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Analysis of Next-Generation VVC/H.266 Standard for Gaming Content

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Abstract

Game streaming has emerged as a key technology that enables high-end gaming on various devices by offloading complex processing tasks to remote, high-performance servers. However, delivering high-quality game streams with minimal latency and high compression efficiency presents several challenges in video compression. This paper evaluates the impact of key coding tools in the Versatile Video Coding (VVC)/H.266 standard on gaming content. Experimental results show that tools such as Intra Block Copy (IBC) and Linear Model for Chrominance intra prediction (LMChroma) provide excellent compression performance for screen content sequences, while Chroma Transform Skip (ChromaTS) and Joint Cb and Cr (JCCR) exhibit limited performance due to differences in chroma structure. These findings highlight the need for next-generation coding standards to more effectively reflect the unique characteristics of gaming content, ensuring high-quality, low-latency streaming.

Keyword : VVC/H.266, Gaming contents, Video Coding

I. Introduction

Game streaming is the practice of playing video games that are rendered and processed on a remote server and then broadcast to the player in real time via the internet. Instead of running games on local hardware, users utilize a client device (e.g., PC, console, smartphone, etc.) to connect to games hosted on powerful servers, allowing even low-end devices to execute graphically complex games[1].

Thanks to services such as Google Stadia, Microsoft xCloud, NVIDIA GeForce Now, and Sony PlayStation Now, game streaming has become more and more popular. These services process games on distant servers, streaming the visual feed to the user's device and sending real-time player inputs from a mouse, keyboard, or controller back to the server[2].

The global cloud gaming market is growing rapidly, driven by increased internet penetration, the rise of mobile gaming, and the development of 5G networks. According to market reports, the cloud gaming market size was valued at $1.6 billion in 2021, and it is expected to reach $13.7 billion by 2028, growing at a Compound Annual Growth

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Rate (CAGR) of around 40-50% over the forecast period [3]-[4].

However, alongside this rapid market growth comes the challenge of ensuring a smooth and responsive gaming experience. To achieve this, cloud gaming services must overcome issues such as latency, which is critical for real-time gameplay. This requires the use of advanced video compression technologies that can reduce data size while preserving high-quality visuals and minimizing lag, enabling the seamless delivery of graphically intense games even over bandwidth-limited connections.

To address these challenges, standard bodies have recently begun studying video coding technologies dedicated to future applications in gaming content. In particular, [5] proposed the creation of a new class of gaming sequences for the common test conditions used in the development of next-generation video coding standards. Building on this suggestion, numerous proposals have emerged, aiming to support critical new applications and incorporate gaming-specific test conditions, reflecting the evolving demands of video coding for high-performance gaming environments.

In this paper, we explore the latest advancements in video coding standard, specifically focusing on the key tools of Versatile Video Coding (VVC)/H.266[6]. The investigation assesses how these tools can be effectively applied to sequence of gaming contents, which are anticipated to play a significant role in the industry. By examining their compatibility and performance with gaming content, we provide an insight into how VVC/H.266's advanced features can meet the growing demands of high-quality, low-latency game streaming[7].

The remainder of this paper is structured as follows: Section II provides a review of video coding standards as applied to gaming content. Section III and IV presents an examination and evaluation of the coding performance of individual VVC/H.266 tools on game sequences. Sections V and VI analyze the testing results and offer concluding this paper.

II. Video coding standards for gaming streaming

The quality of game streaming heavily relies on effective video compression technology. Video compression reduces the amount of data required to represent video content, which is essential for streaming games that feature fast-paced, high-resolution graphics. By compressing video efficiently, these technologies help minimize bandwidth usage, reduce latency, and ensure a seamless and smooth gaming experience.

The codec standard code below is available for streaming games:

- AVC/H.264[8]: A widely-used video coding standard known for its balance between video quality and compression efficiency. It is the foundational codec for platforms such as YouTube, Twitch, and many game streaming services, efficiently supporting HD and even Full HD video streams. Despite being older, AVC/H.264 remains popular due to its broad compatibility with various devices and its ability to deliver stable performance across a range of network conditions.
- HEVC/H.265[9]: Building on AVC/H.264, HEVC/H.265 offers approximately twice the compression efficiency, allowing for the same video quality at half the bitrate. This is especially beneficial for 4K game streaming, where bandwidth demands are higher. As a result, services such as Netflix and cloud gaming platforms have adopted HEVC/H.265 for high-quality streaming experiences with reduced data requirements, making it suitable for 4K and HDR content delivery in gaming.
- VP9[10]: Developed by Google, VP9 is an open-source, royalty-free codec widely used in platforms like YouTube and Google Stadia. VP9 competes with HEVC by offering similar or slightly better compression efficiency. Its ability to reduce bandwidth usage while maintaining good video quality makes it highly efficient for game streaming, particularly on

platforms where low-latency, high-quality streaming is needed for responsive gameplay.

- AV1[11]: AV1 is a next-generation codec designed by the Alliance for Open Media, offering improved compression efficiency over both HEVC and VP9. It is optimized for high-resolution streams, including 4K and 8K, making it ideal for future-proofing game streaming services as video resolutions increase. AV1 is also open-source and royalty-free, which encourages widespread adoption in cloud gaming and video platforms, reducing bandwidth consumption while maintaining high visual quality.
- VVC/H.266[6]: The latest advancement in video compression, VVC/H.266 offers roughly 50% better compression efficiency compared to HEVC. This makes it particularly well-suited for game streaming in 4K, 8K, and HDR formats, where reducing data rates without sacrificing visual quality is crucial. VVC/H.266 is designed to handle ultra-low latency applications and immersive experiences, such as cloud gaming, ensuring that even demanding graphical content can be streamed efficiently. While still in its early stages of adoption, VVC/H.266 is poised to be the standard for next-generation gaming content delivery.

Nevertheless, all of the codecs mentioned, including H.264, H.265, VP9, AV1, and even VVC/H.266, were primarily developed with natural camera-captured content in mind, as these have been the dominant video applications. While VVC/H.266 did consider artificial content, such as gaming and screen content, during its development, its primary focus remained on optimizing for natural video. As a result, most of the tools and functionalities were designed for camera-captured video, with artificially generated content being a secondary consideration.

To better accommodate the unique characteristics of gaming content, the next-generation video coding standard must thoroughly analyze existing tools and identify areas for further improvement. In this paper, we examine key tools in VVC/H.266, using gaming content proposed for the Post-VVC/H.266 exploration experiments, in preparation for the development of future video coding standards. This analysis aims to assess how well current tools perform and what enhancements are needed to optimize compression for gaming content.

III. Analysis of Key Tools in VVC/H.266 for Gaming Content

1. Testing contents

The testing conditions are based on the draft version of the common test conditions (CTC) for gaming content, currently being developed by JVET[12]. To simplify the process, we selected four gaming sequences specified in the draft CTC. Details of the specific content used in the tests are provided in Table 1, while Figure 1 displays sample screenshots from the tested gaming sequences.

2. Testing procedures

To assess the effectiveness of individual coding tools, we performed turn on/off testing based on the default setting of VVC/H.266 CTC. For tools enabled by default, we conducted tests by disabling them, and for tools not enabled by default, we tested by enabling them. To quantify the

Table 1. Details of the Tested Gaming Sequences

Class	Sequence name	Resolution	Frame count	Low delay frame count	Frame rate	Bit depth
G1	Level1_SDR	1920x1080	600	300	60	10
	Darktree_SDR	1920x1080	600	300	60	10
G2	GTAV	1920x1080	600	300	60	8
	Minecraft	1920x1080	600	300	60	8

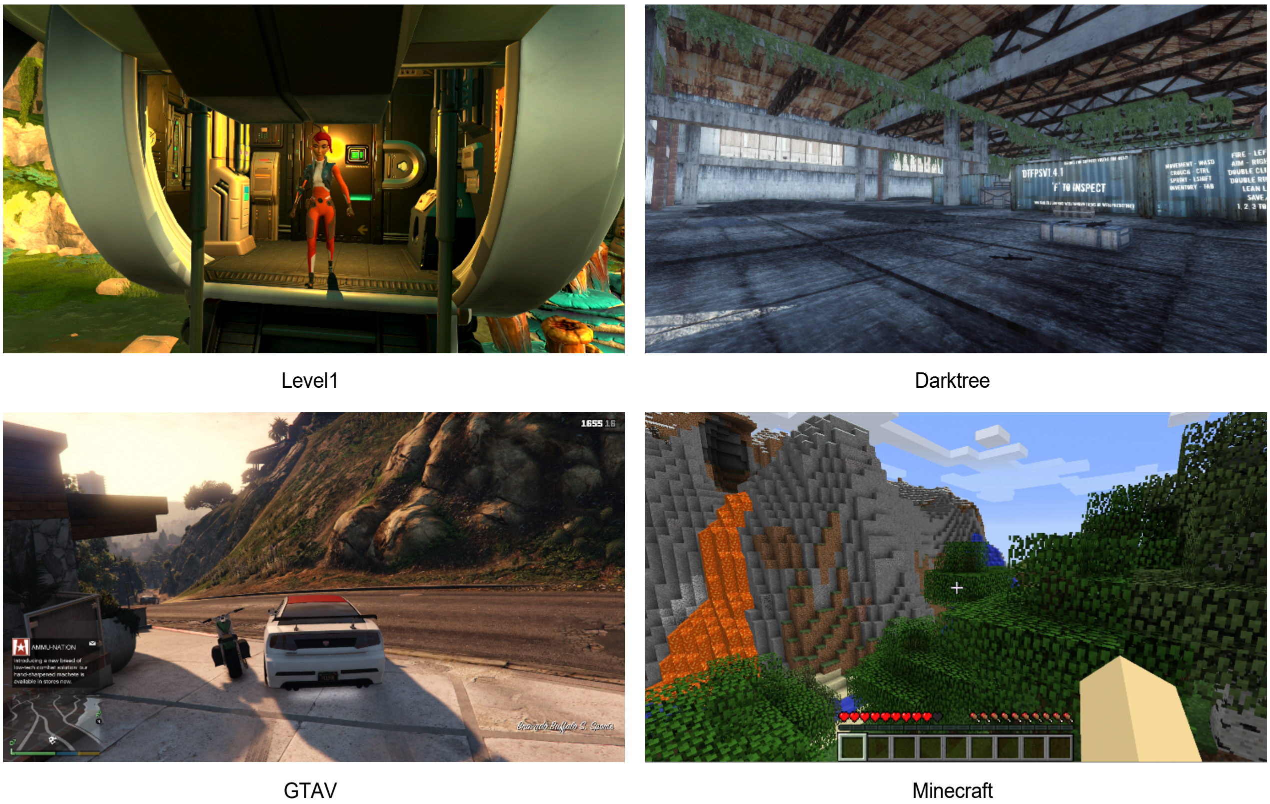

Fig. 1. Sample Screenshots of Tested Gaming Sequences

results, we measured the changes in BD-rate[13] compared to the anchor, which used the default settings. For simplicity, we utilized AI configurations with four selected gaming sequences from the draft CTC for gaming content. These sequences were compressed using the reference software VTM-11.0[14]. The coding parameters followed the CTC[12], established by JVET for VVC/H.266 standardization. Quantization parameters (QPs) of 22, 27, 32, 37, 42, and 47 were used to evaluate changes in BD-rate

Ⅳ. Testing results

1. Intra prediction tools

In evaluating the intra prediction tools[15] for game streaming, we tested Intra Subpartition (ISP), Multiple Reference Line (MRL), Matrix-based Intra Prediction (MIP), and Intra Block Copy (IBC). Since ISP, MRL, and MIP are enabled by default, we conducted tool-off tests for these tools. For IBC, which is disabled by default, we performed a tool-on test to assess its impact. In the tool-off tests, a positive number in the results indicates an increase in bitrate at the same PSNR quality, showing the impact of disabling the tool. By examining the increase in BD-rate during tool-off tests, we can evaluate the contribution of each tool compared to the default settings. Conversely, in the tool-on test, a negative number indicates a decrease in bitrate at the same PSNR quality, allowing us to measure the benefit of enabling the tool relative to the default configuration.

1.1 ISP

In VVC/H.266, ISP tool enhances compression efficiency by dividing a coding block into smaller sub-blocks, allowing each sub-block to be predicted and encoded separately. This approach is especially beneficial for complex textures and detailed areas, as it enables more accurate intra predictions and reduces prediction errors.

Table 2. Results of ISP Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	0.51%	-0.36%	0.41%
	Darktree	0.64%	-0.94%	-0.72%
G2	GTAV	0.41%	0.49%	0.34%
	Minecraft	0.53%	0.30%	0.22%
Average		**0.52%**	**-0.13%**	**0.06%**

As shown in Table 2, the performance changes by 0.52%, -0.36%, and 0.06% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off testing results suggest that the impact of disabling ISP is relatively comparable to the results observed in natural camera-captured videos[16]. This consistency highlights that ISP's contribution to compression efficiency in gaming content is similar to its role in conventional video content.

1.2 MRL

MRL tool in VVC/H.266 enhances intra prediction by utilizing multiple reference lines from neighboring blocks instead of relying on one. This approach enables more precise predictions by capturing a wider range of directional patterns, which is particularly beneficial for encoding complex textures. By improving prediction accuracy, MRL helps reduce residual errors, leading to better overall compression efficiency.

Table 3. Results of MRL Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	0.16%	0.73%	1.12%
	Darktree	0.15%	0.17%	-0.12%
G2	GTAV	0.19%	0.39%	0.58%
	Minecraft	0.69%	6.11%	2.34%
Average		**0.30%**	**1.85%**	**0.98%**

As shown in Table 3, the performance changes by 0.30%, 1.85%, and 0.98% for the Y, Cb, and Cr components on average, compared to the default settings. Overall, the tool-off test results indicate that the impact of disabling MRL is quite similar to what is observed in natural camera-captured videos[16]. Notably, MRL has a significant impact on the Minecraft sequence, suggesting that the use of multiple reference lines for intra prediction is highly beneficial even in gaming content, where additional directional references can greatly enhance compression efficiency.

1.3 MIP

MIP tool in VVC/H.266 introduces an innovative approach to intra prediction by using matrix-based transformations to predict pixel values. This method is particularly effective for blocks with non-linear or complex textures, where conventional directional prediction methods may be less accurate. MIP enhances prediction precision in such cases, leading to improved compression efficiency.

Table 4. Results of MIP Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	0.70%	1.60%	1.18%
	Darktree	0.52%	0.22%	0.10%
G2	GTAV	0.55%	0.59%	0.59%
	Minecraft	0.80%	5.76%	2.10%
Average		**0.64%**	**2.04%**	**0.99%**

As shown in Table 4, the performance changes by 0.64%, 2.04%, and 0.99% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off test results indicate that the impact of disabling MIP is similar to that observed in natural camera-captured videos, with a slight improvement in Chroma coding performance[16].

1.4 IBC

IBC tool in VVC/H.266 is designed for compressing screen content by reusing previously reconstructed blocks within the same frame. It functions similarly to inter prediction but operates within the same frame, allowing for efficient encoding of repeating patterns, text, or graphics.

By leveraging existing data within a frame, IBC significantly improves compression efficiency for screen content applications, reducing the need for redundant coding.

Table 5. Results of IBC Tool-On Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	-0.04%	0.05%	0.06%
	Darktree	-0.24%	0.06%	-0.18%
G2	GTAV	-0.86%	-0.68%	-0.70%
	Minecraft	-12.33%	-10.78%	-11.11%
Average		**-3.37%**	**-2.84%**	**-2.98%**

As shown in Table 5, the performance changes by -3.37%, -2.84%, and 0-2.98% for the Y, Cb, and Cr components on average, compared to the default settings. Since IBC is disabled by default in the AI configuration, we conducted a tool-on test to assess its impact. The results demonstrate a significant reduction in BD-rate, indicating that enabling IBC leads to notable improvements. Given that IBC is designed to provide accurate predictions for screen content, it is reasonable to observe such substantial performance gains in gaming sequences.

2. Transform tools

In evaluating the Transform tools[17] for game streaming, we tested Intra Transform Skip (TS), Multiple Transform Selection (MTS), and Low-Frequency Non-Separable Transform (LFNST) are enabled by default, we conducted tool-off tests for these tools.

2.1 TS

TS tool in VVC/H.266 allows certain blocks of residual data to bypass the transform stage, which normally converts spatial domain data to the frequency domain. This is particularly useful for small blocks or regions with simple textures, where applying a transform may not provide compression gains.

As shown in Table 6, the performance changes by 2.01%, 2.26%, and 1.38% for the Y, Cb, and Cr components on average, compared to the default settings. The

Table 6. Results of TS Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	0.66%	0.55%	1.07%
	Darktree	0.44%	-0.25%	-0.59%
G2	GTAV	0.86%	0.37%	0.70%
	Minecraft	6.09%	8.37%	4.33%
Average		**2.01%**	**2.26%**	**1.38%**

tool-off test results show a significant reduction in BD-rate, particularly for the Minecraft sequence. Given that Transform Skip is designed to handle screen content where the prediction closely matches the original, it is reasonable to observe such notable improvements in gaming content.

2.2 MTS

MTS tool in VVC/H.266 enhances the compression process by offering a selection of different transform types including DCT-II and DST-VII to better adapt to varying block characteristics. By selecting the most suitable transform for each block, MTS improves the representation of both smooth and detailed areas, leading to more efficient residual compression.

Table 7. Results of MTS Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	0.97%	2.38%	0.50%
	Darktree	1.01%	0.90%	0.80%
G2	GTAV	1.38%	1.27%	0.82%
	Minecraft	-0.06%	0.19%	-0.14%
Average		**0.83%**	**1.18%**	**0.50%**

As shown in Table 7, the performance changes by 0.83%, 1.18%, and 0.50% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off test results indicate that the impact of disabling MTS is similar to that observed in natural camera-captured videos[16]. However, an interesting result was observed in the Minecraft sequence. This can be explained by the characteristics of Minecraft, which are more aligned with screen content, while the other sequences resemble natural content in their transform usage, leading to different results across sequences.

2.3 LFNST

LFNST tool in VVC/H.266 improves compression efficiency by applying an additional transform to low-frequency components of intra-predicted blocks. This tool is designed to capture residual energy more effectively in smooth or flat regions, where traditional transforms may not provide optimal compression. By refining the representation of low-frequency details, LFNST helps reduce the overall bitrate while preserving video quality, particularly for high-resolution and low-texture areas.

Table 8. Results of LFNST Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	0.43%	1.61%	2.67%
	Darktree	0.43%	1.80%	2.26%
G2	GTAV	0.50%	2.00%	1.42%
	Minecraft	0.43%	0.20%	0.88%
Average		**0.45%**	**1.40%**	**1.81%**

As shown in Table 8, the performance changes by 0.45%, 1.40%, and 1.81% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off test results indicate that disabling LFNST has a smaller impact compared to natural camera-captured videos [16]. This may be due to the more uniform residual patterns in gaming sequences, which differ from the more varied textures in natural content. As a result, the additional transform applied by LFNST is less effective in gaming sequences, where intra-prediction and core transforms are already highly efficient.

3. In-loop filtering tools

In evaluating the In-loop filtering tools[18] for game streaming, we tested Sample Adaptive Offset (SAO), Adaptive Loop Filter (ALF), and Luma Mapping with Chroma Scaling (LMCS) are enabled by default, we conducted tool-off tests for these tools.

3.1 SAO

SAO tool, carried over from HEVC to VVC/H.266, enhances video quality by reducing artifacts and improving edge preservation after the primary compression process. It works by applying offsets to reconstructed pixels based on the characteristics of neighboring pixels, thus correcting distortion introduced during block-based compression. SAO effectively improves visual quality while maintaining compression efficiency, making it useful for both high-resolution and detailed content.

Table 9. Results of SAO Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	-0.04%	-0.10%	0.03%
	Darktree	0.08%	0.03%	-0.01%
G2	GTAV	0.07%	0.25%	0.01%
	Minecraft	0.51%	1.30%	0.75%
Average		**0.15%**	**0.37%**	**0.19%**

As shown in Table 9, the performance changes by 0.15%, 0.37%, and 0.19% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off test results indicate that the impact of disabling SAO is similar to what is observed in natural camera-captured videos[16]. This outcome is expected, as SAO was primarily designed to enhance the visual quality of reconstructed video rather than to improve objective coding performance. However, the results suggest that SAO may be particularly beneficial for artificially generated content, as evidenced by the improved coding performance observed in the Minecraft sequence.

3.2 ALF

ALF tool in VVC/H.266 refines the quality of reconstructed video frames by applying a filter after the decoding process, targeting specific areas to reduce artifacts and improve visual quality. ALF dynamically adjusts its filtering based on the content of each frame, enhancing edge detail and reducing block artifacts introduced during compression. This tool helps improve overall video quality while maintaining compression efficiency, particularly for high-resolution and complex content.

Table 10. Results of ALF Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	1.05%	20.40%	6.07%
	Darktree	1.41%	5.17%	5.86%
G2	GTAV	1.64%	12.94%	32.30%
	Minecraft	3.50%	17.71%	8.61%
Average		**1.90%**	**14.06%**	**13.21%**

As shown in Table 10, the performance changes by 1.90%, 14.06%, and 13.21% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off test results indicate that the impact of disabling ALF is smaller than what is observed in natural camera-captured videos[16]. However, the coding improvement in the Chroma components is particularly noteworthy, demonstrating ALF's effectiveness in enhancing color accuracy and compression efficiency.

3.3 LMCS

LMCS tool in VVC/H.266 enhances video quality by adjusting the brightness (i.e., Luma) and color (i.e., Chroma) components separately to better match the visual characteristics of the content. It applies dynamic scaling to luma values, which allows for more efficient encoding of scenes with varying brightness levels, while simultaneously ensuring that the chroma components are adjusted accordingly.

Table 11. Results of LMCS Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	0.00%	0.00%	0.00%
	Darktree	-0.08%	-0.42%	-0.25%
G2	GTAV	0.16%	-0.36%	-0.97%
	Minecraft	0.53%	0.85%	1.56%
Average		**0.15%**	**0.02%**	**0.08%**

As shown in Table 11, the performance changes by 0.15%, 0.02%, and 0.08% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off test results indicate that the impact of disabling LMCS is smaller than what is observed in natural camera-captured videos[16]. Notably, the sequences in the G1 class show no coding improvements for either Luma or Chroma components, suggesting that the effectiveness of LMCS may vary depending on the characteristics of the content.

4. Chroma related tools

In this section, we conducted separate tests for Linear Model for Chrominance intra prediction (LMChroma)[19], Joint Cb and Cr (JCCR)[20], and Chroma Transform Skip (ChromaTS)[21], as these tools are primarily designed to enhance the compression of chroma components. Since the chroma characteristics in gaming content differ from those in natural videos, it is important to evaluate these chroma-focused tools independently. This allows us to better understand their performance and efficiency in handling the unique properties of gaming sequences.

4.1 LMChroma

LMChroma tool in VVC/H.266 improves chroma (e.g., color) prediction accuracy by utilizing information from the luma (e.g., brightness) component to enhance chroma prediction. This tool exploits the correlation between luma and chroma components, adjusting chroma values based on the luma content within a block. By doing so, LMChroma enhances color representation and reduces residual errors, leading to better compression efficiency and visual quality, especially in scenes with complex color textures.

As shown in Table 12, the performance changes by 2.21%, 69.63%, and 42.25% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off test results demonstrate significant improvements in both Luma and Chroma components, with particularly impressive gains in Chroma performance. This suggests

Table 12. Results of LMChroma Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	3.81%	55.24%	17.17%
	Darktree	0.64%	55.43%	70.76%
G2	GTAV	1.65%	91.06%	25.73%
	Minecraft	2.75%	76.78%	55.33%
Average		**2.21%**	**69.63%**	**42.25%**

that the relationship between Luma and Chroma in gaming content is stronger than in natural camera-captured videos, potentially allowing these tools to achieve more effective compression in gaming sequences.

4.2 JCCR

JCCR tool in VVC/H.266 enhances compression efficiency by jointly coding the chroma components (i.e., Cb and Cr), rather than treating them independently. This tool leverages the correlation between the two chroma channels, allowing for more efficient prediction and reduced residual data.

Table 13. Results of JCCR Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	0.41%	1.36%	-0.65%
	Darktree	0.06%	1.10%	2.43%
G2	GTAV	0.23%	2.21%	0.40%
	Minecraft	0.23%	-0.54%	-0.83%
Average		**0.23%**	**1.03%**	**0.34%**

As shown in Table 13, the performance changes by 0.23%, 1.03%, and 0.34% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off test results indicate that the impact of disabling JCCR is smaller than what is typically observed in natural camera-captured videos[16]. This suggests that the benefits of JCCR in gaming content may be less pronounced, possibly due to differences in the chroma-luma relationships between gaming sequences and natural video content.

4.3 ChromaTS

ChromaTS tool in VVC/H.266 improves compression efficiency for chroma components by allowing certain chroma blocks to bypass the transform stage, similar to the transform skip for luma. This is particularly useful for chroma blocks with simple or flat color regions, where a transform may not offer significant gains. By skipping the transform in these cases, ChromaTS helps reduce unnecessary complexity and preserve color details, optimizing compression for specific content types.

Table 14. Results of ChromaTS Tool-Off Testing

Class	Sequence	BD-rate		
		Y	U	V
G1	Level1	-0.01%	0.61%	1.10%
	Darktree	0.00%	0.03%	0.03%
G2	GTAV	-0.02%	0.10%	0.38%
	Minecraft	0.04%	5.60%	2.08%
Average		**0.00%**	**1.59%**	**0.90%**

As shown in Table 14, the performance changes by 0.00%, 1.59%, and 0.90% for the Y, Cb, and Cr components on average, compared to the default settings. The tool-off test results suggest that disabling ChromaTS has a relatively small impact on gaming content compared to TS tool. This indicates that the current design of ChromaTS may not align well with the characteristics of chroma components in gaming sequences, limiting its effectiveness in this context.

V. Discussion

The evaluation of key video coding tools within the VVC/H.266 framework provides valuable insights into their suitability and effectiveness for game streaming applications. Tools such as ISP, MRL, MIP, IBC, and TS showed varying degrees of performance based on the unique characteristics of gaming content.

The results indicate that some tools, such as MRL and IBC, are particularly well-suited for gaming sequences for example Minecraft, which align more closely with screen content patterns. These tools efficiently leverage repetitive textures and structured patterns, resulting in significant coding gains. Conversely, other tools, such as ChromaTS and LFNST, demonstrate reduced effectiveness, likely due to the distinct characteristics in gaming content compared to natural video.

Interestingly, the tests show that tools such as JCCR and ChromaTS, which primarily target chroma components, offer only limited improvements in gaming sequences. This suggests that the chroma structures in gaming content may not fully align with the assumptions underlying these tools, reducing their impact. However, the impressive gains observed in tools such as IBC and LMChroma confirm the need for specialized coding strategies dedicated to artificially generated content.

These findings highlight a critical gap in existing video coding tools, which were predominantly developed for natural camera-captured content. Although VVC/H.266 introduces more adaptable tools, further refinements are needed to optimize for the specific characteristics of gaming content. As game streaming continues to grow, future video coding standards must address these unique challenges, ensuring that compression tools can efficiently handle complex, high-resolution gaming sequences.

Ⅵ. Conclusion

This paper presents an evaluation of key tools in VVC/H.266 to determine their effectiveness in compressing gaming content. The results reveal that tools like ISP, MRL, and IBC contribute meaningfully to compression efficiency, particularly in sequences with repetitive patterns or screen content. However, other tools, such as ChromaTS and JCCR, demonstrate limited effectiveness, suggesting that current coding strategies may not fully align with the characteristics of gaming sequences.

The analysis highlights the need for further research and development in video coding technologies to better accommodate the unique properties of gaming content. As game streaming becomes increasingly prominent, future standards must consider these requirements to ensure efficient compression and high-quality streaming. Overall, while VVC/H.266 offers promising improvements, continued efforts are essential to refine these tools and develop new coding strategies tailored to the evolving demands of game streaming.

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