Innovative Information Hiding in H.266/VVC using Sub-Block Transform Technique

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Abstract— **Information hiding in videos plays a crucial role in various applications, such as video authentication and content augmentation. While extensive research has explored information hiding in videos, its integration with the latest video compression standard, H.266/Versatile Video Coding (VVC), has received limited attention. This study proposes novel techniques for embedding information within compressed video streams utilising H.266/VVC. Recent advancements in transform coding techniques have led to the incorporation of advanced tools within VVC. This research investigates the potential of unique VVC features for information hiding, specifically focusing on Sub-Block Transform (SBT). By manipulating SBT selections, we aim to achieve minimal degradation in video quality and compression efficiency while embedding information. Furthermore, we compare the effectiveness of using SBT against the Selective Quantisation Technique (SQT). This comparison assesses their capabilities in maximising the information hiding capacity within H.266/VVC streams with minimal impact on video quality. To the best of our knowledge, this research presents the first information hiding technique specifically designed for H.266/VVC that leverages SBT.**

Keywords— **Information Hiding, Versatile Video Coding (VVC), Sub-Block Transform (SBT), Selective Quantisation Technique (SQT)**

I. INTRODUCTION

Video has become an indispensable component of contemporary society, serving as a primary medium for communication and information dissemination across diverse platforms, including social media, education, business, and entertainment. The medium's capacity to engage audiences through visually compelling and informative content has contributed to its widespread adoption. The ubiquity of high-speed internet and mobile devices has further accelerated video consumption, making it a powerful tool for knowledge sharing and public awareness. Research by Syamsulaini and Mashitoh [1] underscores the pedagogical efficacy of video in educational settings. Nevertheless, the ease with which video content can be created and distributed raises concerns about its reliability as a medium for personal and professional communication in the digital age [2]. This study aims to address this challenge by exploring the potential of the VVC standard and advanced information hiding techniques to fortify the security of digital ecosystems. By investigating these areas, this research contributes to the development of robust solutions that safeguard privacy and confidentiality in future digital transactions and content delivery.

Video technology has emerged as a pivotal force in contemporary society, permeating diverse sectors and reshaping human interaction. Its applications span education, economics, science, healthcare, and entertainment, among others [3], [4], [5]. As a cornerstone of the information age, video has transformed how individuals consume, create, and share content. Its impact on education, in particular, is undeniable, with video-based instruction enhancing engagement. Moreover, the entertainment industry has been revolutionized by immersive experiences offered by virtual reality [6]. The proliferation of social media platforms has further solidified video's role in daily life, enabling global connectivity and content creation [7], [8], [9].

The rapid evolution of video coding standards and the growing importance of digital content security have created a compelling need for robust video protection mechanisms. From early standards like MPEG-2 to the advanced High Efficiency Video Coding (HEVC) and the latest VVC [10], the industry has consistently sought to improve compression efficiency while maintaining visual quality. However, the increasing accessibility and value of video content have made it a prime target for cyberattacks, including unauthorized access and tampering [11], [12], [13].

Information hiding offers a promising countermeasure by embedding data within video content without compromising its perceived quality or functionality [14], [15]. While the concept has a rich history, its integration into the complex structure of VVC remains a relatively unexplored area. Successfully embedding information within VVC video requires a deep understanding of the encoding and decoding processes and the development of innovative techniques to ensure data integrity and security throughout the video lifecycle.

The imperative for this research is driven by the escalating demand for both privacy and robustness in digital communications. As data breaches pose increasingly severe risks to individuals and organizations, the development of sophisticated information hiding techniques within the VVC framework becomes paramount. This study delves into the theoretical underpinnings and practical implementation of embedding and extracting covert information within VVC video streams, assessing their efficacy across diverse scenarios.

II. Information Hiding in Video Coding

Existing research has extensively explored information hiding techniques within the HEVC compression standard. These methods can be classified according to their embedding strategies: partition modes, prediction units, transform coding, and syntax elements. Partition mode-based techniques modify the Prediction Unit (PU) partition modes within Coding Units (CUs) [16] . However, these methods are limited to 16x16 and 8x8 CUs. Another partition mode-based approach [17] extends this concept to 8x8 CUs by modifying PU partition modes during the inter-prediction process. Additionally, a PU-based technique [18] modifies PUs to embed secret messages, employing a non-standard in-loop filter within the HM encoder. Transform coding-based methods [19] modify transform block partitions for information hiding but are restricted to 8x8 Transform Blocks (TBs) and a limited number of frames. Syntax element-based techniques, such as encrypting quantized transform coefficients (QTCs) and motion vector differences (MVDs) during CABAC and inter-prediction processes [15], have also been explored. Nevertheless, these methods primarily focus on HEVC videos in low-delay mode, with limited evaluation in other video modes.

Building upon the successes of information hiding techniques within previous video compression standards, researchers have continued to explore this domain within the VVC framework. Partition mode-based methods have been extended by extracting Coding Unit (CU) partitions during VVC encoding to create binary masks [20]. Additionally, Li et al. [21] proposed a technique modifying chroma CU partition modes, albeit with limitations in terms of frame rate and quantization parameter (QP) values. Both approaches exhibit constraints in terms of embedding capacity.

Transform coding-based techniques have been further explored by modifying transform modes within Multiple Transform Selection (MTS) and Cross-Component Linear Model (CCLM) for I-frames [22]. However, this approach is limited to I-frames, restricting the amount of embeddable information. Syntax element-based information hiding techniques have been integrated into VVC by encrypting critical components within the Context-based Adaptive Binary Arithmetic Coding (CABAC) process. These components include transform coefficients (TCs), motion vectors (MVs), adaptive loop filters (ALFs), inter-prediction modes, sample adaptive offset (SAO) filters, and intra-prediction modes. The application of specific quantization parameter (QP) values (e.g., 17, 22, 27, 32, 37) within this approach can impact overall video quality [23]. Alternatively, a selective encryption method targeting luma intra prediction modes (IPMs), motion vector differences (MVDs), and residual signs has been proposed, potentially resulting in significant visual distortions [24]. Building on these approaches, a data embedding technique that modifies the quantization parameter has also been introduced in VVC, further expanding the possibilities for information hiding [25], [26].

While a plethora of information hiding techniques have been introduced within the Versatile Video Coding (VVC) standard, a notable gap exists in the literature regarding the exploitation of sub-block transforms for covert data embedding. This research aims to address this limitation by proposing a novel information hiding approach that leverages selective sub-block transforms within the VVC framework. It achieves a better trade-off among hidden capacity, video quality and compression efficiency.

III. The Proposed Method

This paper presents a novel information hiding technique tailored to the VVC standard by exploiting sub-block transforms. By modifying sub-block transform indices, we propose a method that effectively conceals messages while minimizing discernible impacts on video quality and compression efficiency.

Selective SBT techniques employ a strategic modification of SBT values to 1 or 2 for embedding binary information within the video stream. While VVC offers four distinct SBT modes (SBT ∈ {1, 2, 3, 4}), which include (SBT ∈ {SBT_VER_HALF, SBT_HOR_HALF, SBT_VER_QUAD, SBT_HOR_QUAD}), experimental analysis revealed that restricting SBT values to 1 and 2 optimizes embedding capacity without compromising video quality. By manipulating SBTs in the transformation process, the proposed method leverages the transform's characteristics to ensure imperceptible data embedding, thereby preserving visual quality and enabling secure information concealment. The subsequent subsection delineates the algorithm for embedding and extracting binary information using Selective SBT Techniques.

A. *Selective Sub-Block Transform Encoding Technique*

This methodology ensures that alterations to the stream are conducted only when there are enough bits available for embedding within the video stream. The upper limit of bits that can be embedded is represented by η. In situations where data concealment is not required, η is adjusted to zero to ensure minimal degradation, modifying the SBT only when there are bits to be concealed. The SBT modification strategy involves switching the existing SBT to '1' for encoding a '0' bit, and to '2' for a '1' bit. Alterations to the SBT are omitted if data concealment is unnecessary or if the limit of embeddable bits has been met. A comprehensive account of the process for encoding binary data within the video stream is provided subsequently.

Let's define:

$\mathscr{b}_i$	:	The i-th bit of the binary representation of the message intended for concealment, where $\mathscr{b}_i \in \{0,1\}$
$\mathcal{S}_{orig,i}$	:	The original sub-block transform of the i-th slice.
$\mathfrak{s}_i$	:	The modified sub-block transform of the i-th slice.
η	:	The maximum number of bits designated for embedding.

Modification of SBT based on detected bits:

$$\mathfrak{s}_i = \begin{cases} 1, & if\ \mathscr{b}_i == 0\ \wedge i < \eta \\ 2, & if\ \mathscr{b}_i == 1\ \wedge\ i < \eta \\ \mathcal{S}_{orig,i}, & if\ \ i \geq \eta \vee \eta\ ==\ 0 \end{cases} \quad (1)$$

The modification of SBT might not be fully exploited for the purpose of information hiding during the transformation stage. Therefore, in CABAC, this technique evaluates the potential to embed additional bits into the current transform block. The method is described in the pseudocode presented below:

Algorithm 1: Algorithm to Find the Opportunity to Hide Bits in CABAC
Input
α: Current coding unit data.
β: Array of encoded text data, with each element containing a bit and an encoding status ('N' for not encoded, 'Y' for encoded).
γ: Index to the first non-encoded text element (set to -1 for no operation).
$\mathfrak{s}$: Current modified sub-block transform.
$\mathfrak{e}$: Encoding status for each coding unit.
$\mathfrak{b}$: Binary bits, where $\mathfrak{b} \in \{0,1\}$.
Output
Encoded bits status updated, returns true if bits were hidden successfully.
Initialization
If $\gamma \neq -1$, proceed to check the encoding status.
SBT Mode Verification
If $\alpha_{\mathfrak{s}} = SBT\_VER\_HALF$:
Iterate over $\beta_i\ from\ 0\ to\ \beta_{i_{\max-1}}$
If $\beta_{i_{\mathfrak{b}}} = '0'$ and $\beta_{i_{\mathfrak{e}}} = 'N'$
Set $\beta_{i_{\mathfrak{e}}} \leftarrow$ 'Y'
Write the position i to the text file.
Return true and terminate the algorithm.
Alternative SBT Mode:
Else, if $\alpha_{\mathfrak{s}} = SBT\_HOR\_HALF$:
Iterate over $\beta_i\ from\ 0\ to\ \beta_{i_{\max-1}}$
If $\beta_{i_{\mathfrak{b}}} = '1'$ and $\beta_{i_{\mathfrak{e}}} = 'N'$
Set $\beta_{i_{\mathfrak{e}}} \leftarrow$ 'Y'
Write the position i to the text file.
Return true and terminate the algorithm.
Completion:
Write a termination indicator to the file with value -1.
Return true.

Algorithm 1 is intended to handle the current CU and modify an array of encoded text data based on certain conditions. This algorithm is vital in the field of information hiding within VVC, especially in deciding how and when to embed specific bits into the text data array. The algorithm starts by checking the validity of the index parameter (γ). If γ is deemed invalid ($\gamma = -1$), the function exits without making any alterations. Otherwise, it continues to inspect the SBT mode of the current CU ($\alpha_{\mathfrak{s}}$) to decide the next steps. In the case of a vertical half sub-block transform ($\alpha_{\mathfrak{s}} = SBT\_VER\_HALF$), the algorithm looks for the first '0' bit that has not been encoded in the array, which includes both binary data and the status of each bit's encoding (β). Once it finds a valid bit, it updates the encoding status (e) and records the index (i) in a text file through the writeToFile function. For a horizontal half sub-block ($\alpha_{\mathfrak{s}} = SBT\_HOR\_HALF$), the algorithm searches for the first unencoded '1' bit in the β array and updates accordingly. If no suitable bits are found for encoding in either case, a default value of -1 is written to the file using writeToFile(-1). The function returns true to signal that the operation is complete, regardless of whether a bit was encoded.

B. *Selective Sub-Block Transform Decoding Technique*

The order of encoded bits is crucial for enabling efficient decoding. The decoding algorithm begins by loading all index values from the sequence text file into an array for further analysis. It then evaluates the SBT of the current CU. If the SBT is '1' and the corresponding index in the sequence is not '-1' (indicating the presence of a hidden bit), a '0' is appended to the decoded text array. Conversely, if the SBT is '2', a '1' is appended. A counter is used to track the number of processed locations. This decoding mechanism depends on the presence of hidden bits at specific indices. If no bit is concealed at a given index (as indicated by a sequence value of '-1'), no decoding occurs, and the counter is incremented to move on to the next location. The following algorithm outlines the extraction of binary information using the selective sub-block transform technique:

Let:

$\mathbb{d} = \{d_{i}{}_{i=1}^{M}\}$	:	The array of decoded text, where M is the length of the text.
$\mathbb{n} = \{n_{i}{}_{i=1}^{N}\}$	:	The array of loaded indices from the sequences file (text file), where N is the total number of indices.
$\mathfrak{s}$	:	The current sub-block transform mode

Extraction of binary bits based on detected SBT:

$$d_{n_i} = \begin{cases} 0, & if\ \mathfrak{s} = SBT\_VER\_HALF\ and\ n_i\ \neq\ -1 \\ 1, & if\ \mathfrak{s} = SBT\_HOR\_HALF\ and\ n_i\ \neq\ -1 \\ No\ Operation, if\ n_i\ =\ -1. & \end{cases} \quad (2)$$

IV. Experiment Results and Discussions

In this study, we utilized the VTM 23.1 encoder with the random access configuration profile to assess the performance of our proposed information hiding technique with targeted bitrate ranging from 100kbps to 5000kbps. A total of 60 frames from the selected video sequences were encoded, ensuring a comprehensive analysis across diverse content types. The random access configuration provided efficient frame navigation and retrieval, which is crucial for applications requiring frequent access to various parts of the video stream. This configuration also enabled a balanced evaluation of both visual quality and information hiding capacity, as it supports inter-frame dependencies while maintaining ease of access for decoding.

It is important to note that all our proposed methods, along with the benchmark methods, were implemented within the same coding environment—specifically, the VVC reference software VTM 23.1. This uniform coding environment was chosen to eliminate any potential bias that could arise from using different coding standards, thereby ensuring fair and consistent comparisons. The objective of this research is to demonstrate the effectiveness of the selective sub-block transform technique in achieving higher information hiding capacity within H.266/VVC, compared to other embedding strategies. The results, presented in Tables 1 and 2, provide a comprehensive comparison of the proposed method with two other techniques involved in transformation and quantisation domain in VVC framework: the MTS-based approach [22] and the SQT [25]. This setup provided a reliable basis for evaluating the performance metrics of the proposed method against other embedding strategies.

Table 1 presents the quality metrics, specifically SSIM and PSNR, for the three methods across two video sequences ("Blowing Bubbles" and "People On Street"), under the conditions of embedding both '0' and '1' bits. The selective sub-block transform technique consistently achieves high SSIM values across all test cases, indicating minimal perceptual degradation. For instance, in the "Blowing Bubbles" sequence, the SSIM values for the proposed method are consistently above 0.9157, with a maximum of 0.9984. This is comparable to the SQT method and generally superior to the MTS-based, which shows slightly lower SSIM values. The "People On Street" sequence, which contains more complex motion and texture, exhibits slightly lower SSIM values overall. However, the proposed method still maintains strong performance, with SSIM values ranging from 0.8453 to 0.9678, demonstrating robust visual quality preservation even in challenging scenarios. Additionally, PSNR values reflect the objective quality, with higher values indicating better reconstruction fidelity. The proposed method shows competitive PSNR values, slightly trailing the SQT approach but outperforming the MTS-based in most cases. For example, in the "Blowing Bubbles" sequence, the proposed method achieves PSNR values ranging from 27.8335 dB to 43.5494 dB, which are very close to those achieved by the SQT method with maximum 0.1 dB differences and noticeably better than the MTS-based. Other than that, SBT method showing an

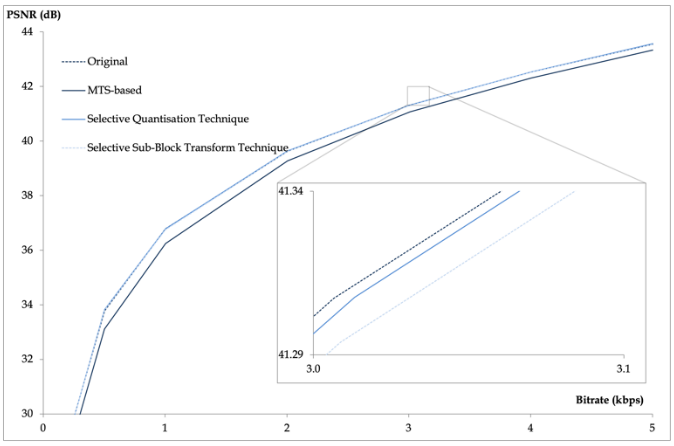

Figure 1: RD Curve of BlowingBubbles with All Bit '0' Hidden: A Focus on Original Vs Proposed Algorithm

outperforms of both SSIM of 0.8663 and PSNR of 24.3804 values in "People On Street" effectively maintains a high level of video quality and structural integrity, even with substantial data embedding.

Table 2 highlights the information hiding capacity of the three methods, comparing the number of bits that can be embedded for different targeted bitrates. The MTS-based approach shows considerable variation in capacity depending on the video content and bitrate. For "Blowing Bubbles," the capacity ranges from 122 to 1028 bits for '0' bits and 244 to 794 bits for '1' bits. However, in "People On Street," the capacity increases significantly, indicating sensitivity to video complexity and motion. The SQT exhibits a fixed and notably low embedding capacity of 60 bits per frame for both '0' and '1' bits across all conditions. The low capacity highlights a significant limitation, restricting its applicability for scenarios requiring higher data embedding. The proposed technique outperforms both alternatives, especially at higher bitrates. For "Blowing Bubbles," the method achieves a capacity ranging from 61 to 1929 bits for '0' bits and 50 to 1831 bits for '1' bits. Notably, for "People On Street," the proposed method significantly outpaces the other techniques, reaching capacities up to 9188 bits for '0' bits and 6186 bits for '1' bits. This substantial increase in capacity demonstrates the efficacy of the selective sub-block transform technique in leveraging the structural aspects of VVC to embed a larger amount of information without compromising video quality significantly. From the graph in Figure 1, it is evident that the SQT generally achieves the highest PSNR across the range of bitrates, indicating superior preservation of video quality.

This suggests that SQT involves minimal modification of the video signal, resulting in only slight degradation when embedding information. The Selective SBT method, represented by a distinct line, shows slightly lower PSNR values compared to SQT. However, the PSNR difference is

Table 1: Comparison of Embedding Strategies for MTS-based, SQT, and Proposed Method with All Bit '0' and '1' Hidden

Video Sequences	Target Bitrate (kbps)	MTS-based [22]				SQT [25]				Proposed Method (Selective Sub-Block			
		Bit '0'		Bit '1'		Bit '0'		Bit '1'		Bit '0'		Bit '1'	
		SSIM	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM	PSNR
Blowing Bubbles	100	0.9026	27.3536	0.9024	27.3352	0.9152	27.8385	0.9175	27.8594	0.9157	27.8424	0.9157	27.8335
	500	0.9785	33.1087	0.9782	33.0761	0.9831	33.8170	0.9827	33.7846	0.9827	33.7971	0.9825	33.7668
	1000	0.9912	36.2484	0.9912	36.2541	0.9924	36.7852	0.9923	36.7652	0.9923	36.7445	0.9924	36.7616
	2000	0.9959	39.2690	0.9959	39.2749	0.9962	39.6325	0.9962	39.6350	0.9962	39.6183	0.9962	39.6158
	3000	0.9973	41.0683	0.9973	41.0693	0.9974	41.3076	0.9974	41.3097	0.9974	41.2939	0.9974	41.2950
	4000	0.9979	42.3036	0.9979	42.3075	0.9980	42.5312	0.9980	42.5277	0.9980	42.5215	0.9980	42.5204
	5000	0.9983	43.3325	0.9983	43.3549	0.9984	43.5696	0.9984	43.5532	0.9984	43.5491	0.9984	43.5494
People On Street	100	0.8222	23.2314	0.8226	23.2353	0.8457	23.7342	0.8446	23.7016	0.8456	23.7220	0.8453	23.7250
	500	0.8444	23.8586	0.8440	23.8483	0.8632	24.2880	0.8622	24.2645	0.8663	24.3804	0.8653	24.3613
	1000	0.8801	25.2264	0.8802	25.2368	0.8946	25.6738	0.8942	25.6617	0.8944	25.6578	0.8940	25.6483
	2000	0.9170	27.4074	0.9166	27.4043	0.9276	27.9910	0.9269	27.9321	0.9272	27.9294	0.9270	27.9275
	3000	0.9361	28.9803	0.9363	28.9834	0.9452	29.6455	0.9462	29.7340	0.9450	29.5754	0.9449	29.5754
	4000	0.9472	30.0635	0.9471	30.0547	0.9585	31.0900	0.9567	30.8925	0.9565	30.8637	0.9566	30.8636
	5000	0.9575	31.3081	0.9576	31.3103	0.9678	32.4626	0.9655	32.1310	0.9655	32.1171	0.9653	32.0964

notably minimal, with a maximum divergence of around 0.1 dB, particularly evident in the zoomed-in section of the graph for bitrates between 3.0 and 3.1 kbps. This slight difference underscores that while SQT might slightly outperform SBT in terms of video quality retention, the degradation introduced by SBT is marginal and likely imperceptible to most viewers. This suggests that the SBT method, despite embedding more information, maintains a high level of video quality.

The experimental results validate the effectiveness of the selective sub-block transform technique for information hiding in H.266/VVC. The proposed method not only maintains high visual quality, as evidenced by competitive SSIM and PSNR values, but also significantly enhances the information hiding capacity, particularly in more complex video sequences. The findings underscore the potential of this technique to provide a robust and efficient solution for applications requiring high-capacity data embedding with minimal visual distortion.

V. Conclusion

In this research, we have introduced a novel information hiding technique for H.266/VVC using the SBT method. Our approach leverages the advanced encoding capabilities of VVC to conceal data efficiently without significantly impacting the visual quality of the video. By selectively modifying the sub-block transform modes, we ensure minimal perceptual degradation while maintaining a high capacity for hidden information.

Table 2: Comparison of Information Hiding Capacity for MTS-based, SQT and Proposed Method with All Bit '0' and '1' Hidden

Video Sequences	Targeted Bitrate (kbps)	Information Hiding Capacity					
		MTS-based [22]		SQT [25]		Proposed Method (Selective Sub-Block Transform)	
		Bit '0'	Bit '1'	Bit '0'	Bit '1'	Bit '0'	Bit '1'
Blowing Bubbles	100	122	244	60	60	61	50
	500	578	754	60	60	527	444
	1000	726	760	60	60	1085	905
	2000	906	790	60	60	1569	1447
	3000	940	676	60	60	1815	1706
	4000	1028	770	60	60	**1929**	1831
	5000	974	794	60	60	1892	1827
People On Street	100	2	72	60	60	328	282
	500	244	1128	60	60	419	290
	1000	694	2660	60	60	860	627
	2000	1776	4286	60	60	2215	1618
	3000	2612	5106	60	60	4058	2827
	4000	3868	6718	60	60	6093	4065
	5000	5076	7654	60	60	**9188**	6186

The experimental results demonstrate that our method effectively embeds and extracts hidden data, providing a secure and robust means of communication. Additionally, the algorithm's adaptability allows for seamless integration with existing VVC encoding pipelines, making it a practical solution for real-world applications.

For future research, we plan to investigate the feasibility of real-time information hiding and extraction. Implementing these capabilities in live video streams presents unique challenges, such as minimizing latency and optimizing resource usage.

VI. Acknowledgement

We would like to extend my sincere gratitude to everyone who has supported me throughout this research. We are deeply appreciative of the assistance provided by Tunku Abdul Rahman University of Management and Technology (TAR UMT). The university's valuable resources, including its library, online databases, and laboratory facilities, were instrumental in the completion of this study.

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