection rule based on three aspects: the effect on the quality of video stream, the statistical features of the distribution of the IPMs in the same CU and the bitrate of the compressed video stream caused by modifying IPMs. Then the mapping rules are presented to map between the IPMs and the secret information.

A. THE COVER SELECTION RULE

To the best of our knowledge, existing IPM-based video steganography in both H.264/AVC and HEVC mainly adopts all the IPMs of I4×4 blocks as the cover in which to embed information. However, the advances of technologies in HEVC (such as the flexible quad-tree structure) provide us more choices for cover selection, which is important for the security of video steganography. Therefore, a cover selection rule that uses the coding information of the CU and PU instead of using all the IPMs of I4×4 blocks as cover, as in the previous literature, is proposed in this paper. It can be specified in terms of the following three conditions.

Firstly, the effect of modifying IPMs on the quality of HEVC video stream is a primary consideration. In order to embed information into IPMs, the IPMs always need to be modified from optimal ones to suboptimal ones, which will inevitably cause a distortion of the video quality. Therefore, how to reduce the distortion as much as possible must be taken into account. As we all know, in HEVC, a CU with large size is always used for coding the areas with a smooth texture, whereas a small size CU is a more appropriate choice for areas with complex texture. In addition, it is widely acknowledged that areas with complex textures can tolerate more distortion. Hence, we employ CUs with a small size to embed information. The minimum CU size in HEVC is 8×8 (the corresponding depth is 3), and it can be further split into four 4×4 PU with the $N \times N$ partition type. So, a 4×4 PU is also the minimum PU size. Note that only an 8×8 CU can be split into four 4×4 PUs. From the above, we select the IPMs of 4×4 PUs for embedding the secret information. However, not all IPMs of 4×4 PUs are appropriate for being a cover. So, the following two aspects are used to choose the appropriate 4×4 PUs.

Secondly, the statistical features of the distribution of the IPMs in the same CU are considered, something which is more important for the security of the stego video. Here, we divide all 4×4 PUs into two categories – uniform 4×4 PUs and non-uniform 4×4 PUs. If the four 4×4 PUs in one 8×8 CU have the same IPM, we classify the four 4×4 PUs as uniform 4×4 PUs. Otherwise, the four 4×4 PUs are classified as non-uniform 4×4 PUs. We find that modifying the IPMs of uniform 4×4 PUs will destroy the statistical features of the distribution of the IPMs and leave traces for steganalysis, which may lead to a security threat to the steganography. This is also demonstrated in Section V. Therefore, the IPMs of uniform 4×4 PUs can be regarded as the "wet" spots which can not be used as the cover. In addition, the ratios of the uniform 4×4 PUs to all 4×4 PUs under different QP are given in Table 2. From this table, we can see that the uniform 4×4 PUs constitute only a small proportion of the total: they make up only less than 8% of all 4×4 PUs. This means that ignoring the IPMs of uniform 4×4 PUs does not have a significant effect on the capacity of the steganography, and is entirely feasible.

Thirdly, the problem of an increase in the bitrate of the compressed video stream caused by modifying IPMs is also

TABLE 2. The ratios of uniform 4×4 PUs in all 4×4 PUs.

Sequences	Ratios(%)			
	QP=22	QP=27	QP=32	QP=37
Traffic	2.30	2.95	3.57	4.27
PeopleOnStreet	2.37	2.52	2.97	3.45
Kimono	2.54	3.50	4.00	4.44
ParkScene	1.96	2.99	4.13	5.50
Cactus	1.62	2.27	2.91	3.50
BasketballDrive	2.38	2.58	2.96	3.45
BQTerrace	2.43	2.97	3.37	3.73
BasketballDrill	1.93	2.55	3.06	2.43
BQMall	1.79	2.23	2.76	3.26
PartyScene	1.03	1.32	1.69	2.35
RaceHorses	1.47	1.92	2.40	3.20
BasketballPass	1.57	1.75	2.08	2.69
BQSquare	0.88	1.20	1.75	2.13
BlowingBubbles	0.89	1.20	1.62	2.35
RaceHorses	1.09	1.92	1.86	3.20
FourPeople	2.19	2.69	3.38	4.23
Johnny	2.30	2.60	3.31	3.94
KristenAndSara	2.41	2.63	2.78	3.10
BasketballDrillText	1.96	2.45	2.74	2.15
ChinaSpeed	5.00	5.77	6.92	7.14
Vidyo1	2.20	2.51	3.06	3.22
Vidyo3	2.39	2.80	3.19	3.58
Vidyo4	2.44	2.84	3.27	3.57
AVERAGE	2.05	2.53	3.03	3.52

TABLE 3. The ratios of the best mode equal to MPMs in all 4×4 PUs.

Sequences	Ratios(%)			
	QP=22	QP=27	QP=32	QP=37
Traffic	67.17	71.20	75.68	79.48
PeopleOnStreet	62.71	67.51	70.69	73.34
Kimono	71.61	76.31	77.16	77.56
ParkScene	65.76	75.55	82.23	86.23
Cactus	61.43	68.40	72.22	73.96
BasketballDrive	70.25	73.09	75.34	77.14
BQTerrace	63.68	70.60	73.40	76.15
BasketballDrill	64.33	68.84	67.47	66.73
BQMall	62.44	67.30	70.94	74.59
PartyScene	50.96	56.53	61.53	69.27
RaceHorses	52.57	62.95	68.59	74.04
BasketballPass	58.00	60.61	64.21	69.49
BQSquare	44.48	49.67	54.84	60.70
BlowingBubbles	47.91	54.00	60.73	69.34
RaceHorses	57.36	58.21	63.96	68.24
FourPeople	67.51	71.62	74.47	77.52
Johnny	70.43	73.75	75.67	76.83
KristenAndSara	66.89	69.06	70.85	74.00
BasketballDrillText	63.48	67.06	65.29	64.45
ChinaSpeed	60.35	63.43	65.60	67.75
Vidyo1	66.66	68.83	71.22	73.38
Vidyo3	67.07	42.20	70.03	72.93
Vidyo4	71.20	72.90	74.37	75.33
AVERAGE	62.36	65.64	69.85	72.98

worth considering. According to Section II-B, we can see that if we modify an IPM which is one of the MPMs to one which is not one of the MPMs, this will increase the bits used to code the mode. In H.264/AVC, the kind of IPMs that are similar are not used as the cover. However, due to changing from one MPM in H.264/AVC to three MPMs in HEVC, the proportion of IPMs equal to one of the MPMs rises sharply. The experiments indicate that the lowest proportion of all sequences is more than 50%, as shown in Table 3. So, in our work, if the current IPM is equal to one of the MPMs, whether the IPM can be the cover depends on the embedding rate and the capacity of the current CU. If the capacity of the current CU is sufficient, the IPMs equal to one of the MPMs should be excluded from the cover. Otherwise, all the IPMs of the non-uniforms 4×4 PUs should be added to the cover set.

From the above analysis, the cover selection rule can be summarized in Algorithm 1. In Algorithm 1, the "wet" mode is defined as the IPM of the 4×4 PU which is regarded as the wet spot and can not be used for embedding.

B. MAPPING RULES

Taking into consideration the fact that the fewer the IPMs that are modified, the smaller the effect on the quality of the video. Then, as a coding example, matrix coding [14], [21], [22] is used to improve the embedding efficiency in this paper, because it can embed k bits of information into an n-bit cover with only one bit being modified. Here, the embedding efficiency refers to the expected number of bits to be embedded when one bit is modified, and the relation between n and k satisfies (2). More about matrix coding is introduced briefly as follows.

$$n = 2^k - 1. \tag{2}$$

Let us assume that C is the cover information and S is the secret information. Then C and S are divided into several groups, with lengths of n and k, respectively. Thus, $C_i = (C_{i1}, C_{i2}, \ldots, C_{in})$ represents the i^{th} group of cover information with n bits, whereas $S_i = (S_{i1}, S_{i2}, \ldots, S_{ik})$ represents the i^{th} group of secret information with k bits. Finally, Equations (3) and (4) are combined to calculate the position α of the element which needs to be modified. Here, $\oplus$ denotes xor operation. Note that we should convert the value of $(C_{ij}).j$ from decimal to binary before xor operation. Similarly, α calculated by (4) is a binary number, we should convert it to a decimal number to determine the position of the element which needs to be modified.

$$b(C_i) = \bigoplus_{j=1}^{n} (C_{ij}).j \tag{3}$$

$$\alpha = S_i \oplus b(C_i) \tag{4}$$

Therefore, the modified information is obtained by

$$M_i = \begin{cases} C_i, & \alpha = 0 \\ C_{i1}, \ldots, \neg C_{i\alpha}, \ldots, C_{in}, & \alpha \neq 0, \end{cases} \tag{5}$$

Algorithm 1 The Selection of Candidate Embedding Blocks

Require: Current CU
Ensure: the set of candidate embedding IPMs –– CIPM

Obtain the depth of current CU –– d
Obtain the partition type of current CU –– P
if d==3 && P == $N \times N$ **then**
  Obtain the IPMs of the four PUs (denote as PU_0 to PU_4) in current CU: M_0, M_1,M_2, M_3.
  if $M_0 == M_1 == M_2 == M_3$ **then**
    the IPMs are "wet" modes and excluded from the CIPM
  else
    for $i = 1$ to 3 **do**
      Obtain the three MPMs of PU_i : MPM_0, MPM_1, MPM_2.
      if M_i equals to one of the three MPM above **then**
        if the capacity is enough to embed information **then**
          the IPMs are "wet" modes and excluded from the CIPM
        else
          the IPMs are added to the CIPM
        end if
      else
        the IPMs are added to the CIPM
      end if
    end for
  end if
end if

where ¬ denotes the negation operation.

The receiver can obtain the k bits of secret information by decoding the n bits of modified information M_i using (6).

$$S_i = b(M_i) \tag{6}$$

The value of k is set to 2 in our work, thus, n = 3. Therefore, every three IPMs can embed two bits secret information. And the matrix coding based mapping rules between IPMs and secret information can be expressed as a combination of (3) to (5), which can be described as follows.

Let assume m_1, m_2, m_3 are the three IPMs, w is the secret information with two bits: w_1, w_2 . According to (3) and (4), the position α can be calculate as:

$$\alpha = w \oplus (\overset{3}{\underset{j=1}{\oplus}} (P(m_i)).j), \tag{7}$$

where $P(m_i)$ represents the LSB of m_i. Then if α is not equals to zero, m_α needs to be modified to map the secret information w, otherwise no IPMs should be modified. The modified mode m'_α should meet $\mathrm{P}(m'_\alpha) = 1 - \mathrm{P}(m_\alpha)$. And the exact value of m'_α can be obtained by the following rules.

We first divide the rest of the 34 IPMs of HEVC except m_α into two groups based on their LSB (Least Significant Bit). Group *SLSB* includes the modes which have the same LSB as m_α whereas Group *OLSB* includes the modes which have the opposite LSB from m_α.

Then, the rest of the 34 IPMs of HEVC can be divided into another two groups based on SATD. Similar to the intra-coding process of HEVC (as seen in Figure 5), we sort the modes by their STAD values in ascending order. The rest of the 34 IPMs can be divided into two groups: the IPM whose SATD ranks among the top N (the value of N is specified in Section II-B) is assigned to Group *TSATD*, otherwise, the mode is assigned to Group *LSATD*.

In this paper, we combine the above two kinds of classification and divide the rest of the 34 modes into three groups, namely, as follows:

Group 1: the IPMs in Group *SLSB*;
Group 2: the IPMs in both Group *OLSB* and Group *LSATD*;
Group 3: the IPMs in both Group *OLSB* and Group *TSATD*.

By comprehensive consideration of the LSB and the compression efficiency, m'_α should be contained in Group 3. Here, the RDO technique is used to get the exact value of m'_α – the mode which has the minimum RD cost in Group 3.

The following is a example to show how to use these mapping rules.

Let us assume $m_1 = 20$, $m_2 = 14$, $m_3 = 11$, thus $P(m_1) = 0$, $P(m_2) = 0$, $P(m_3) = 1$; the two bits secret information $w = 10$. Then, according to (7), $\alpha = 10 \oplus (0\times1 \oplus 0\times2 \oplus 1\times3) = 10 \oplus 11 = 01$. Therefore, m_1 should to be modified to m'_1 which satisfying $P(m'_1) = 1$. So, Group OLSB = $\{1, 3, 5, \ldots, 33\}$. Assume that Group TSATD = $\{1, 2, 4, 5, 26, 29, 32, 33\}$, then Group 3 = $\{1, 5, 29, 33\}$. Next we calculate the RD cost of mode 1, 5, 29 and 33 respectively. If mode 1 has the minimum RD cost in all four modes, $m'_\alpha = 1$.

IV. INFORMATION EMBEDDING AND EXTRACTION

In this section, we introduce how to embed secret information and extract it.

A. EMBEDDING

According to Section III, the process of the proposed algorithm for embedding information is illustrated in Figure 6.

1). Read one frame from the original video stream, and the default process of compression of the HEVC encoder is implemented to compress the current frame.

2). Since the coding information in HEVC is stored in 4×4 blocks, we obtain the CU depth information and PU partition mode as well as the IPM of every 4×4 block of the current frame and select the appropriate blocks as the candidate embedding blocks according to Algorithm 1.

3). In order to enhance the security, the position of the blocks which are used for embedding the information is selected by a pseudo-random sequence controlled by a private key. Here, we first use the private key to select the candidate blocks and then we divide them into groups, and each group has three blocks.

4). Obtain the secret information and group every two bits together. It is worth noting that to further guarantee the

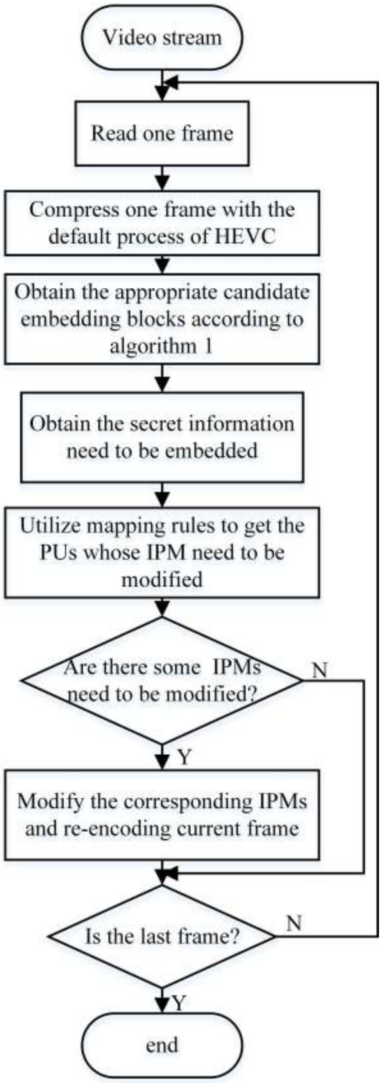

FIGURE 6. Information embedding based on IPMs in HEVC.

security of the secret information, the secret information is scrambled by another private key.

5). Use matrix coding to embed two bits of secret information w_1, w_2 into every group of candidate embedding blocks, and record the position of the corresponding block whose IPM needs to be modified.

6). Repeat Step 5 until all groups have had information embedded into them.

7). Use SATD and RDO to obtain the modified modes of the blocks recorded in Step 5 and re-encode the current frame with the modified IPMs.

8). Return to Step 1 until the last frame.

From the above, the proposed algorithm is not only easy to understand and implement, but also is of low computational complexity.

B. EXTRACTION

The steps of the procedure for the extraction are as follows.

TABLE 4. The details of the video datasets.

sequence	resolution	frame number	frame rate(fps)
Traffic	2560×1600	150	30
PeopleOnStreet	2560×1600	150	30
Kimono	1920×1080	240	24
ParkScene	1920×1080	240	24
Cactus	1920×1080	500	50
BasketballDrive	1920×1080	500	50
BQTerrace	1920×1080	600	60
BasketballDrill	832×480	500	50
BQMall	832×480	600	60
PartyScene	832×480	500	50
RaceHorses	832×480	300	30
BasketballPass	416×240	500	50
BQSquare	416×240	600	60
BlowingBubbles	416×240	500	50
RaceHorses	416×240	300	30
FourPeople	1280×720	600	60
Johnny	1280×720	600	60
KristenAndSara	1280×720	600	60
BasketballDrillText	832×480	500	50
ChinaSpeed	1024×768	500	30
Vidyo1	1280×720	600	60
Vidyo3	1280×720	600	60
Vidyo4	1280×720	600	60

1). Partially decode the HEVC video stream and obtain the depths and PU partition modes as well as the IPMS of every 4×4 block.

2). Use the private key to generate the sequence of positions of the embedding blocks, and obtain all the blocks which have secret information bits embedded in them.

3). From every group of blocks, obtain M_i, and recover its two bits of embedded information w_1, w_2 using (6).

4). Repeat Step 3 until all secret information has been recovered, and then unscramble the recovered secret information.

As we can see, the extraction is also of low complexity.

V. EXPERIMENTAL RESULTS

In this section, experimental results are presented to demonstrate the feasibility and effectiveness of the proposed method. A video database containing 23 YUV sequences was used for the experimental simulation. A more detailed description of these sequences is presented in Table 4. The experimental simulations were implemented on the well-known HEVC test model (HM) 15.0 reference software [23] under all intra (AI) and low delay with P pictures (LDP) simulation environment. The I frame period was set to 4 under the LDP simulation environment. The quantization parameters (QPs) were set to 22, 27, 32, and 37, respectively, which are the same as the usual HEVC test conditions. By default, the other encoder configurations which are not mentioned in this paper also conform to the usual HEVC test conditions. The payload α is defined as the number of bits embedded per

TABLE 5. BDBR and BD-SSIM under the AI coding structure with different payloads $\alpha = 0.1, 0.3, 0.5$.

sequence	BDBR						BD-SSIM					
	$\alpha = 0.1$		$\alpha = 0.3$		$\alpha = 0.5$		$\alpha = 0.1$		$\alpha = 0.3$		$\alpha = 0.5$	
	Ours	Sheng	Ours	Sheng	Ours	Sheng	Ours	Sheng	Ours	Sheng	Ours	Sheng
Traffic	0.96	1.32	1.76	2.70	2.21	3.53	0.76	0.94	1.40	1.98	1.78	2.67
PeopleOnStreet	1.20	1.71	2.23	3.48	2.80	4.60	1.04	1.40	1.99	2.96	2.50	4.02
Kimono	0.27	0.40	0.53	0.85	0.64	1.09	0.24	0.31	0.47	0.70	0.57	0.88
ParkScene	1.11	1.48	1.92	2.81	2.35	3.55	0.90	1.06	1.59	2.11	1.97	2.72
Cactus	1.25	1.78	2.19	3.45	2.69	4.45	0.97	1.23	1.72	2.49	2.15	3.34
BasketballDrive	0.95	1.39	1.73	2.80	2.14	3.68	0.78	1.06	1.45	2.25	1.80	3.04
BQTerrace	0.92	1.30	1.64	2.55	2.02	3.32	0.81	1.07	1.46	2.20	1.82	2.95
BasketballDrill	2.11	2.90	3.57	5.55	4.37	7.28	1.74	2.16	3.03	4.45	3.74	6.00
BQMall	1.55	2.12	2.72	4.21	3.38	5.55	1.30	1.70	2.62	3.55	2.97	4.77
PartyScene	1.81	2.70	2.76	4.61	3.33	5.77	1.55	2.12	2.46	3.92	3.00	5.08
RaceHorses	1.43	2.10	2.41	3.89	2.95	5.03	1.17	1.55	2.02	3.09	2.58	4.11
BasketballPass	1.37	1.99	2.34	3.85	2.96	5.01	1.08	1.06	1.96	3.07	2.54	4.09
BQSquare	1.51	2.34	2.40	4.12	2.94	5.23	1.25	1.82	2.04	3.45	2.58	4.54
BlowingBubbles	1.93	2.81	2.97	4.88	3.55	6.06	1.60	2.13	2.62	4.08	3.19	5.29
RaceHorseC	1.13	1.63	1.95	3.10	2.42	3.99	1.35	1.60	2.07	2.85	2.53	3.68
FourPeople	1.35	1.81	2.53	3.82	3.19	5.10	1.20	1.51	2.63	3.27	2.86	4.44
Johnny	1.14	1.58	2.17	3.33	2.71	4.41	0.94	1.26	1.87	2.78	2.37	3.73
KristenAndSara	1.22	1.72	2.34	3.66	2.96	4.97	1.03	1.40	2.03	3.18	2.58	4.40
BasketballDrillText	1.96	2.78	3.40	5.41	4.24	7.18	1.63	2.11	2.90	4.41	3.69	6.02
ChinaSpeed	1.51	2.19	2.97	4.63	3.89	6.35	1.35	1.71	2.63	3.90	3.54	5.54
Vidyo1	1.10	1.58	2.05	3.27	2.58	4.32	0.96	1.26	1.78	2.70	2.23	3.63
Vidyo3	0.87	1.25	1.72	2.75	2.21	3.77	0.81	1.14	1.57	2.58	2.06	3.61
Vidyo4	0.85	1.25	1.64	2.65	2.06	3.49	0.71	1.00	1.39	2.22	1.77	2.98
AVERAGE	1.28	1.83	2.26	3.58	2.81	4.74	1.09	1.42	1.99	2.96	2.50	4.04

IPM of 4×4 PUs. Three kinds of payload ($\alpha = 0.1, 0.3, 0.5$) are analyzed in this paper.

To measure the performance of the compression, the Bjontegaard Delta Bit rate (BDBR) [24] and Structural Similarity Index Measure gain (BD-SSIM) [25] have been calculated to evaluate the video quality with four different groups of QP and bitrate. Here, BDBR considers both the PSNR (Peak Signal to Noise Ratio) and the bit rate of the compressed video, which is commonly used in an objective way to evaluate video quality. BD-SSIM considers both the SSIM and the bit rate of the compressed video, and it is in better accordance with subjective human vision. With both BDBR and BD-SSIM, higher values mean greater distortions of video quality. In addition, Sheng's method in [18] has been implemented for a performance comparison with our method.

A. CODING PERFORMANCE AND ANALYSIS

All the 23 sequences have been tested to verify the coding performance of the proposed algorithm. Table 5 shows the coding performance of our method as well as Sheng's method under the AI coding structure. The table shows that when the payload α is 0.1, 0.3, or 0.5, the increase in the BDBR is 1.28%, 2.26%, and 2.81%, and the increase in the BD-SSIM is 1.09%, 1.99%, and 2.5%, on average, respectively; whereas the BDBR increases by 1.83%, 3.58%, and 4.74%, and the BD-SSIM increases by 1.42%, 2.96%, and 4.04%, respectively, with Sheng's method. That is to say, the video quality of our method outperforms Sheng's method. When testing the coding performance under the inter-coding configurations, the statistics provided in Table 6 show that the average BDBR of our method increases by 1.10%, 1.95%, and 2.43%, and the average BD-SSIM increases by 0.98%, 1.82%, and 2.25%, respectively, for our method. From Table 5 and Table 6, we can see that both our method and Sheng's method may cause slight distortion in the video streams, and the larger the payload, the greater the distortion. But we can also see that our method achieves better performance both in terms of BDBR and BD-SSIM for all embedding payloads under the AI and LDP coding structures. In addition, the BDBR and BD-SSIM of our method in Table 5 and Table 6 also demonstrate that our method is suitable for videos with various scenes and bitrates.

B. SECURITY

Since existing IPM-based steganalysis methods are all implemented on H.264/AVC, an extension of Zhao's method [26] based on IPM Calibration (IPMC), which has the best performance in detecting IPM-based steganography of H.264/AVC, has been built as the detector to evaluate the security performance of our method. The detection performance is measured by the accuracy rate (AR), which can be calculated by as follows:

$$AR = (TPR + TNR)/2, \tag{8}$$

where TPR is the true positive rate, and TNR is the true negative rate.

TABLE 6. BDBR and BD-SSIM under the LDP coding structure with different payloads $\alpha = 0.1, 0.3, 0.5$.

sequence	BDBR						BD-SSIM					
	$\alpha = 0.1$		$\alpha = 0.3$		$\alpha = 0.5$		$\alpha = 0.1$		$\alpha = 0.3$		$\alpha = 0.5$	
	Ours	Sheng	Ours	Sheng	Ours	Sheng	Ours	Sheng	Ours	Sheng	Ours	Sheng
Traffic	0.92	1.26	1.71	2.60	2.16	3.40	0.77	0.95	1.47	2.06	1.81	2.78
PeopleOnStreet	0.77	1.06	1.45	2.21	1.82	2.93	0.72	0.97	1.39	2.10	1.76	2.84
Kimono	0.26	0.35	0.48	0.77	0.58	0.94	0.28	0.31	0.46	0.71	0.58	0.85
ParkScene	1.03	1.40	1.83	2.69	2.25	3.40	0.91	1.09	1.64	2.21	2.00	2.85
Cactus	1.14	1.61	2.01	3.12	2.47	4.05	0.97	1.28	1.73	2.56	2.15	3.45
BasketballDrive	0.70	0.99	1.27	2.06	1.61	2.74	0.60	0.84	1.13	1.82	1.46	2.42
BQTerrace	0.91	1.27	1.59	2.50	1.97	3.26	0.92	1.19	1.67	2.48	2.02	3.30
BasketballDrill	1.61	2.28	2.82	4.42	3.51	5.78	1.50	1.93	2.63	3.85	3.31	5.14
BQMall	1.33	1.82	2.36	3.63	2.92	4.75	1.19	1.64	2.23	3.27	2.78	4.40
PartyScene	1.54	2.34	2.36	4.00	2.84	5.00	1.45	2.07	2.28	3.72	2.78	4.76
RaceHorses	0.93	1.37	1.59	2.66	2.02	3.43	0.78	1.18	1.66	2.35	2.00	3.18
BasketballPass	0.90	1.21	1.54	2.47	1.91	3.25	0.77	1.12	1.49	2.25	1.85	3.01
BQSquare	1.35	2.14	2.15	3.78	2.66	4.75	1.25	1.86	1.99	3.47	2.50	4.52
BlowingBubbles	1.70	2.51	2.64	4.41	3.17	5.51	1.57	2.10	2.51	4.03	3.11	5.18
RaceHorseC	0.82	1.14	1.42	2.15	1.69	2.81	0.73	0.97	1.35	1.94	1.60	2.65
FourPeople	1.34	1.84	2.53	3.84	3.21	5.17	1.19	1.59	2.33	3.40	2.95	4.67
Johnny	1.22	1.64	2.28	3.51	2.89	4.69	1.08	1.27	2.05	2.94	2.56	4.03
KristenAndSara	1.22	1.69	2.30	3.63	2.98	4.92	1.04	1.45	2.11	3.25	2.68	4.41
BasketballDrillText	1.58	2.23	2.77	4.38	3.41	5.79	1.40	1.91	2.55	3.86	3.13	5.27
ChinaSpeed	1.16	1.57	2.22	3.47	2.93	4.81	0.95	1.16	1.89	2.90	2.54	4.18
Vidyo1	1.09	1.63	2.02	3.28	2.58	4.29	0.95	1.28	1.65	2.82	2.24	3.71
Vidyo3	0.91	1.25	1.76	2.78	2.19	3.75	0.79	1.18	1.67	2.72	2.02	3.72
Vidyo4	0.84	1.22	1.65	2.65	2.08	3.51	0.73	1.06	1.50	2.31	1.85	3.03
AVERAGE	1.10	1.56	1.95	3.09	2.43	4.04	0.98	1.32	1.82	2.74	2.25	3.67

TABLE 7. Average accuracies (AR) against IPMC under different QP with payload $\alpha = 0.5$.

method	AR(%)			
	QP=22	QP=27	QP=32	QP=37
Sheng	95.28	82.67	61.33	63.53
MTC	91.00	85.52	68.28	62.86
Ours	90.85	80.37	59.93	56.03

In this section, we first verify the security performance of the proposed cover selection rule. A data hiding method which only uses matrix coding (MTC) to embed the information into HEVC without the proposed cover selection rule is used for comparison with our method. The results are shown in Table 7. Then, in order to further demonstrate the security performance of our method, a comparison is made between our method and Sheng's method. The *AR* against the detector built by IPMC features under different QP with payload $\alpha = 0.5$ is shown in Table 7. From Table 7, we can see that our method, which adopts the cover selection rule, outperforms MTC without the cover selection rule as well as Sheng's method. That is to say, our method can effectively improve the security performance.

VI. CONCLUSION

In this paper, a novel IPM-based video steganography in HEVC has been proposed. Since the previous literature on steganography in HEVC mainly focuses on using the features of HEVC to construct a mapping rule or distortion function for STC, this paper first shows that the features of HEVC can also be used for cover selection. The experimental results demonstrate its feasibility and effectiveness. The proposed method is easy to implement and can also be conducted as a preliminary screening of covers in the other IPM-based HEVC steganographies. That is to say, the proposed algorithm can also be integrated into other IPM-based video steganographies. Therefore, we will further study how to implement the proposed algorithm using the framework of STC to further enhance the coding efficiency and security.

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