JOIV : Int. J. Inform. Visualization, 8(3-2): IT for Global Goals: Building a Sustainable Tomorrow - November 2024 1496-1505

INTERNATIONAL JOURNAL
ON INFORMATICS VISUALIZATION

journal homepage : www.joiv.org/index.php/joiv

A Novel Information Hiding Approach Using Selective Quantization Technique in Video Coding

Joan Hau [a,*], Yiqi Tew [a], Li Peng Tan [a]

[a] *Faculty of Computing and Information Technology, Tunku Abdul Rahman University of Management and Technology, Kuala Lumpur, Malaysia*

Corresponding: [*]joanh-wm18@student.tarc.edu.my

***Abstract*—This research examines the different areas of information hiding in current and emerging video compression standards. In the subsequent sections, we provide a detailed comparison of these techniques based on partition modes, prediction units, transform coding, and syntax elements. It shows the engineer and the reader that none of the methods are perfect but are the best for selected applications. We also consider the new video coding standards that have recently appeared, H.266/Versatile Video Coding (VVC) and H.265/High-Efficiency Video Coding (HEVC) and stress the fact that information hiding is critical in attaining such high compression efficacy. To facilitate the reader's understanding of all the relative information, the table that provides the analysis of each technique is presented in the form of a simple listing containing information about each technique's advantages, disadvantages, impacts, and practical applications. The current resource is intended to assist researchers and practitioners in optimizing information hiding for improved video compression. The study's outcome can contribute to enhancing knowledge of information hiding and the new developments of information hiding in video compression beyond what current research offers now, as well as provide a foundation for fresh advances in the field. Further, it is introduced to selective quantization techniques as the approach to information hiding. This method also minimizes this distortion while putting the information into the compressed stream. Finally, we evaluate the performance of this introduced approach towards information hiding capacity and maintaining video quality, with the potential to inspire further research and development in the field.**

***Keywords*—H.266/Versatile Video Coding (VVC); H.265/High-Efficiency Video Coding (HEVC); information hiding; selective quantization techniques.**

Manuscript received 15 Mar. 2024; revised 24 Aug. 2024; accepted 22 Oct. 2024. Date of publication 30 Nov. 2024.

I. Introduction

Videos have become ubiquitous in modern life, serving as a primary channel for communication and information dissemination across social media, education, businesses, and entertainment [1]. Their effectiveness lies in capturing attention and presenting information in an engaging, interactive format. The proliferation of high-speed internet and mobile devices has further democratized video access, making it a powerful tool for education (health, safety, government affairs, environment), marketing (product promotion, brand awareness, customer engagement), and collaboration.

However, the explosion of digital communication necessitates robust information security [2]. Video information hiding plays a critical role in various video services, including authentication (digital watermarking for intellectual property protection, copyright enforcement), integrity analysis [3] and data embedding (hiding sensitive information within a video) [6], [7] as shown in Fig. 1.

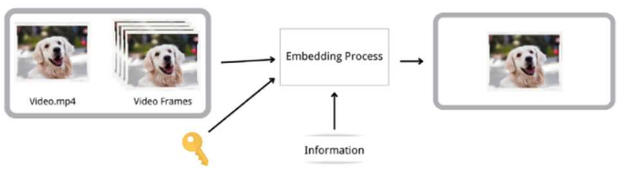

Fig. 1 General Framework of Digital Data

This hidden information can also be used for identification and verification, ensuring video integrity in the age of deepfakes, where malicious actors manipulate videos to spread misinformation. As video content prevalence rises, safeguarding its authenticity and integrity becomes paramount. Information-hiding technology allows videos to function as reliable channels for communication, education, and entertainment. It encompasses embedding information (Fig. 2) and subsequent extraction, facilitating secure transmission of confidential data between senders and receivers.

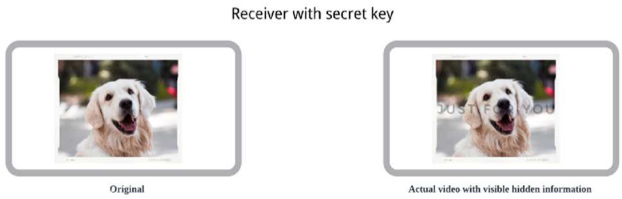

Fig. 2 The Actual Video with Visible Hidden Information

Video information hiding techniques have gained significant traction with video storage and transmission often relying on compressed formats. Existing research has extensively explored information-hiding methods within compressed video standards. For instance, Tew et al. [8] leverage coding block size decisions in H.265/HEVC to embed information by altering coding tree unit choices for block size selection based on predefined mapping rules. Each coding block must adhere to specific dimensions to accommodate hidden information without compromising perceived quality. Similarly, Zhang et al. [9] utilize the multiple sign bit hiding technique to embed a single sign bit into selected coefficient groups. They further perform additional sign bit hiding on chosen transform blocks. Chang et al. [10] propose an information hiding method employing DCT and DST coefficients, building upon the work of Lin et al. [11] who applied information hiding using DCT in intra-coded frames without transmission errors. Finally, Liu [12] proposes embedding information into the multi-coefficients of chosen frames' 4x4 DST luminance blocks.

While prior techniques have achieved success in earlier video compression standards, there's a gap in research on leveraging the proprietary tools available in the latest standard, H.266/VVC. Liu et al. [13] explore a unique information hiding technique specifically designed for H.266/VVC's intra-frame coding of luminance and chrominance blocks. VVC introduces a plethora of new compression options for significantly enhanced compression efficiency compared to previous standards. For instance, matrix-weighted internal prediction allows for more than one internal reference pattern to be selected; the multiple reference lines, Cross-Component Linear Model (CCLM), and similar techniques allow for selecting one or multiple reference patterns in the frequency domain. This makes VVC a suitable method in applications which require information hiding [4].

As video content applications have become more widespread, making information security reliable was crucial. Information-hiding technology is necessary to preserve the identity and genuineness of videos employed in communication, learning, and entertainment. The following information hiding techniques are described in the literature sources of this paper, and their advantages and disadvantages are presented. We also aim to provide a general survey of these methods, according to their general concepts.

We also introduce a method called selective quantization techniques, which we have previously described. This technique employs the qualities of video quantization to effect data insertion without much distortion to the video signal. By carefully adjusting quantization parameters, our method hides information effectively while making it resistant to common video processing tasks. Through this analysis and our innovative method, we aim to push forward the field of video information hiding.

The paper is structured as follows: Section I provides an overview of the latest video coding standards and their relevance to information hiding as well as reviews related information hiding techniques, discussing their advantages and limitations. Section II delves into the theoretical and practical aspects of these techniques with the details of the selective quantization technique, including the algorithm and processes for embedding and extracting information. Section III assesses the performance of our introduced method with various experiments, comparing it to existing techniques. Finally, Section IV concludes by summarizing the findings and suggesting future research directions.

A. Overview of the Latest Video Coding Standard

A conventional hybrid video encoder, as shown in Fig. 3, operates within the frameworks of HEVC and VVC. The VVC [14] methodology encompasses several phases, including partitioning, prediction, transformation, and entropy coding, which are crucial for generating or decoding bitstreams.

The video compression process begins with pre-processing the source video using the VVC encoder. The video frames are then divided into Coding Units (CUs) of various sizes. Intra prediction techniques and inter prediction techniques are applied at every CU to predict pixel values of the blocks. Following this, a transform is done on the residual signal such that it changes from being in the spatial domain to that of the frequency domain. The encoder also quantizes the Transform Coefficients (TCs), codes entropy for these quantized coefficients, and carries out in-loop filtering on the reconstructed video to restrain noise. This leads to the generation of compressed bitstream.

On receiving the compressed video bit stream, the VVC decoder performs several operations. These comprise extracting the header data and metadata, entropy-decoding the bitstream using CABAC, de-quantizing the TCs, and finally applying the inverse transform to get the residual signal. The predicted values are then summed with the residual signal to reconstruct the video. The decoder also performs in-loop filtering to denoise and deblock the video parts before the final reconstructed video of the format and resolution of the input stream is produced.

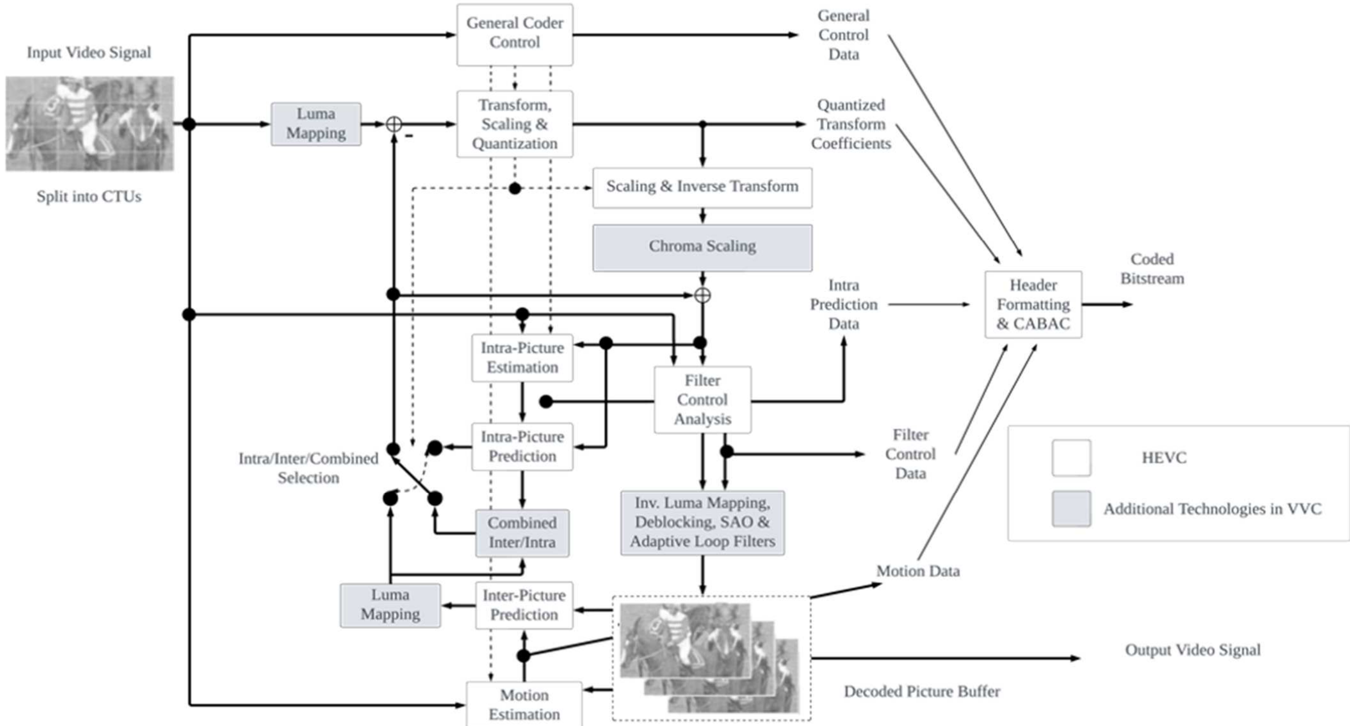

Fig. 3 Typical Hybrid Video Encoder in HEVC with Additional Technologies (grey regions) proposed in VVC [4], [5]

The VVC method incorporates many other progressive approaches and methods to reach the highest compression ratios without sacrificing pictorial quality, which makes it one of the most efficient standard tools for video compression for most practical purposes.

1) H.266/VVC: The VVC [14] standard has been created by the Joint Video Experts Team that unites specialists from the ITU-T Video Coding Experts Group and the ISO/IEC Moving Picture Experts Group. The new standard aimed to offer more enhancement in the aspect of video compression efficiency in comparison with the previous protocols, including HEVC [4]The VVC methodology involves several operations, such as intra- and inter-prediction, transform coding, quantization, entropy coding, in-loop filtering, and bitstream encoding or decoding.

The video compression shall pre-process the source video using the VVC encoder as a pre-processing step for compression. The frames which make up the video are then partitioned into coding units of varying sizes. In the case of each coding unit, intra and inter-prediction methods are applied to predict the pixel values of the blocks. After that, a transformation is performed on the residual signal to transform it from the spatial domain to the frequency domain.

Subsequently, the encoder, using the quantized transform coefficients, performs entropy coding and in-loop filtering to spruce up the reconstructed picture and eliminate the actual noise. This leads to generating the compressed video bitstream of a particular video content.

On receiving this compressed bitstream, the VVC decoder executes several processes that help in reversing this compression. The decoding process includes header information and metadata extraction, entropy decoding using context-based adaptive binary arithmetic code, de-quantization of transform coefficients, and inverse transformation for reconstructing residual information. This is then added to the predicted values to generate the reconstructed video. Subsequently, in-loop filtering is run on this video to eliminate any more noise and debris before exporting the video into the format and resolution of the users' preference.

a. Intra-prediction

The VVC codec has available planar, DC, angular, and directional modes of prediction that aim at estimating pixel value inside the coding unit from the values of the surrounding pixels. Some of the special properties of this codec are the DC and Planar modes, the latter of which is useful in achieving more accurate prediction of pixel values. It also includes Position Dependent Prediction Combination and Adaptive Color Transform to increase the capability of prediction. Further, VVC offers 65 Angular Intra Prediction Modes with the shape of blocks being direction adaptive and the use of four-tap interpolation filters for higher precision [15].

b. Inter Prediction

In the context of VVC standard, motion estimation and motion compensation are employed to anticipate pixel- value for a coding unit. It does this by comparing the corresponding blocks in the frames that have been coded earlier. This approach assists in precise estimation of the pixel values considering the motion, and variation scene in previous frames [16].

c. Transformation

The VVC codec supports several types of transforms, including the DCT [17] and DST. Depending on the block size of the coding unit, the size of these transforms can range from 4x4 to 64x64. To improve coding efficiency, the VVC introduces four new transform coding techniques: Multiple Transform Selection (MTS), Low-Frequency Non-separable Secondary Transform, Sub-Block Transform, and a large (64-point) type-2 DCT. These innovations are designed to enhance the codec's performance and efficiency. [18].

d. Quantization

Quantization is a conversion where not continuous values, but only discrete ones are considered. This technique is applied in the VVC codec using transform coefficient quantization to minimize the data used to encode a transform coefficient. This is done by dividing the coefficients by a QP value. This QP value holds the information about the size of the quantization step and, therefore, the level of data reduction [19].

e. Entropy Coding

Entropy coding is a method that is used to represent source symbols employing code words [19]. In the VVC codec, the entropy coding method used is CABAC, which is very efficient in using statistical characteristics of the input data. This enables CABAC to better compress the data based on how frequently a given symbol reoccurs.

f. In-Loop Filtering

In-loop filtering aims to enhance the picture quality of compressed videos and lower distortions that may come up during video compression. It will be necessary to remember that the VVC standard contains several in-loop filtering techniques for this purpose. These techniques include luma mapping with chroma scaling, deblocking filters, sample adaptive offsets, adaptive loop filters and cross-component adaptive loop filters [20]. In-loop filtering is used at the encoder and decoder parts of the video coding. These filters also address the VVC standard to ensure that the final videos are as efficient as possible in terms of quality.

The VVC standard significantly enhances the partition's versatility by presenting numerous partition modes, including the quadtree and the multi-type of tree. This makes it possible to work with block sizes as small as 4×4 and also has further partitioning through binary trees. At the same time, VVC supports much larger block sizes, up to 128 x 128, which is very advantageous for high-resolution and high-motion video content. The additional exploratory splits in block partitioning used by VVC extend resolution capability, although they are also designed to increase coding effectiveness across depth. Such improvements make VVC an important step in the development of video coding standards, providing more accurate control of video compression.

2) H.265/HEVC: The HEVC [5], [21] encoding procedure starts from the segmentation of input video into the rectangular regions known as CUs. These CUs can have a size range of 64x64 to 4x4 pixels. Each CU is subdivided into Prediction Units (PUs), which, in terms of size, are either the same or lesser than the size of the CUs. PUs is used in motion compensation, where the objective is to find the most suitable block within the previously coded frame. The residual signal is the difference between the current block and the best match found on the previous search.

After that, the residual signal will go through a mathematical transformation, either DCT or IT, depending on the chosen coding mode. HEVC supports multiple DCT sizes for block size, from 4x4 to 32x32. Increasing block sizes results in better compression ratios as well as increases the level of difficulty as regards the encoding and decoding process involved. Quantization is then performed to quantify the obtained coefficients to minimize the amount of data needed to represent them. The QP determines the quantization step size, which can be varied to find a suitable compromise between compressed file size and visual quality.

Entropy coding is used to further reduce the amount of data. HEVC employs CABAC for this purpose. Technically, once the video stream is encoded, it is either transmitted or stored for later decoding. During decoding, the process is essentially reversed: the entropy-coded data is first decoded, and then the quantization coefficients are reconstructed by inverse quantization. The final frame is reconstructed by applying inverse DCT or IT to retrieve the residual signal, which is then added to the predicted signal.

B. Related Works in Information Hiding Techniques

The following section discusses the different information hiding techniques explored over the past five years within the realm of video compression standards. Table 1 summarizes our findings to offer a clear and detailed overview of these techniques.

1) Partition Modes: Chai et al [22] developed a deep learning-based video steganography framework designed to hide confidential information in videos while maintaining visual similarity between the original and steganographic videos. The system consists of three main components: an encoder, a decoder, and a discriminator network. The encoder first extracts feature from the cover video. The decoder then embeds secret information into these features to generate the pseudo-video. The discriminator network evaluates how similar the pseudo-video is to the original cover video. To improve the visual quality, the framework uses a CU mask extracted from the VVC video, and an attention mechanism called Convolutional Block Attention Module. The CU mask helps the network to understand the CU partitioning pattern of the VVC video, while the attention mechanism improves the visual quality of the stolen video. Empirical results show that the proposed framework outperforms existing steganographic networks in terms of perceptual quality of steganographic videos, accuracy of information decoding, and embedding capacity.

Considering the visual quality, bit rate cost and capacity of the video after information hiding, Li et al [23] proposed a VVC steganography algorithm utilizing chroma block segmentation, which effectively exploits the inherent features of the VVC block segmentation structure. The algorithm utilizes the VVC standard to embed confidential data by changing the block partitioning structure of the chroma component. In addition, Li et al. proposed a four-embedding level algorithm that can satisfy different requirements in terms of visual quality, bit rate cost and capacity. They also proposed a complementary inner loop filter in the VVC standard, i.e., a multi-scale residual neural network technique, which aims to mitigate the adverse effects of using steganographic algorithms.

2) Prediction Units: It has been 10 years since HEVC was released and there has been a lot of research work on information hiding that can be applied to HEVC. The information hiding techniques in HEVC that have been proposed in the past 5 years are also being discussed in this paper as references or guidelines for the information hiding in VVC. Li et. al [24] proposed a data hiding algorithm based on the selection of PU partition modes in different sizes of CU. The researchers selected the CUs of 8×8 and 16×16 to hide the information to achieve high visual quality and high capacity. During the experiments, all the CUs are divided into a series of CU-groups, where each of the CU-groups contains numbers of CU. In the first algorithm, the 16×16 CUs in one of the CU-groups which contain a total of three CUs in each series are being processed. The binary message is converted to base 7 to enlarge the capacity for hiding binary messages. Each of the 16×16 CUs in each series will contain an array which represents the optimal PU partition mode for each CU. The first algorithm will then modify the PU partition modes to hide the information. For the second algorithm a similar process is applied into 8×8 CUs where each of the series of CU contains only one CU in each. The secret message is converted to base 3 for 8×8 CU. According to experimental findings, video sequences with embedded data provide almost identically outstanding visual quality to sequences without data hiding, and the increase in bitrate brought on by data hiding is kept to a tolerably low level.

Yang et. al [25] introduces a novel information hiding algorithm that operates on PU partition modes in P-frames of the HEVC standard. There are a total of six partition modes being utilized by the researchers for CU size 16×16 and larger. The partition modes are being categories into 3 groups which include {N×2N, 2N×N} ∈ Group 1; {nL×2N, 2N×nD} ∈ Group 2; {nR×2N, 2N×nU} ∈ Group 3 where each of the groups represent a binary bit '10', two binary bits '10' and '11' respectively. While for the CU size 8×8, there are also three groups of partition modes being categories which include {N×N} ∈ Group 1; {N×2N} ∈ Group 2; {2N×N} ∈ Group 3, and each of the group is used to represent binary bits '0', '10' and '11' respectively. The modification of PU partition modes is applied based on the binary bits of the information that wanted to be hidden during the inter-prediction process. The proposed algorithm is characterized by its high capacity, multilevel nature, and ability to maintain visual quality while minimizing bit rate increase. Notably, the algorithm outperforms existing works in terms of embedding capacity.

3) Transform Coding: An information hiding technique specifically for VVC was proposed by Liu et. al [13]. The researchers successfully hid information in dedicated tools proposed for VVC, namely MTS and cross-component linear model. Liu e t. al used 4x4 Coding Blocks (CBs) in I-frames to hide information because tiny CBs are used to encode texture-rich parts of video frames, making them suitable for information hiding. The method is used to hide information by controlling the transformation of luminance and the selection of prediction modes of chrominance. In terms of hiding the information in the MTS, Liu et. al [13] carry out the experiment to calculate the optimal transform selection that can be chosen by the frames based on the bit that is going to hide. The proposed method selects the optimal transform for each 4×4 luminance CB from a set of {0, 1, 4} when the information bit is '1'. A set of transforms {2, 3, 5} will be selected for the information bit '0'. To hide the information by modifying the chrominance prediction modes, the researchers divide the prediction modes into two groups where a set of {1, 18, 50, 67} prediction modes is selected when the information bits is '1', Otherwise, the selection of the optimal prediction mode in the 4×4 chrominance CB is from {0, 68, 69, 70}. To extract the information, the inverse process of the proposed information hiding technique is applied.

Zhao et. al [26] proposed a video steganography technique that relies on the Transform Block (TB) decision for H.265/HEVC. The system consists of three distinct elements, namely embedding, transmission of carrier bitstreams, and extraction components. Before embedding, it is necessary to acquire the partitioning structures of CBs, Prediction Blocks, and TBs through the coding decision of H.265/HEVC. The current partitioning structures can achieve the minimum cost of distortion and number of bits, resulting in effective partitioning. The method that has been proposed involves altering the decision of the TB to embed secret messages and simultaneously update the corresponding residuals. The system additionally employs an effective embedding mapping algorithm capable of embedding a message consisting of N bits (where $N > 1$) while modifying, at most, one bit of the transform partitioning flag. The empirical findings indicate that the suggested approach can attain superior visual fidelity, greater capacity for embedding, and reduced bit-rate escalation compared to existing state-of-the-art investigations.

Zhao et. al [27] proposes a novel steganographic approach, namely Prediction Unit based Wide Residual-Net Steganography, for HEVC videos. The rule for embedding a secret message is as follows. The hidden information is encoded as a base-6 numeral d_6 if the CU has dimensions of 16×16 or 32×32. Conversely, if the CU has dimensions of 8×8, the message is encoded as a base-3 numeral d_3. Subsequently, the Prediction Unit (PU) pertaining to the target CU is altered in such a manner that the resultant PU can be correlated with secret information, d. If the bits to be embedded are represented by the binary sequence 011, they are subsequently converted to the senary numeral 3. Furthermore, if the PU that requires modification is a 16×16 CU, it is adjusted to conform to the nR×2N format. The method under consideration enables the alteration of all categories of prediction units, apart from 2N×2N, to attain optimal embedding efficiency while preserving the statistical distribution of PUs both pre- and post-data hiding.

4) Syntax Elements: Syntax elements in video processing represent crucial components and parameters within a video bitstream, encompassing details like motion vectors, transform coefficients, coding modes, and quantization parameters. These components are important for the efficiency of the video compression and the accuracy for decoding in maintaining video quality.

Fotovvat et. al [28] propose a selective encryption technique designed to secure video data in VVC to encode a high compression efficiency. This approach aims to reduce the computational load of encryption. This method is useful when dealing with video containing watermarking or transcoding. The method proposed by Fotovvat involves selecting various syntax elements for encryption, including luma intra-prediction modes, Motion Vector Difference

(MVD), and residual signs. An encryption algorithm is designed with an XOR operation between the stream and the selected syntax elements. The result presented by Fotovvat showing the algorithm offers better visual security compared to selective encryption techniques proposed in AVC and HEVC by Boyadjis et al. [29] and Shahid et al. [30].

Another selective encryption algorithm for VVC compression standard is introduced by Farajallah et al. [28]. This algorithm selectively encrypts the video content to enhance security while preserving compression efficiency. By using this technique, only certain parts of the video are encrypted. This reduces the encryption process more complex while elevating the video compression process. The procedure involves dividing the video into different parts and applying many encryption schemes on the partitions depending on the partition's confidentiality level. This makes it possible to manage the compromise between security and video quality. This encryption is located at the CABAC. The syntax elements that are encrypted in this algorithm are TCs, MV, adaptive loop filter, inter-prediction, sample adaptive offset filter, and intra-prediction.

Dawen Xu [31] introduces a novel approach for concealing information within incompletely encrypted iterations of HEVC videos, utilizing a particular coefficient modification methodology. The frames and processes involved in this proposed algorithm are CABAC and inter-prediction processes in both I-frames and P-frames. The sign bits of quantized TCs and MVD undergo encryption by utilizing the bitwise XOR operation in conjunction with a stream cipher. The findings indicate that there is no discernible effect on the compression rate, while still achieving a perceptually effective scrambling. The researcher has shown that the proposed algorithm is well-suited for real-time applications due to its utilization of solely XOR operations during the encryption process, resulting in a significantly low computational complexity.

C. *Discussion of Existing Methodologies*

The methodologies incorporate supplementary information into compressed video streams while preserving fidelity. The hiding of information within video streams has many pragmatic uses, including but not limited to digital watermarking, safeguarding intellectual property rights, and verifying the authenticity of video content. Scholars have devised diverse methods for hiding information within video compression standards in recent years. The analysis reveals a diverse range of information hiding techniques employed in the VVC and HEVC standards. These techniques primarily focus on modifying various components of video coding, such as partition modes, prediction units, transform coding and syntax elements to embed secret information. Different approaches are utilized, including binary masking, encryption, and modification of CUs, prediction modes, and TB partitioning. The comparative analysis highlights the pros and cons of each method as tabulated in Table 1. For instance, techniques that extract CU partitions as binary masks offer flexibility by supporting different-sized cover video frames and arbitrary binary data. However, they require significant computational resources for dataset training and have limitations in terms of message size and embedding capacity.

On the other hand, selective encryption methods provide improved visual security, but they may impact video frame quality and require careful consideration of QPs. The impact of each technique is categorized as high, medium, or low based on factors such as performance, video quality, computational complexity, and security. These ratings help researchers and practitioners identify the most suitable technique for their specific application. For instance, methods that achieve the highest visual quality at low bitrates are well-suited for applications where video quality is paramount.

On the other hand, the technique with less computational complexity is inapplicable in real-time processing. The paper also identifies different areas of using information hiding techniques based on the analysis of differing applications. Such applications include Video security applications, Secure exchange of secret messages, Video surveillance, Video conferencing, Digital Right Management and Security cameras with secured video. These can be used by researchers and practitioners while defining and choosing various techniques to be used in the given task. The evaluation also defines some directions for further research and development in the sphere of information hiding in video coding. These are considering the possibility of using more than one technique, studying the effect of the techniques on various standards of video coding and attempting to fine-tune the techniques for a particular application area. However, there are possibilities for more detailed studies of the computational complexity and further refinements to the secret message's capacity and 'stealth'.

II. Materials and Method

The current information-hiding techniques for video processing provide a wide range of functions that may present many problems, such as high computational capacity, low quality of video compression, or low hiding capacity. This review also investigates these trade-offs and also looks at the Selective Quantization Technique (SQT) [32], which was proposed earlier as a method for data hiding within video frames when encoding. SQT prioritizes maximizing information hiding capacity while considering the specific constraints imposed by the total number of frames in a video sequence. This integration seamlessly occurs within the transformation and quantization stages, establishing SQT as an intrinsic component of the video processing pipeline.

We have previously investigated the details of the SQT algorithm, which strategically modifies the QP values of video slices based on the information to be concealed, which is assigned at the outset [34]. By employing a switching mechanism between odd and even QP values corresponding to the embedded data bits {0, 1}, the algorithm facilitates the covert integration of secret information within the video frames.

TABLE I
COMPARISON VIEW ON INFORMATION HIDING TECHNIQUES

Video Standard	Year	Method	Pros	Cons	Impact	Application
VVC	2022	Proposed PyraGAN achieves better performance in invisibility and capacity for hidden messages and accurately decoded messages. [22]	Enhanced performance in terms of invisibility and capacity for hidden messages with accurate message decoding. Supports different-sized cover video frames and arbitrary binary data.	Limitations in message size and the types of messages that can be hidden, as well as embedding capacity. Required a significant number of computational resources for dataset training.	High	Applications with specific data requirements.
		Modifying the partition modes of chroma CUs to include secret information with additional CNN-based in-loop filter. [23]	Supports dynamic data embedding and video quality improvement.	Frame rate limited to 30 fps with three specific QPs: 26, 32, and 38.	High	High-quality video applications.
		Encrypt syntax elements including Transform Coefficients (TCs), Motion Vector (MV), Adaptive Loop Filter (ALF), prediction, Sample Adaptive Offset (SAO) filter, and intra prediction in CABAC. [28]	Robust application of CABAC modification enhances security.	Specific QP values, which may affect video frame quality.	High	Security-focused applications.
	2021	Modification of Transform Mode in MTS and Prediction modes in CCLM. [13]	Tailored for VVC's new features.	Limited to I-frames, restricting the scope of information embedding.	Low	General VVC applications.
		Selective encryption method by modifying syntax elements, enhances visual security of VVC. [33]	Improves visual security significantly.	May impact the visual quality of the video frames.	High	Security camera applications.
HEVC	2022	Modify PUs for secret messages. [27]	Achieves lower bitrate costs and maintains high visual quality at optimal message capacity.	Replacement of the official in-loop filter mechanism.	High	Secure communication applications.
	2021	Modify Transform block partition, designed to enhance embedding capacity and efficiency. [26]	Increased capacity and efficiency for data embedding. A fast traversal and hybrid extraction scheme mechanism was designed.	Involves only 8x8 TBs and 30 frames.	High	Any video applications require high data embedding capacity.
	2020	Encrypt syntax elements, including quantized transform coefficients (QTCs) and motion vector differences (MVDs) during intra-prediction in CABAC. [31]	Encryption does not affect compliance with HEVC video format or bitrate.	Specific to low-delay mode, it may not be effective in other modes.	Medium	Real-time applications.
	2019	Modify PU Partition Modes in CU. [24]	Suitable for VVC as it is based on a series group of CUs to modify the PU Partition Mode. Convert the binary message into base 7 (in 16 x 16 CU) and base 3 (in 8 x 8 CU) which enlarge the information hiding capacity.	Apply information hiding only within 16 x 16 CU and 8 x 8 CU.	Medium	Security videos
		Modification of PU Partition Modes in CU during inter-prediction process. [25]	Applicable for VVC as it is based on the groups of PUs partition modes. Categories the partition modes based on 8x8, 16x16 or larger CU which enable large capacity for hiding the bits.	Information can be hidden up to a depth of 3 in 8 x 8 CU."	Low	Security videos

These subtle variations in QP values serve as the key for extracting the embedded data during decoding. This approach offers a robust solution for concealing information while maintaining the fidelity of the video content.

A. *Encryption Process of Selective Quantization Technique*

To formalize the process of the information hiding in video processing by modifying the QP in each slice of a VVC-encoded video, we can define a mathematical formula as follows:

b_i: The i-th bit of the binary representation of the message to be hidden, where $b_i \in \{0,1\}$.

α: The original quantization parameter of the i-th slice

β: The modified quantization parameter of the i-th slice

The modification rule for encryption can be defined as:

$$\beta = \begin{cases} \alpha + 1, if\ (b_i = 0)\ \wedge (\alpha\ \%\ 2 = 0) \\ \alpha, if\ (b_i = 0)\ \wedge (\alpha\ \%\ 2 \neq 0) \\ \alpha + 1, if\ (b_i = 1)\ \wedge (\alpha\ \%\ 2 \neq 0) \\ \alpha, if\ (b_i = 1)\ \wedge (\alpha\ \%\ 2 = 0) \\ \alpha, if\ (b_i =\ b_{max_{i-1}}) \end{cases} \quad (1)$$

This rule ensures that:

- If the bit to be hidden is 0, the modification β will be odd.
- If the bit to be hidden is 1, the modified β will be even.

During encryption, if the information bit (b_i) to be hidden is 1 and the original QP (α) is odd, the equation increments α_i by 1 is applied in order to embed the information bit. This selective modification based on the parity of the α helps maintain the statistical properties of the QP sequence, making it less susceptible to steganalysis techniques that exploit these properties. However, when the b_i is 0 and the α is even, the β will be incremented by 1. In all other cases, the β remain unchanged, preserving the original α value.

B. Decryption Process of Selective Quantization Technique

The modification rule for decryption can be defined as:

$$b_i = \begin{cases} 0, if\ \beta\ \%\ 2 \neq 0 \\ 1, if\ \beta\ \%\ 2 = 0 \end{cases} \quad (2)$$

During decryption, if the modified QP (β) is odd, the b_i is recovered as 0. Conversely, if the β is even, the b_i is recovered as 1. The $b_{\max-1}$ will convert to the alphabet for every 8 bits. To ensure adherence to established protocols, both the information concealment and extraction procedures incorporate a reset mechanism after each operation. This mechanism effectively eliminates any unauthorized or extraneous modifications. By reverting to the standard operating procedure after each operation, the algorithms guarantee controlled and reliable execution, thereby safeguarding data integrity and maintaining compliance with professional standards. By modifying the QP only in specific scenarios based on the original QP parity and information bit, this technique introduces less predictable changes in the QP sequence. This can make it more challenging to detect the presence of hidden information through statistical analysis techniques often employed in steganalysis.

III. Results and Discussion

The data embedding technique was assessed using Peak Signal-to-Noise Ratio (PSNR) to quantify the impact on video quality. PSNR is a common metric used to evaluate the quality of a reconstructed video compared to the original. Higher PSNR values indicate better quality.

The evaluation employed four standard video sequences (BasketballPass, BasketballDrill, FourPeople, ParkScene) at various resolutions (ranging from 416×240 to 1920×1080) and bitrates (from 100 kbps to 5 Mbps). Each sequence was encoded using a modified VVC reference model (VTM 18.1) with four default encoders (Random Access (RA), Intra (I), Low Delay B slices (LDB), and Low Delay P slices (LDP). This process resulted in two sets of videos for each scenario: one encoded using the original VVC standard and another encoded using the SQT with data embedding.

The PSNR results, presented in Table 2, demonstrate that the SQT introduces minimal quality degradation compared to the original VVC standard. Across all video sequences, resolutions, bitrates, and encoders, the maximum observed PSNR difference was 0.5228 dB. This degradation occurred in the FourPeople sequence at 2 mbps with the RA encoder. In most cases, the PSNR difference between the original and SQT's videos was substantially lower, ranging from 0.05 to 0.1 dB. These results demonstrate that SQT effectively embeds data within video frames while preserving the visual fidelity of the video content.

TABLE II
EVALUATION OF PEAK SIGNAL-TO-NOISE RATIO (PSNR) PERFORMANCE IN VVC: ORIGINAL VS. SELECTIVE QUANTIZATION TECHNIQUE (SQT) IN VTM 18.1

Video Sequences	Bitrate (kbps)	I		LDB		LDP		RA	
		Original	SQT	Original	SQT	Original	SQT	Original	SQT
BasketballPass (416 x 240)	100	34.8759	34.8792	32.1283	32.1796	32.3900	32.3904	33.5235	33.5059
	500	43.7090	43.7035	35.9569	35.9119	35.9799	35.9570	36.4627	36.2807
	1000	48.6034	48.6274	40.7622	40.9288	40.5840	40.7708	40.8700	40.9735
	2000	54.6936	54.6866	45.8432	45.7957	45.7487	45.7118	46.1731	46.1592
	3000	58.7961	58.5752	47.8669	47.7498	47.7923	47.6765	48.1203	48.0540
	4000	61.1607	60.8950	49.2321	49.1628	49.1616	49.0715	49.4203	49.4475
	5000	62.9047	62.6561	50.3135	50.2152	50.2237	50.1206	50.4562	50.4873
BasketballDrill (832 x 480)	100	29.5710	29.6625	32.9030	32.6701	32.5068	32.5995	32.3212	32.0835
	500	36.5466	36.5636	35.9512	35.9837	35.4010	35.5106	34.1454	34.1251
	1000	39.6439	39.6142	37.0325	36.9933	36.4644	36.4397	34.7513	34.8255
	2000	42.9819	43.0050	38.0502	38.0818	37.4625	37.4389	35.4961	35.4911
	3000	45.1430	45.1033	38.7744	38.7319	38.1769	38.2240	35.8073	35.8489
	4000	46.8997	46.8452	41.7152	41.7457	41.5560	41.6205	41.8823	41.9093
	5000	48.5458	48.4778	43.1043	43.0965	42.9880	42.9791	43.2276	43.2167
FourPeople (1280 x 720)	100	27.6442	27.6360	35.9400	35.7079	35.7586	35.5280	36.5246	36.5246
	500	34.7163	34.7363	38.9052	38.9980	38.7672	38.7426	39.7509	39.6526
	1000	38.7623	38.7720	40.0956	39.7735	40.1013	39.6094	40.7921	40.7446
	2000	42.6624	42.6782	41.6788	41.4260	41.6005	41.2634	42.4789	41.9561
	3000	44.6769	44.6636	42.0109	41.9825	41.9336	42.0018	42.7055	42.7072
	4000	45.9517	45.9033	42.3174	43.5904	42.2215	43.5742	42.9873	44.0352
	5000	46.9382	46.9275	43.7475	43.7299	43.7077	43.7074	44.6679	44.6465

Video Sequences	Bitrate (kbps)	I		LDB		LDP		RA	
		Original	SQT	Original	SQT	Original	SQT	Original	SQT
ParkScene (1920 x 1080)	100	29.0854	29.0581	31.8142	31.7675	31.7269	31.6708	32.5336	32.5186
	500	33.0172	33.0241	33.1719	33.1205	33.0659	33.0815	34.1048	34.1533
	1000	35.3405	35.3445	33.8416	33.8354	33.7727	33.7599	34.8086	34.7925
	2000	38.0045	38.0023	34.9960	34.9975	34.9292	34.9693	36.0340	35.9482
	3000	39.6917	39.6909	35.5052	35.4395	35.4533	35.4573	36.4494	36.4427
	4000	40.9272	40.9277	35.8193	35.8328	35.7198	35.7433	36.7766	36.8032
	5000	41.9175	41.9096	36.0677	36.0790	35.9548	35.9500	32.5336	32.5186

In some instances, the SQT even yielded slight improvements in PSNR compared to the original standard. For example, the ParkScene sequence encoded at 4 mbps with the Intra (I) encoder exhibited a PSNR improvement of 0.026 dB. Fig. 4 illustrates the PSNR performance of the original video compared to the video encoded using our SQT's information hiding technique with varying bitrates.

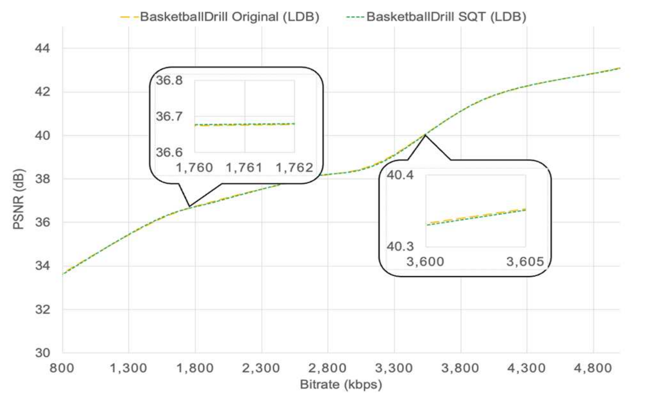

Fig. 4 Rate-distortion curve comparing the original video and SQT's video for the BasketballDrill video sequence

As observed, the PSNR values remain relatively close with maximum 0.1 dB different for both the original and encoded videos at higher bitrates. However, as the bitrate decreases (indicating higher compression), the PSNR for the encoded video starts to deviate slightly from the original video. Building upon the trend observed in Fig. 5.

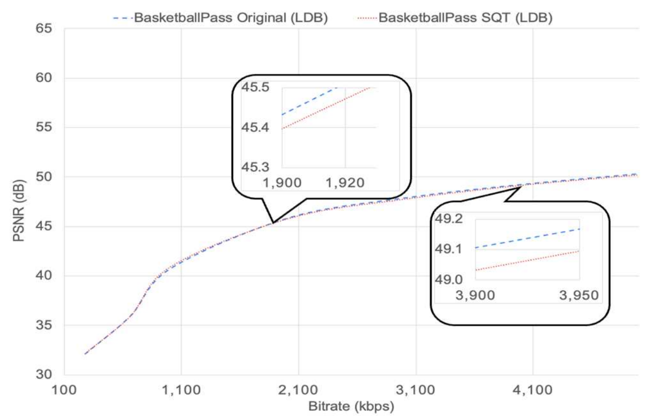

Fig. 5 The rate-distortion curve compares the original video and SQT's video for the BasketballPass sequence.

At higher bitrates (e.g., above 3 Mbps), the PSNR values for both the original and encoded video are very similar, indicating minimal visual quality degradation due to the information-hiding process. As the bitrate decreases (e.g., below 2 Mbps), a slight decrease in PSNR is observed for the encoded video compared to the original. This suggests a small introduction of noise due to the information embedding process at higher compression levels. Overall, the graph demonstrates that our SQT's information-hiding technique balances information-hiding capacity and visual quality preservation. Although there may be a slight decrease in PSNR at lower bitrates, this reduction will likely have a minimal impact on visual quality as perceived by the human eye.

IV. Conclusion

Our comprehensive survey of information-hiding techniques in video compression standards presents the advancement and issues in this field. By considering different approaches, let us share the knowledge of coding units, syntax elements, transform modes, prediction units, and transform blocks used in modern standards such as VVC and HEVC. Besides, it contributes to improving the understanding of the approaches to information hiding and offers a valuable resource to researchers and practitioners in this area.

The table that we have compiled gives clear and concise information on the advantages, disadvantages, effects, and application of different methods of information hiding. It allows one to digest the advantages and drawbacks of each technique and thus select the most appropriate method based on certain requirements and conditions.

In the context of synthesizing the studies, we contribute to the theory of information hiding in video compression. Our research increases our knowledge of this area's prospects and concerns and provides some suggestions on how to design and apply more efficient and secure video compression systems. The knowledge obtained can be further used in future experiments when constructing studies based on currently existing approaches to information hiding with the creation of new staking methods.

It also provides the practical implications of these techniques, which we draw from the analysis. They play a significant role in different areas, including military and intelligence communication, video surveillance, conferencing, and digital rights management. At this point, the question of information hiding becomes a central feature of scholars, technocrats, and even policymakers.

Moreover, another algorithm involved evaluating the new video compression method in the context of VVC in VTM 18.1. The tests proved that information hiding is possible while incurring little or no penalty on the quality of the videos. But in the current implementation, there are some shortcomings in information hiding capacity; it fully depends on the frame number of the video. For the betterment of this, future work should consider using other better information-hiding methods, and a detailed analysis of the SQT should be made. Such limitations could be overcome, and new opportunities for adequate information hiding in video sequences could be created if the feasibility of information embedding in various stages of the encoding process were investigated.

ACKNOWLEDGMENT

We thank the Computational Intelligence Research Laboratory at Tunku Abdul Rahman University of Management and Technology for providing the necessary resources and support for this research. This work was made possible by a financial grant from the Ministry of Education Malaysia (MOE) under the Fundamental Research Grant Scheme (FRGS): FRGS/1/2018/ICT01/TARUC/02/1.

REFERENCES

[1] Falon Fatemi, "How The Pandemic Has Changed Video Content And Consumption." Accessed: Jul. 06, 2023. [Online]. Available: https://www.forbes.com/sites/falonfatemi/2021/02/01/how-the-pandemic-has-changed-video-content-and-consumption/?sh=15696b256ec0.

[2] L. Kareem Qurban, W. Najah Abdullah, and W. Abed Shukur, "Information Hiding In Digital Video Using DCT, DWT and CvT 3," p. 12035, 2018, doi: 10.1088/1742-6596/1003/1/012035.

[3] D. Chandra, S. Yusnita, D. B. Sitepu, - Rusfandi, and D. Meidelfi, "The Analysis of Service Integrity on Video Streaming Services Using Time Division Duplex and Frequency Division Duplex Technology on LTE Networks," *International Journal of Advanced Science Computing and Engineering*, vol. 3, no. 2, pp. 73–87, Aug. 2021, doi: 10.62527/ijasce.3.2.65.

[4] B. Bross *et al.*, "Overview of the Versatile Video Coding (VVC) Standard and its Applications," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 31, no. 10, pp. 3736–3764, Oct. 2021, doi: 10.1109/tcsvt.2021.3101953.

[5] G. J. Sullivan, J. R. Ohm, W. J. 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. 1649–1668, 2012, doi: 10.1109/tcsvt.2012.2221191.

[6] Y. Tew and K. 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, Feb. 2014, doi: 10.1109/tcsvt.2013.2276710.

[7] M. Dalal and M. Juneja, "A survey on information hiding using video steganography," *Artif Intell Rev*, vol. 54, no. 8, pp. 5831–5895, Dec. 2021, doi: 10.1007/S10462-021-09968-0/figures/3.

[8] Y. Tew and K. Wong, "Information hiding in HEVC standard using adaptive coding block size decision," in *2014 IEEE International Conference on Image Processing, ICIP 2014*, Institute of Electrical and Electronics Engineers Inc., Jan. 2014, pp. 5502–5506. doi:10.1109/ICIP.2014.7026113.

[9] X. Zhang, O. C. Au, C. Pang, W. Dai, Y. Guo, and L. Fang, "Additional Sign Bit Hiding of Transform Coefficients in HEVC," 2013.

[10] P.-C. Chang, K.-L. Chung, J.-J. Chen, C.-H. Lin, and T.-J. Lin, "An Error Propagation Free Data Hiding Algorithm in HEVC Intra-Coded Frames," 2013.

[11] Y. K. Lin, "A data hiding scheme based upon DCT coefficient modification," *Comput Stand Interfaces*, vol. 36, no. 5, pp. 855–862, Sep. 2014, doi: 10.1016/j.csi.2013.12.013.

[12] Y. Liu, S. Liu, H. Zhao, and S. Liu, "A new data hiding method for H.265/HEVC video streams without intra-frame distortion drift," *Multimed Tools Appl*, vol. 78, no. 6, pp. 6459–6486, Mar. 2019, doi:10.1007/s11042-018-6320-y.

[13] X. Liu, K. Shi, A. Li, H. Zhang, J. Ming, and H. Fang, "A Novel Information Hiding Method for H.266/VVC Based on Selections of Luminance Transform and Chrominance Prediction Modes," in *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, Institute of Electrical and Electronics Engineers Inc., 2021, pp. 3158–3163. doi:10.1109/SMC52423.2021.9659244.

[14] ITU-T, "Versatile video coding ITU Publications International Telecommunication Union," 2023. [Online]. Available: https://handle.itu.int/.

[15] J. Pfaff *et al.*, "Intra Prediction and Mode Coding in VVC," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 31, no. 10, pp. 3834–3847, Oct. 2021, doi:10.1109/TCSVT.2021.3072430.

[16] S. Kuanar, V. Athitsos, D. Mahapatra, and K. R. Rao, "Gated fusion network for SAO filter and inter frame prediction in Versatile Video Coding," *Signal Process Image Commun*, p. 116839, Nov. 2022, doi:10.1016/j.image.2022.116839.

[17] W. Imen, B. Fatma, M. Amna, and N. Masmoudi, "DCT-II Transform Hardware-Based Acceleration for VVC Standard," *3rd IEEE International Conference on Design and Test of Integrated Micro and Nano-Systems, DTS 2021*, Jun. 2021, doi:10.1109/DTS52014.2021.9498196.

[18] X. Zhao *et al.*, "Transform Coding in the VVC Standard," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 31, no. 10, pp. 3878–3890, Oct. 2021, doi:10.1109/TCSVT.2021.3087706.

[19] H. Schwarz *et al.*, "Quantization and Entropy Coding in the Versatile Video Coding (VVC) Standard," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 31, no. 10, pp. 3891–3906, Oct. 2021, doi: 10.1109/TCSVT.2021.3072202.

[20] M. Karczewicz *et al.*, "VVC In-Loop Filters," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 31, no. 10, pp. 3907–3925, Oct. 2021, doi: 10.1109/TCSVT.2021.3072297.

[21] ITU-T, "High efficiency video coding ITU Publications International Telecommunication Union," 2023. [Online]. Available: https://handle.itu.int/.

[22] H. Chai, Z. Li, F. Li, and Z. Zhang, "An End-to-End Video Steganography Network Based on a Coding Unit Mask," *Electronics 2022, Vol. 11, Page 1142*, vol. 11, no. 7, p. 1142, Apr. 2022, doi:10.3390/electronics11071142.

[23] M. Li, Z. Li, and Z. Zhang, "A VVC Video Steganography Based on Coding Units in Chroma Components with a Deep Learning Network," *Symmetry (Basel)*, vol. 15, no. 1, Jan. 2023, doi:10.3390/sym15010116.

[24] Z. Li, L. Meng, X. Jiang, and Z. Li, "High Capacity HEVC Video Hiding Algorithm Based on EMD Coded PU Partition Modes," *Symmetry 2019, Vol. 11, Page 1015*, vol. 11, no. 8, p. 1015, Aug. 2019, doi: 10.3390/SYM11081015.

[25] Y. Yang, Z. Li, W. Xie, and Z. Zhang, "High capacity and multilevel information hiding algorithm based on pu partition modes for HEVC videos," *Multimed Tools Appl*, vol. 78, no. 7, pp. 8423–8446, Apr. 2019, doi: 10.1007/s11042-018-6859-7.

[26] H. Zhao, Y. Liu, Y. Wang, S. Liu, and C. Feng, "A Video Steganography Method Based on Transform Block Decision for H.265/HEVC," *IEEE Access*, vol. 9, pp. 55506–55521, 2021, doi:10.1109/access.2021.3059654.

[27] Z. Li, X. Jiang, Y. Dong, L. Meng, and T. Sun, "An Anti-Steganalysis HEVC Video Steganography With High Performance Based on CNN and PU Partition Modes," *IEEE Trans Dependable Secure Comput*, vol. 20, no. 1, pp. 606–619, Jan. 2023, doi:10.1109/tdsc.2022.3140899.

[28] M. Farajallah, G. Gautier, W. Hamidouche, O. Deforges, and S. El Assad, "Selective Encryption of the Versatile Video Coding Standard," *IEEE Access*, vol. 10, pp. 21821–21835, 2022, doi:10.1109/access.2022.3149599.

[29] B. Boyadjis, C. Bergeron, B. Pesquet-Popescu, and F. Dufaux, "Extended Selective Encryption of H.264/AVC (CABAC)-and HEVC-Encoded Video Streams," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 27, no. 4, pp. 892–906, Apr. 2017, doi: 10.1109/tcsvt.2015.2511879.

[30] Z. Shahid and W. Puech, "Visual protection of HEVC video by selective encryption of CABAC binstrings," *IEEE Trans Multimedia*, vol. 16, no. 1, pp. 24–36, Jan. 2014, doi:10.1109/tmm.2013.2281029.

[31] D. Xu, "Data hiding in partially encrypted HEVC video," *ETRI Journal*, vol. 42, no. 3, pp. 446–458, Jun. 2020, doi:10.4218/etrij.2018-0484.

[32] H. Joan, L. P. Tan, and Y. Tew, "Data Embedding with Dynamic Slice Quantisation in Versatile Video Coding," in *2023 IEEE International Conference on Computing, ICOCO 2023*, Institute of Electrical and Electronics Engineers Inc., 2023, pp. 41–46. doi:10.1109/icoco59262.2023.10397877.

[33] A. Fotovvat and K. A. Wahid, "Selective Encryption of VVC Encoded Video Streams for the Internet of Video Things," Mar. 2021, Accessed: Aug. 05, 2023. [Online]. Available: https://arxiv.org/abs/2103.14844v1

[34] H. Joan, L. P. Tan, and Y. Tew, "Quick Response (QR) codes embedding in VVC using Quantisation Parameter Manipulation," in *2023 Asia Pacific Signal and Information Processing Association Annual Summit and Conference, APSIPA ASC 2023*, Institute of Electrical and Electronics Engineers Inc., 2023, pp. 1697–1704. doi:10.1109/apsipaasc58517.2023.10317417.