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

Hau Joan[#], Yiqi Tew[*] and Li Peng Tan[+]

Faculty of Computing and Information Technology

Tunku Abdul Rahman University of Management and Technology

Kuala Lumpur, Malaysia

E-mail: {[#]joanh-wm18@student., [*]yiqi@, [+]tanlp@} tarc.edu.my

Abstract— **This paper presents a novel method for information hiding in H.266/Versatile Video Coding (VVC) using the Sub-Block Transform (SBT) technique. The proposed method embeds data by selectively manipulating SBT modes to achieve minimal impact on video quality and compression efficiency. By manipulating SBT selections, we aim to achieve minimal degradation in video quality and compression efficiency while embedding information. By limiting the embedding to SBT modes 1 (SBT_VER_HALF) and 2 (SBT_HOR_HALF), the method ensures higher hiding capacity while preserving video integrity. Performance evaluation shows that the proposed method achieves a favorable trade-off between hiding capacity, video quality, and compression efficiency, outperforming benchmark methods like Selective Quantization Technique (SQT) and Multiple Transform Selection (MTS). Experimental results confirm that our approach offers a robust solution for information hiding with minimal visual degradation and higher information hiding capacity. 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 Quantization 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 Versatile Video Coding (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 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 - 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 and learning outcomes. 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 - 9]. Recent advancements in steganography and watermarking techniques have explored distortion-less and energy efficient approaches for embedding data in multimedia content, particularly in images and videos, as demonstrated in [10], [11].

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 [12], 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 [13], [14], [15].

Information hiding offers a promising countermeasure by embedding data within video content without compromising its perceived quality or functionality [16], [17]. While the concept has a rich history, its integration into the complex structure of VVC remains a relatively unexplored area. The imperative for this research is driven by the escalating demand for both privacy and robustness in digital communications, offering

solutions for enhancing security, protecting copyright, and enabling covert communication. 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 Unit (CU) [18] . However, these methods are limited to 16x16 and 8x8 CUs. Another partition mode-based approach [19] extends this concept to 8x8 CU by modifying PU partition modes during the inter-prediction process. Additionally, a PU-based technique [20] modifies PUs to embed secret messages, employing a non-standard in-loop filter within the HM encoder. Transform coding-based methods [21] 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 (TC) and motion vector differences (MVDs) during Context-based Adaptive Binary Arithmetic Coding (CABAC) and inter-prediction processes [16], 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 CU partitions during VVC encoding to create binary masks [22]. Additionally, Li et al. [23] proposed a technique modifying chroma CU partition modes for information embedding, 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 for I-frames [24]. 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 CABAC process. These components include TC, motion vectors (MVs), adaptive loop filters, inter-prediction modes, sample adaptive offset filters, and intra-prediction modes. The application of specific QP values (e.g., 17, 22, 27, 32, 37) within this approach can impact overall video quality [25]. Alternatively, a selective encryption method targeting luma intra prediction modes, MVDs, and residual signs has been proposed, potentially resulting in significant visual distortions [26]. 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 [27], [28].

While a plethora of information hiding techniques have been introduced within the VVC standard, a notable gap exists in the literature regarding the exploitation of sub-block transforms (SBT) for covert data embedding. This research aims to address this limitation by proposing a novel information hiding approach that leverages selective SBT 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 SBT. 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 $\in$ {1, 2, 3, 4}), which include SBT_VER_HALF, SBT_HOR_HALF, SBT_VER_QUAD and SBT_HOR_QUAD, experimental analysis revealed that restricting SBT values to 1 and 2 optimizes embedding capacity without compromising video quality. These modes are advantageous for embedding binary data because their larger sub-block size introduces minimal distortion when modified. In contrast, the SBT_VER_QUAD and SBT_HOR_QUAD modes, which split the blocks into smaller segments, are more prone to affecting video quality when altered. By restricting data embedding to SBT modes 1 and 2, our approach maintains a higher hiding capacity with minimal perceptual degradation. This selective approach allows for efficient data concealment without significantly affecting visual quality or compression efficiency.

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, which is determined based on the size of the file being embedded whenever necessary. 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:

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

Modification of SBT based on detected bits:

$$\mathcal{s}_i = \begin{cases} 1, & if \ \mathcal{b}_i == 0 \ \wedge i < \eta \\ 2, & if \ \mathcal{b}_i == 1 \ \wedge i < \eta \\ s_{orig,i}, & if \ i \geq \eta \vee \eta == 0 \end{cases} \qquad (1)$$

The modification of SBT might not be fully exploited for the purpose of information hiding during the transformation stage. Therefore, during the CABAC stage, 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
1   α: Current coding unit data.
2   β: Array of encoded text data, with each element containing a bit and an encoding status ('N' for not encoded, 'Y' for encoded).
3   γ: Index to the first non-encoded text element (set to -1 for no operation).
4    $\mathcal{s}$: Current modified SBT.
5    $\mathcal{e}$: Encoding status for each coding unit.
6    $\mathcal{b}$: Binary bits, where $\mathcal{b} \in \{0,1\}$.
Output
Encoded bits status updated, returns true if bits were hidden successfully.
Initialization
7   If $\gamma \neq -1$, proceed to check the encoding status.
SBT Mode Verification
8   If $\alpha_{\mathcal{s}} = SBT\_VER\_HALF$:
9   Iterate over $\beta_i \ from \ 0 \ to \ \beta_{i_{\max-1}}$
10   If $\beta_{i_{\mathcal{b}}} = '0'$ and $\beta_{i_{\mathcal{e}}} = 'N'$
11   Set $\beta_{i_{\mathcal{e}}} \leftarrow$ 'Y'
12   Write the position i to the text file.
13   Return true and terminate the algorithm.
Alternative SBT Mode:
14   Else, if $\alpha_{\mathcal{s}} = SBT\_HOR\_HALF$:
15   Iterate over $\beta_i \ from \ 0 \ to \ \beta_{i_{\max-1}}$
16   If $\beta_{i_{\mathcal{b}}} = '1'$ and $\beta_{i_{\mathcal{e}}} = 'N'$
17   Set $\beta_{i_{\mathcal{e}}} \leftarrow$ 'Y'
18   Write the position i to the text file.
19   Return true and terminate the algorithm.
Completion:
20   Write a termination indicator to the file with value -1.
21   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 $(\alpha_{\mathcal{s}})$ to decide the next steps. In the case of a vertical half SBT $(\alpha_{\mathcal{s}} = SBT\_VER\_HALF)$, 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 $(\mathcal{e})$ and records the index (i) in a text file through the writeToFile function. For a horizontal half sub-block $(\alpha_{\mathcal{s}} = SBT\_HOR\_HALF)$, 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 if the operation is complete, regardless of whether a bit was encoded

B. Selective Sub-Block Transform Decoding Technique

The decoding algorithm begins by loading all index values from the sequence text file into an array. 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 and move to the next location. The following algorithm outlines the extraction of binary information using the selective SBT technique:

Let:

$\mathbb{d} = \{d_{i_{i=1}}^M\}$	:	The array of decoded text, where M is the length of the text.
$\mathbb{m} = \{n_{i_{i=1}}^N\}$	:	The array of loaded indices from the sequences file (text file), where N is the total number of indices.
$\mathcal{s}$	:	The current SBT mode

Extraction of binary bits based on detected SBT:

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

IV. EXPERIMENT RESULTS AND DISCUSSIONS

In this study, the encoder with a random access configuration profile is utilized to evaluate the proposed information hiding technique at bitrates ranging from 100 kbps to 5000 kbps. 60 frames are encoded from selected test video sequences to

ensure a comprehensive analysis of diverse content types. The random access configuration enabled efficient frame navigation and retrieval, crucial for applications requiring frequent access to various video segments, allowing for a balanced assessment of visual quality and information hiding capacity while supporting inter-frame dependencies.

All proposed methods, along with benchmark techniques, were implemented within the same coding environment—VVC reference software VTM 23.1. This consistency eliminates potential bias from using different coding standards, ensuring fair comparisons. The research objective is to demonstrate the effectiveness of the selective SBT technique in achieving a higher information hiding capacity within the H.266/VVC compared to other strategies. Results in Tables 1 and 2 provide a comprehensive comparison of our method against the MTS-based [24] and the SQT [27] approaches.

To evaluate the effectiveness of the proposed method, three key metrics: Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM), and information hiding capacity are employed. PSNR measures visual quality retention, with higher values indicating better preservation. SSIM assesses the structural and perceptual quality maintained from the viewer's perspective. Lastly, information hiding capacity quantifies the amount of embedded data without significant degradation, with higher capacity facilitating greater data concealment while preserving video quality.

Table 1 presents quality metrics, specifically SSIM and PSNR, for three methods applied to two test video sequences ("Blowing Bubbles" and "People On Street"), under conditions of embedding both '0' and '1' bits. The selective SBT technique consistently achieves high SSIM values across all test cases, indicating minimal perceptual degradation. For example, in the "Blowing Bubbles" sequence, the SSIM values for the proposed method remain above 0.9157, peaking at 0.9984. This performance is comparable to the SQT method and generally superior to the MTS-based approach, which shows slightly lower SSIM values. In the "People On Street" sequence, characterized by more complex motion and texture, the proposed method still performs strongly, with SSIM values ranging from 0.8453 to 0.9678, thereby demonstrating robust visual quality preservation even in challenging scenarios. PSNR values, reflecting objective quality, indicate that the proposed method exhibits competitive performance, slightly trailing the SQT approach but outperforming the MTS-based method in most instances. For instance, in the "Blowing Bubbles" sequence, PSNR values for the proposed method range from 27.8335 dB to 43.5494 dB, closely aligning with SQT values with a maximum difference of 0.1 dB and significantly better than MTS-based results. In the "People On Street" sequence, the SBT method achieves SSIM and PSNR values of 0.8663 and 24.3804, respectively, effectively

maintaining high 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 at different targeted bitrates. The MTS-based approach exhibits considerable variation in capacity based on video content and bitrate. In "Blowing Bubbles", the capacity ranges from 122 to 1028 bits for '0' bits and from 244 to 794 bits for '1' bits. Conversely, in "People On Street", the capacity increases significantly, indicating a sensitivity to video complexity and motion. The SQT method demonstrates a fixed and notably low embedding capacity of 60 bits per frame for both '0' and '1' bits across all conditions, which limits its applicability in scenarios requiring higher data embedding. In contrast, the proposed technique outperforms both alternatives, particularly at higher bitrates. For "Blowing Bubbles", the method achieves capacities ranging from 61 to 1929 bits for '0' bits and from 50 to 1831 bits for '1' bits. Notably, in "People On Street", the proposed method significantly surpasses the other techniques, reaching capacities of up to 9188 bits for '0' bits and 6186 bits for '1' bits. This substantial increase in capacity demonstrates the effectiveness of the selective SBT technique in leveraging the structural aspects of VVC to embed a larger amount of information without significantly compromising video quality.

From the graph in Fig. 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 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.
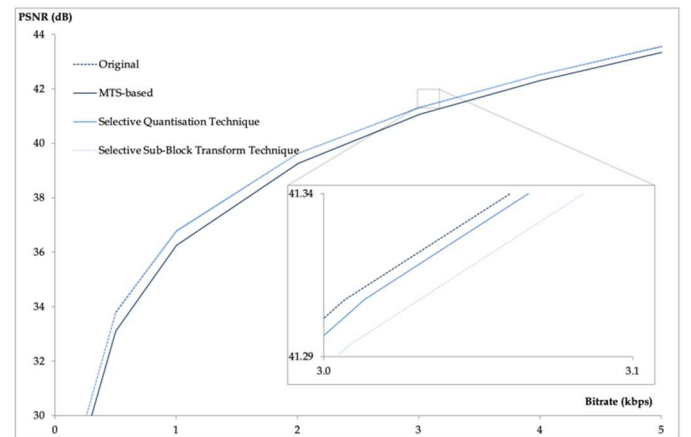

Fig. 1: RD Curve of BlowingBubbles with All Bit '0' Hidden:

A Focus on Original Vs Proposed Algorithm

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

Video Sequences	MTS-based [24]				SQT [27]				Proposed Method (Selective Sub-Block Transform)			
	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	0.9026	27.3536	0.9024	27.3352	0.9152	27.8385	0.9175	27.8594	0.9157	27.8424	0.9157	27.8335
	0.9785	33.1087	0.9782	33.0761	0.9831	33.8170	0.9827	33.7846	0.9827	33.7971	0.9825	33.7668
	0.9912	36.2484	0.9912	36.2541	0.9924	36.7852	0.9923	36.7652	0.9923	36.7445	0.9924	36.7616
	0.9959	39.2690	0.9959	39.2749	0.9962	39.6325	0.9962	39.6183	0.9962	39.6183	0.9962	39.6158
	0.9973	41.0683	0.9973	41.0693	0.9974	41.3076	0.9974	41.3097	0.9974	41.2939	0.9974	41.2950
	0.9979	42.3036	0.9979	42.3075	0.9980	42.5312	0.9980	42.5277	0.9980	42.5215	0.9980	42.5204
	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	0.8222	23.2314	0.8226	23.2353	0.8457	23.7342	0.8446	23.7016	0.8456	23.7220	0.8453	23.7250
	0.8444	23.8586	0.8440	23.8483	0.8632	24.2880	0.8622	24.2645	0.8663	24.3804	0.8653	24.3613
	0.8801	25.2264	0.8802	25.2368	0.8946	25.6738	0.8942	25.6617	0.8944	25.6578	0.8940	25.6483
	0.9170	27.4074	0.9166	27.4043	0.9276	27.9910	0.9269	27.9321	0.9272	27.9294	0.9270	27.9275
	0.9361	28.9803	0.9363	28.9834	0.9452	29.6455	0.9462	29.7340	0.9450	29.5754	0.9449	29.5754
	0.9472	30.0635	0.9471	30.0547	0.9585	31.0900	0.9567	30.8925	0.9565	30.8637	0.9566	30.8636
	0.9575	31.3081	0.9576	31.3103	0.9678	32.4626	0.9655	32.1310	0.9655	32.1171	0.9653	32.0964

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, a novel information hiding technique for H.266/VVC using the SBT method is introduced. This 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, a minimal perceptual degradation is ensured while maintaining a high capacity for hidden information. The experimental results demonstrate that the proposed method effectively embeds and extracts hidden data, providing a secure and robust means of communication.

Table 1: 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 [24]		SQT [27]		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

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, investigation on the feasibility of real-time information hiding and extraction will be conducted. This includes the implementation of proposed methods in live video streams presents unique challenges, such as minimizing latency and optimizing resource usage.

VI. Acknowledgment

References

[1] R. Syaripuddin, A. Razaq Ahmad, and M. Mahzan Awang, "The Use of Video in Teaching and Learning 21st Century History Education in Malaysia," Redwhite Press, Oct. 2019, pp. 182–186. doi: 10.32698/gcs.0194.

[2] F. & D. Y. & Y. A. Topsümer, "Media and Communication in the Digital Age: Changes and Dynamics," 2023. [Online]. Available: https://www.researchgate.net/publication/375116310.

[3] W. Bumia, "Emerging Technologies For 21st Century Education—Strategies For The Use Of Video Mediated Instruction," 2018.

[4] B. Ilyassova, L. S. Zarkenova, and G. K. Alshinbekova, "Information technology and its importance in modern teaching methods," 2018.

[5] I. Mambetova, "The Use of Multimedia Technologies in the Teaching Process," *Bulletin of Science and Practice*, vol. 6, no. 11, pp. 427–432, Nov. 2020, doi: 10.33619/2414-2948/60/53.

[6] O. R. Deshmukh, "Virtual Reality Next-gen Gaming Experience," *Int J Res Appl Sci Eng Technol*, vol. 10, no. 6, pp. 3442–3443, Jun. 2022, doi: 10.22214/IJRASET.2022.44662.

[7] V. B. Dzobelova, L. A. Aguzarova, A. V. Olisaeva, and E. E. Kornilova, "Digital Technologies in Education and Their

Influence on Modern Society," *Proceedings of the "New Silk Road: Business Cooperation and Prospective of Economic Development" (NSRBCPED 2019)*, Apr. 2020, doi: 10.2991/AEBMR.K.200324.030.

[8] M. A. Quainoo and T. Pasawano, "The Use of Digital Media Platforms Education and Supporting Self During The COVID," 2020.

[9] G. Wang, G. Zhou, and Z. Li, "Research on the Application of Chinese Teaching Based on Social Media Video Platforms," *International Journal of Distance Education Technologies*, vol. 20, no. 1, pp. 1–16, Mar. 2022, doi: 10.4018/IJDET.296699.

[10] R. Noor, A. Khan, and A. Sarfaraz, "High Performance and Energy Efficient Image Watermarking for Video Using a Mobile Device," *Wirel Pers Commun*, vol. 104, no. 4, pp. 1535–1551, Feb. 2019, doi: 10.1007/S11277-018-6097-3/FIGURES/8.

[11] A. Khan and A. Sarfaraz, "FFT-ETM based distortion less and high payload image steganography," *Multimed Tools Appl*, vol. 78, no. 18, pp. 25999–26022, Sep. 2019, doi: 10.1007/S11042-019-7664-7.

[12] D. R. Bull and F. Zhang, "Video coding standards and formats," *Intelligent Image and Video Compression*, pp. 435–484, Jan. 2021, doi: 10.1016/B978-0-12-820353-8.00021-9.

[13] M. Conti, E. Losiouk, and A. Visintin, "What You See is Not What You Get: a Man-in-the-Middle Attack Applied to Video Channels," *Proceedings of the ACM Symposium on Applied Computing*, pp. 1723–1726, Apr. 2022, doi: 10.1145/3477314.3507233.

[14] Y. Huang, X. Li, W. Wang, T. Jiang, and Q. Zhang, "Forgery Attack Detection in Surveillance Video Streams Using Wi-Fi Channel State Information," *IEEE Trans Wirel Commun*, vol. 21, no. 6, pp. 4340–4349, Jun. 2022, doi: 10.1109/TWC.2021.3129188.

[15] Y. Huang, S. Yang, T. Ma, Z. Liu, Z. Ding, and Q. An, "A Low-cost Active Defense Mechanism against DDoS Attacks in Streaming Media Scenarios," *Proceedings - 2022 International Conference on Networking and Network Applications, NaNA 2022*, pp. 130–135, 2022, doi: 10.1109/NANA56854.2022.00030.

[16] A. Elhadad, S. Hamad, A. Khalifa, and A. Ghareeb, "High capacity information hiding for privacy protection in digital video files," *Neural Comput Appl*, vol. 28, no. 1, pp. 91–95, Dec. 2017, doi: 10.1007/S00521-016-2323-7/FIGURES/4.

[17] 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.

[18] 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.

[19] 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.

[20] 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.

[21] 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.

[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 2023, Vol. 15, Page 116*, vol. 15, no. 1, p. 116, Dec. 2022, doi: 10.3390/SYM15010116.

[24] 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.

[25] 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.

[26] 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.

[27] 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.

[28] 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.