A Novel Information Hiding Method for H.266/VVC Based on Selections of Luminance Transform and Chrominance Prediction Modes

Xiyao Liu¹, Kaiyue Shi¹, Aihua Li¹, Hao Zhang¹*, Jiang ming² and Hui Fang³

Abstract—This paper proposes a novel information hiding method designed for H.266/Versatile Video Coding (VVC) compressed video streams. In this work, we explore two exclusive tools in H.266/VVC standard, named Multiple Transform Selection (MTS) and Cross-component linear model (CCLM), to hide information. These two tools are utilized to preserve high video reconstruction quality and compression efficiency as well as enhance hidden capacity. In specific, MTS is for hiding information into luminance blocks by modifying the selections of transforms. Comparing with other tools, MTS has less significant impact on compression quality and efficiency. In addition, CCLM is further used to hide information into chrominance blocks to further enlarge the hidden capacity with little impact on the other two metrics. To our best knowledge, it is the first information hiding method exclusively designed for H.266/VVC. Experimental results show that our proposed information hiding method ensures high hidden capacity, remarkable video reconstruction quality and insignificant impact on compression efficiency, which achieves better overall performances comparing to existing methods for compressed video.

I. INTRODUCTION

Video information hiding is one of the crucial techniques to provide diverse video services, such as video authentication and augmentation [1], [2], [3]. It refers to hiding different types of featured information into video streams for either security authentication, e.g., watermarking, or metadata in video augmentation, e.g., depth-map embedding, motion information embedding, and extended-color information. Thus, the development of advanced video information hiding techniques has high value for various new multimedia applications.

Recently, information hiding techniques for compressed video have received significant attention because videos are typically stored and transmitted in compressed format [4], [5]. Existing compressed video information hiding methods have been well researched in compression standards, including MPEG [6], [7], H.264 [8], [9] and H.265/High Efficiency Video Coding (HEVC) [10], [11]. These methods could be categorized based on their embedding strategies, i.e., transform-domain-based, intra-prediction-based, and inter-prediction-based methods. Transform-domain-based methods modify quantized transform coefficients [12], [13], [14], [15] to embed information. However, this type of method could cause error drifts problems, thus degrading video quality with embedded information. Intra-prediction-based and inter-prediction-based methods are widely proposed to avoid the error drifts problem. Wang et al. [16], [17] and Sheng et al. [18] modify the intra prediction modes in HEVC video format to embed information. Gaj et al. [19] group intra prediction modes based on spatial texture analysis to enhance the re-compression robustness. Shanableh et al. [20] and Yang et al. [21] modify the Coding Block (CB) structure of P frame to embed information. Yang and Li [22] utilize the motion vectors in P-frames of HEVC videos for this purpose. Tew et al. [23] modify the structure of CBs and non-zero transform coefficients to embed information.

Despite the success of the above-mentioned information hiding techniques in previous video compression standards, there is little work to investigate exclusive tools provided in the latest video compression standards H.266/Versatile Video Coding (VVC) [24], [25], [26] to further improve the information hiding methods. H.266/VVC uses a hybrid coding framework, including prediction, transform, quantization, and entropy coding, which is identified as the previous coding standard. But VVC introduces many new compression tools to enhance compression efficiency. For the intra prediction, VVC introduces several new mechanisms [27], such as Matrix weighted Intra Prediction (MIP) [28], Multiple reference line (MRL) [29], and Cross-component linear model (CCLM) [30], which increases the flexibility of mode selection, thus potentially suit information hiding. Further, H.266/VVC designs a novel adaptive transform selection mechanism, named Multiple Transform Selection (MTS) [31], to switch between horizontal and vertical residual transforms based on the hybrid DCT+DST scheme and make the compression more effective. This provides further flexibility for information hiding.

In this work, we propose a novel compressed video information hiding method in H.266/VVC by exploring its unique tools of intra-frame coding for both luminance and chrominance blocks. It achieves a better trade-off among hidden capacity, video quality and compression efficiency. Here, we hide messages into the luminance blocks via modifying the selected transforms of MTS because its impact on...
Our key contributions are summarized as follows:

- To has superior overall performance compared to other state-of-the-art information hiding methods for compressed video in terms of hidden capacity, video quality and compression efficiency. A novel compressed video information hiding method is proposed by exploring the unique tools of intra-frame coding in VVC. To our best knowledge, it is the first information hiding method exclusively designed for VVC.

- A unique coding tool in VVC, namely MTS, is deployed to hide information into luminance blocks. It has less significant impact on video quality and compression efficiency than other tools in luminance blocks e.g. MIP and MRL. This characteristic could ensure the high video quality, sufficient hidden capacity and insignificant impact on compression efficiency, which cannot be achieved by any information hiding methods designed for previous video coding standards because they cannot use this tool since the transforms for previous video coding standards are fixed.

- Another unique tool in VVC, namely CCLM, is also used to hide information into chrominance blocks. This tool introduces several new chrominance prediction modes. In this manner, the prediction mode selections for information hiding are enlarged, yielding better video quality and lower bitrate increment, which cannot be achieved by any information hiding methods designed for previous video coding standards.

The remainder of the paper is organized as follows. Section II describes the details of the proposed compressed video information hiding method. In Section III, the experimental results are presented to demonstrate the effectiveness of the proposed algorithm. Finally, Section IV draws a conclusion and suggests future work.
on analyzing statistical probability to minimize the negative impact on video reconstruction quality when switching the optimal transform to another transform for information hiding. To mitigate the negative impact of hiding, the sub-optimal transform, which is defined as the transform with the highest frequency chosen by the VVC encoder when excluding the optimal transform, is better to be divided into the opposite group of the optimal transform. Fig. 2 illustrates the frequency distributions to select the sub-optimal transform when the optimal transform is excluded. For example, the transforms \{2, 3, 5\} are in the first group and transforms \{0, 1, 4\} are in the second group. In our proposed method, if the information bit is ’1’, the optimal transform in each 4 \times 4 luminance CB is selected from \{0, 1, 4\} listed in Table I. Otherwise, the optimal transform is selected from the transforms \{2, 3, 5\}.

\[
mtsIdx_h = \begin{cases} 
\arg\min_{mtsIdx \in \{0,1,4\}} (D(mtsIdx) + \lambda \cdot R(mtsIdx)), & \text{if bit} = 1 \\
\arg\min_{mtsIdx \in \{2,3,5\}} (D(mtsIdx) + \lambda \cdot R(mtsIdx)), & \text{if bit} = 0 
\end{cases}
\]

where \(mtsIdx\) and \(mtsIdx_h\) represent the index of different transform and the selected transform for information hiding, \(D(\cdot)\) and \(R(\cdot)\) represent the compressed distortion and the number of bits required by using the transform with index of \(mtsIdx\), and \(\lambda\) is the Lagrangian parameter.

2) Chrominance-prediction-mode-based Hiding: VVC adopts eight chroma intra prediction modes, including five traditional prediction modes which are PLANAR, VER, HOR, DC, DM_CHROMA, and three innovative cross-component linear models (CCLM), which are LM_CHROMA, MDM_L, MDM_T, to reduce the redundancy between color components. Similarly to the grouping division of MTS transforms, we divide chrominance prediction modes into two different groups for information hiding. The frequency distributions of the sub-optimal chrominance prediction modes are shown in Fig 3. As a result, if the secret information is ’1’, the optimal prediction mode in the 4 \times 4 chrominance CB is selected from \{1, 18, 50, 67\}. Otherwise, the optimal prediction mode is selected from \{0, 68, 69, 70\}.

\[
mode_h = \begin{cases} 
\arg\min_{mode \in \{1,18,50,67\}} (D(mode) + \lambda \cdot R(mode)), & \text{if bit} = 1 \\
\arg\min_{mode \in \{0,68,69,70\}} (D(mode) + \lambda \cdot R(mode)), & \text{if bit} = 0 
\end{cases}
\]

where \(mode\) and \(mode_h\) represent different prediction mode and the selected prediction mode for information hiding, \(D(\cdot)\) and \(R(\cdot)\) represent the compressed distortion and the number of bits required by using the prediction mode, and \(\lambda\) is the Lagrangian parameter.

B. Information extraction

The extraction of secret information is very simple and fast, and the information can be extracted only by partially decoding the I frame, the extraction framework is shown in Fig. 4. We use 4 \times 4 luminance and chrominance CBs for information extraction. For a 4 \times 4 luminance CB, its partially decoded to obtain its index of utilized transform. If this index is belong to \{0, 1, 4\}, the extracted information bit is ’1’. Otherwise, the extracted information bit is ’0’. For a 4 \times 4 chrominance CB, the extracted information bit

| MTSIdx | Transform matrices |
|--------|--------------------|
| 0      | DCT2               |
| 1      | Transform skip(TS) |
| 2      | DST7, DST7         |
| 3      | DCT8, DST7         |
| 4      | DST7, DCT8         |
| 5      | DCT8, DCT8         |

Fig. 2. When the optimal transform is determined, the distribution of the transforms excluding the optimal transform

Fig. 4. We use 4 \times 4 luminance and chrominance CBs for information extraction. For a 4 \times 4 luminance CB, its partially decoded to obtain its index of utilized transform. If this index is belong to \{0, 1, 4\}, the extracted information bit is ’1’. Otherwise, the extracted information bit is ’0’. For a 4 \times 4 chrominance CB, the extracted information bit
To further demonstrate the superiority of our proposed method, we compare its information hiding performance with three existing information hiding methods. Using MTS-based hiding only, proving the superiority of the proposed combined method. The MTS-based hiding is a part of our proposed method (II-A.1). The testing results are listed in Table II. In this table, Proposed I only uses MTS-based hiding while the Proposed II combines the MTS-based hiding and chrominance-prediction-mode-based hiding. NA values of bitrate and PSNR under a certain hidden capacity mean that this hidden capacity is not achievable. In addition, the bolded number in the table represents the best performance. Note that the hidden capacities of different video sequences vary based on the resolutions and texture complexity. For example, the BlowingBubbles with lower resolutions and the vidyo1 with lower texture complexity are expected to have smaller hidden capacities comparing to the others.

As shown in Table II, all the testing hiding strategies have insignificant increase of video bitrate or decrease of PSNR under different hidden capacities, confirming the insignificant impact on compression efficiency and the remarkable video quality. Moreover, the proposed MTS-based hiding has much higher hidden capacity than lower bitrate increment and higher PSNR compared with MRL-based hiding and MIP-based hiding due to its insignificant impact on the compression efficiency. It demonstrates that the MTS is the most suitable tool for information hiding in Intra-frame coding of VVC. Moreover, the proposed combined method further enhances the hidden capacity and achieves similar video quality and compression efficiency comparing to the method using MTS-based hiding only, proving the superiority of the combined method.

A. Ablation study

In this section, we evaluate different hiding strategies based on three unique tools in Intra-frame coding of VVC, which are MRL, MIP, and MTS, and compare them with our proposed combined method. The MRL-based hiding modifies the selected reference frames while the MIP-based hiding modifies the selected prediction modes. The MTS-based hiding is a part of our proposed method (II-A.1). The testing results are listed in Table II. In this table, Proposed I only uses MTS-based hiding while the Proposed II combines the MTS-based hiding and chrominance-prediction-mode-based hiding. NA values of bitrate and PSNR under a certain hidden capacity mean that this hidden capacity is not achievable. In addition, the bolded number in the table represents the best performance. Note that the hidden capacities of different video sequences vary based on the resolutions and texture complexity. For example, the BlowingBubbles with lower resolutions and the vidyo1 with lower texture complexity are expected to have smaller hidden capacities comparing to the others.

As shown in Table II, all the testing hiding strategies have insignificant increase of video bitrate or decrease of PSNR under different hidden capacities, confirming the insignificant impact on compression efficiency and the remarkable video quality. Moreover, the proposed MTS-based hiding has much higher hidden capacity than lower bitrate increment and higher PSNR compared with MRL-based hiding and MIP-based hiding due to its insignificant impact on the compression efficiency. It demonstrates that the MTS is the most suitable tool for information hiding in Intra-frame coding of VVC. Moreover, the proposed combined method further enhances the hidden capacity and achieves similar video quality and compression efficiency comparing to the method using MTS-based hiding only, proving the superiority of the combined method.

B. Comparison with other compressed video methods

To further demonstrate the superiority of our proposed method, we compare its information hiding performance
with those of three existing compressed video methods in HEVC [18], [21], [23] in terms of bitrate and PSNR under different hidden capacities. The results are shown in Table III. Here, NA values of bitrate and PSNR under a certain hidden capacity mean that the method cannot achieve this hidden capacity. In addition, the bolded number in the table represents the best performance. As shown in Table III, our proposed method achieves a better overall performance in terms of capacity, bitrate and PSNR compared with existing methods. Compared with [18], the hidden capacity of our proposed method is much higher although the reconstruction quality and bitrate increment of these two methods is comparable. In specific, the hidden capacities of our hiding method are about 2.5 times of those of [18] for the testing videos. Comparing to the methods [21], [23], our proposed method achieves much lower bitrate increment with higher PSNR under different hidden capacities. Specifically, the average increment between the bitrates of the compressed videos after information hiding and the original compressed videos by using our proposed method is as small as 3.096. This value is only 8.7% and 0.6% of those by using [21], [23] on the testing videos under different hidden capacities, which are 35.385 and 488.643, respectively.
In this paper, we have proposed a novel compressed video information hiding method for VVC by selecting the luminance transform and chrominance prediction modes. This is the first information hiding method exclusively designed for VVC to achieve better information hiding performance comparing to the methods designed for previous compression standards. Experimental results have demonstrated that our proposed method outperforms existing methods in terms of the overall performances of hidden capacity, video quality and compression efficiency. Our future work aims to commercialize our proposed method to address copyright breach issues and video forgery problems.

**REFERENCES**

[1] “A survey on information hiding using video steganography,” Artificial Intelligence Review, vol. 1, pp. 1–65, 2021.

[2] A. Robert, O. Alvarez, and G. Doerr, “Adjusting bit-stream video watermarking systems to cope with http adaptive streaming transmission,” in 2014 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 2014, pp. 7416–7419.

[3] Shuang Yi, Yicong Zhou, Chi-Man Pun, and CL Philip Chen, “A new reversible data hiding algorithm in the encryption domain,” in 2014 IEEE International Conference on Systems, Man, and Cybernetics (SMC). IEEE, 2014, pp. 3215–3220.

[4] Yiqi Tew and KokSheik Wong, “An overview of information hiding in h.264/avc compressed video,” IEEE transactions on circuits and systems for video technology, vol. 24, no. 2, pp. 305–319, 2013.

[5] A. A. Elrowayati, M. A. Alresh, Mfl Abdullah, and R. Latip, “Hvc watermarking techniques for authentication and copyright applications: Challenges and opportunities,” 2021.

[6] Didier Le Gall, “Mpeg: A video compression standard for multimedia applications,” Communications of the ACM, vol. 34, no. 4, pp. 46–58, 1991.

[7] Weiping Li, “Overview of fine granularity scalability in mpeg-4 video standard,” IEEE Transactions on circuits and systems for video technology, vol. 11, no. 3, pp. 301–317, 2001.

[8] T. Wiegand, G. J. Sullivan, G. Bjontegaard, and A. Luthra, “Overview of the h.264/avc video coding standard,” IEEE Transactions on Circuits and Systems for Video Technology, vol. 13, no. 7, pp. 560–576, 2003.

[9] Heiko Schwarz, Detlev Marpe, and Thomas Wiegand, “Overview of the scalable video coding extension of the h.264/avc standard,” IEEE Transactions on circuits and systems for video technology, vol. 17, no. 9, pp. 1103–1120, 2007.

[10] G. J. Sullivan, J. Ohm, W. Han, and T. Wiegand, “Overview of the high efficiency video coding (hevc) standard,” IEEE Transactions on Circuits and Systems for Video Technology, vol. 22, no. 12, pp. 1669–1688, 2012.

[11] Jani Lainema, Frank Bossen, Woo-Jin Han, Junghye Min, and Kemal Ugur, “Intra coding of the hevc standard,” IEEE transactions on circuits and systems for video technology, vol. 22, no. 12, pp. 1792–1801, 2012.

[12] Po-Chun Chang, Kuo-Liang Chung, Jian-Jone Chen, Chien-Hsiung Lin, and Tseng-Jung Lin, “A dct/dst-based error propagation-free data hiding algorithm for hevc intra-coded frames,” Journal of Visual Communication and Image Representation, vol. 25, no. 2, pp. 239–253, 2014.

[13] A. Mansouri, A. M. Azaaev, F. Torkamani-Azar, and F. Karagollu, “A low complexity video watermarking in h.264 compressed domain,” IEEE Transactions on Information Forensics and Security, vol. 5, no. 4, pp. 649–657, 2010.

[14] Tanima Dutta and Hari Prabhat Gupta, “A robust watermarking framework for high efficiency video coding (hevc)—encoded video with blind extraction process,” Journal of Visual Communication and Image Representation, vol. 38, pp. 29–44, 2016.

[15] Y. Liu, H. Zhao, S. Liu, C. Feng, and S. Liu, “A robust and improved visual quality data hiding method for hevc,” IEEE Access, vol. 6, pp. 53984–53997, 2018.

[16] Jiaji Wang, Rangding Wang, Wei Li, Dawen Xu, and Meiling Huang, “A large-capacity information hiding method for hevc video,” in 3rd International Conference on Computer Science and Service System. Atlantis Press, 2014.

[17] Jiaji Wang, Rangding Wang, Dawen Xu, and Wei Li, “An information hiding algorithm for hevc based on angle differences of intra prediction mode,” JSW, vol. 10, no. 2, pp. 213–221, 2015.

[18] Qi Shuang, Rangding Wang, Anshun Pei, and Bin Wang, “An information hiding algorithm for hevc based on differences of intra prediction modes,” in International Conference on Cloud Computing and Security. Springer, 2016, pp. 63–74.

[19] Sibaji Gai, Arijit Sur, and Prabin Kumar Bora, “Prediction mode based h.265/hev video watermarking resisting re-compression attack,” Multimedia Tools and Applications, pp. 1–31, 2020.

[20] Tamer Shanabreh, “Alternating split decisions of coding units for message embedding in hevc,” Multimedia Tools and Applications, vol. 77, no. 7, pp. 8939–8953, 2018.

[21] Yi Yuan Yang, Zhaohong Li, Wenchao Xie, and Zhenzhen Zhang, “High capacity and multilevel information hiding algorithm based on pa partition modes for hevc videos,” Multimedia Tools and Applications, vol. 78, no. 7, pp. 8423–8446, 2019.

[22] Jie Yang and Songbin Li, “An efficient information hiding method based on motion vector space encoding for hevc,” Multimedia Tools and Applications, vol. 77, no. 10, pp. 11979–12001, 2018.

[23] Yiqi Tew and KokSheik Wong, “Information hiding in hvc standard using adaptive coding block size decision,” in 2014 IEEE International Conference on Image Processing (ICIP). IEEE, 2014, pp. 5502–5506.

[24] Mohsen Abdoli, Felix Henry, Patrice Brault, Pierre Duhamel, and Frédéric Dufaux, “Short-distance intra prediction of screen content in versatile video coding (vvc),” IEEE Signal Processing Letters, vol. 25, no. 11, pp. 1690–1694, 2018.

[25] Ahmed Kamoun, Wassim Hamidouche, Fatma Belghith, Jean-François Nezan, and Nouri Masmoudi, “Hardware design and implementation of adaptive multiple transforms for the versatile video coding standard,” IEEE Transactions on Consumer Electronics, vol. 64, no. 4, pp. 424–432, 2018.

[26] Jong-Seok Lee, Jun-Taek Park, Han-Sol Choe, Ju-Hyong Byeon, and Dong-Gyu Sim, “Overview of vvc,” Broadcasting and Media Magazine, vol. 24, no. 4, pp. 10–25, 2019.

[27] Alexey Filipov and Vasily Rufitskiy, “Recent advances in intra prediction for the emerging h.266/vc video coding standard,” in 2019 International Multi-Conference on Engineering, Computer and Information Sciences (SIBIRCON). IEEE, 2019, pp. 0525–0530.

[28] Michael Schäfer, Björn Stallenberger, Jonathan Pfaff, Philipp Helle, Heiko Schwarz, Detlev Marpe, and Thomas Wiegand, “An affine-linear intra prediction with complexity constraints,” in 2019 IEEE International Conference on Image Processing (ICIP). IEEE, 2019, pp. 1089–1093.

[29] Yao-Jen Chang, Hong-Jheng Jhu, Hui-Yu Juan, Liang Zhao, Xin Zhao, Xiang Li, Shan Liu, Benjamin Bross, Paul Keydel, Heiko Schwarz, et al., “Intra prediction using multiple reference lines for the versatile video coding standard,” in Applications of Digital Image Processing XLII. International Society for Optics and Photonics, 2019, vol. 11137, p. 1113716.

[30] Yong-Uk Yoon, Do-Hyone Park, and Jae-Gon Kim, “Enhanced derivation of model parameters for cross-component linear model (cclm) in vvc,” IEICE TRANSACTIONS on Information and Systems, vol. 103, no. 2, pp. 469–471, 2020.

[31] I Farhat, W Hamidouche, A Grill, Daniel Menard, and O Deforges, “Lightweight hardware implementation of vvc transform block forasic decoder,” in ICASSP 2020-2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). IEEE, 2020, pp. 1663–1667.

[32] Xin Zhao, Ianle Chen, Marta Karczewicz, Li Zhang, Xiang Li, and Wei-Jung Chien, “Enhanced multiple transform for video coding,” in 2016 Data Compression Conference (DCC). IEEE, 2016, pp. 73–82.

[33] E. Alshina J. Chen, “Algorithm description for versatile video coding and test model 1 (vtm),” in document JVTJ1002. ITU-T/ISO/IEC Joint Collaborative Team on Video Coding (JVT VC), 2018.

[34] E. Bossen, “Common test conditions and software reference configurations,” in document JCTVC-L1100. ITU-T/ISO/IEC Joint Collaborative Team on Video Coding (JCT-VC), 2013.