Journal of Information Hiding and Multimedia Signal Processing ©2023 ISSN 2073-4212
Ubiquitous International Volume **14**, Number **4**, December **2023**

Enhancing Cloud Gaming Performance through Game Object-aware Encoding and Macroblock Classification

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Received May 2023; revised August 2023, accepted August 2023

Abstract. *Cloud computing is a technology model that provides access to reliable, flexible, and cost-effective system resources to various users and applications with advanced levels of service. One industry that benefits greatly from cloud computing is gaming, as it has seen the introduction of several new cloud gaming designs. These cloud gaming designs offer many advantages, including improved performance over traditional online gaming. However, cloud gaming also faces challenges such as the significant amount of video processing required and the associated computational complexity. This paper identifies the limitations of the current system and presents a new algorithm to accelerate the encoding process by reducing the computational complexity. The improvements made to the video codec resulted more than 9% reduction in overall encoding time with only minimal impact on users' satisfaction.*

Keywords: Cloud gaming, Computational complexity, Motion estimation, HEVC, Video Encoding

1. **Introduction.** The advent of digital communication has brought about a revolution in the world of video gaming. Online gaming has soared in popularity, permeating societies across the globe. The United States, for example, boasts a substantial population of avid gamers, with approximately 60% regularly engaging in video game entertainment, leading to a remarkable expenditure of $56.6 billion in 2022, as reported by the Entertainment Software Association (ESA) [1]. This surge in digital gaming has propelled the gaming industry to unprecedented heights, with revenues reaching staggering billions of dollars [2]. To tap into this limitless potential for growth, game developers are ceaselessly innovating,

with one area of focus being the integration of cloud computing techniques into game development.

Cloud gaming has emerged as a captivating and novel technology, enabling game developers to harness the immense capabilities of the cloud. By leveraging cloud computing, games can be processed at an accelerated pace, surpassing the performance of traditional consoles and personal computers. This translates to swifter gameplay experiences and broader accessibility for customers. Cloud gaming empowers clients to offload complex computational tasks to the cloud, effectively reducing the processing burden on their end. These tasks encompass rendering high-definition video sequences and conducting intricate mathematical computations, all seamlessly performed on the cloud. The game content is subsequently delivered to the client side utilizing a video (GaV) technique [3].

The world of video gaming has been greatly influenced by the rapid growth and popularity of digital communication. As the industry continues to expand, game developers are constantly pushing the boundaries of innovation, incorporating cutting-edge technologies like cloud computing to elevate the gaming experience for players and broaden their reach. The future of gaming holds tremendous promise, with a multitude of exciting developments on the horizon.

Cloud gaming has witnessed a remarkable surge in popularity within the realm of online gaming, leveraging the power of cloud computing to enhance the overall gaming experience. In this paradigm, the game engine operates in the cloud, while the data is seamlessly streamed to the user's device. This eliminates the need for the user's device to handle the extensive data processing typically required by conventional consoles. Instead, the client's device focuses solely on processing control inputs and actions, while the cloud takes charge of rendering, compression, and other complex tasks. This streamlined approach optimizes resource utilization and ensures a more immersive and enjoyable gaming experience for the user. Edge computing is a technique which is capable to help reducing latency in cloud gaming. However, several problems still need to be optimized [4-5].

A key advantage of cloud gaming lies in its ability to eliminate the necessity for high-performance hardware on the user's end, relying instead on a minimum internet speed of 5 Mbps. However, it's worth noting that cloud gaming can consume a significant amount of internet bandwidth. Nevertheless, the benefits of alleviating the computational burden on the user's device and delivering an overall more efficient and gratifying gaming experience outweigh these concerns.

To summarize, cloud gaming has emerged as a pivotal advancement in the realm of online gaming. By leveraging cloud infrastructure to run and stream games to users' devices, cloud gaming revolutionizes the gaming experience by alleviating the computational burden on users and eliminating the need for high-performance hardware. While concerns regarding bandwidth exist, the advantages of cloud gaming are substantial, and its accessibility continues to expand alongside global improvements in internet speeds [6-7].

The introduction of cloud gaming has ushered in a myriad of benefits for the gaming industry, extending advantages to game developers, providers, and gamers themselves. Notably, cloud gaming enhances security for developers, as games are stored in secure cloud locations, minimizing the risks of hacking or unauthorized copying. Moreover, users must access games via their own secured accounts and at their own expense, fostering the development of innovative services and business models. For gamers, cloud gaming unlocks convenience as they gain the freedom to access their games anytime and from anywhere with internet connectivity. Furthermore, the absence of game storage on personal devices translates to cost savings on hardware upgrades. Online gaming experiences become seamless, enabling gamers to connect with players worldwide effortlessly and participate in tournaments while placing minimal strain on their devices. A prime illustration of a successful cloud gaming platform is the CloudUnion, where games are streamed as video in various resolutions after users download the client. With a minimum bandwidth requirement of 2Mbps, which is readily available across most countries, high-quality game streaming is guaranteed, while a higher speed of 6 Mbps ensures optimal performance [8].

Cloud gaming encompasses the utilization of cloud computing to enhance the gaming experience for users. However, the manner in which the cloud is employed can exhibit significant variations. Within the realm of cloud gaming, three primary categories are distinguished. The initial category, known as Remote Rendering GaaS (RR-GaaS), relies on server-side rendering for all computational processes, encompassing video capture, rendering, encoding, and streaming. In the RR-GaaS paradigm, the client's device is relieved of the burden of game processing and is solely responsible for receiving the streamed video, decoding it, and presenting it to the user. This approach alleviates the computational strain on the client's device, resulting in a substantial improvement in the overall gaming experience. Nevertheless, a potential drawback of this approach is the potential for end-to-end delays [9].

The second category of cloud gaming places greater emphasis on the client device, assigning a higher degree of responsibility to the client-side operations. This is achieved through Local Rendering GaaS (LR-GaaS) technology, where the client's terminal assumes the tasks of video processing, including coding, decoding, and streaming [9]. However, this approach carries the disadvantage of imposing a significant demand on the client to perform real-time rendering of game scenes. This can detrimentally impact the gaming experience due to increased power consumption and time complexity. The third category of cloud gaming employs hybrid processing techniques, wherein certain processes are executed on the cloud side while others are delegated to the client side. This hybrid approach is exemplified in the Cognitive Resource Allocation (CRA-GaaS) cloud gaming scheme, which dynamically distributes processes across the network based on the system's conditions. Among these categories, RR-GaaS stands as the most developed and widely adopted model, utilized by major cloud gaming companies such as OnLive and Sony (Gaikai).

RR-GaaS cloud gaming has garnered attention for its potential benefits to game developers and users, as outlined in reference [10]. However, it is not without its limitations. The foremost challenge lies in the computational complexity that arises from the extensive processing demands placed on the cloud. Real-time game execution, scene updates, control mechanisms, and encoding tasks necessitate the cloud to perform these operations promptly, which can prove time-consuming. Consequently, this can impede the widespread adoption of this approach.

Various strategies have been proposed to optimize the computational cost associated with cloud gaming. Reference [11] suggests leveraging side information derived from the game engine to determine which components can be skipped or processed based on specific criteria. By analyzing macroblock locations and making compression decisions accordingly, computational complexity can be minimized. Preliminary results indicate potential time savings of up to 18% in game encoding through this approach.

In a separate study discussed in reference [12], efforts were focused on enhancing server-side performance in cloud gaming operations. The particular emphasis was placed on expediting the power-intensive video encoding process by capitalizing on available information about game objects within the game engine. The investigation revealed that motion estimation, a resource-intensive step, significantly impacted both time and power consumption. Leveraging modern video codecs such as H.264 resulted in an approximate 8.86% acceleration of the overall gaming process, as indicated by the study findings.

2. **Related Works.** The architectural framework known as RR-GaaS (Rendering and Encoding as a Service) has encountered substantial computational complexity challenges within the realm of cloud gaming. This is primarily due to the continuous advancements in game graphics, actions, and resolution, which directly impact the rendering and encoding time required for a seamless gaming experience. However, dedicated researchers have diligently worked towards mitigating these challenges by focusing on reducing the encoding time for popular video codecs like H.264/AVC and HEVC. Moreover, additional studies have delved into minimizing the computational complexity of cloud gaming systems to enhance their overall efficiency. In this section, we will delve into the key concepts proposed by these research endeavors, shedding light on their contributions to the advancement of cloud gaming. Real-time video encoding has posed a significant constraint, especially since the advent of H.264/AVC. Given the prevalent nature of online-based games in today's market, which necessitate live streaming, encoding, decoding, and power consumption, these components have become critical focal points for monitoring and research aimed at improvement. Numerous studies have put forth innovative ideas to address these challenges by reducing the computational complexity of H.264/AVC and HEVC codecs. These works have primarily focused on two pivotal steps: motion estimation and mode decision, recognizing their substantial influence on the overall computational time [13].

Certain research approaches advocate for diminishing the number of motion estimation searches to effectively reduce the encoding time, while others concentrate on optimizing mode decision in diverse scenarios to achieve notable time savings in the encoding process. These efforts have proven particularly valuable for real-time applications employing the H.264/AVC encoding system, substantially curbing both the encoding time and computational complexity. Furthermore, a separate strand of research has explored adaptive encoding parameter adjustments to tailor the computational complexity of the encoder according to the available resources at hand [14-15].

In the realm of real-time video encoding for online games, various strategies have been employed to mitigate the computational complexity associated with H.264/AVC and HEVC codecs. These endeavors have proven instrumental in enhancing the efficiency of encoding processes, thereby elevating the overall gaming experience while simultaneously curbing resource consumption tied to encoding, decoding, and power usage [16-17].

Nevertheless, past undertakings to reduce computational complexity have primarily concentrated on refining encoding techniques at a general level, neglecting to consider the idiosyncrasies intrinsic to cloud gaming. A crucial oversight lies in the failure to account for the invaluable side information that often accompanies compressed bitstreams within gaming scenarios. Enhanced approaches are better poised to incorporate the entirety of encoded data gleaned from streamed content and in-game sequences.

To achieve optimal efficiency within the realm of cloud gaming, it becomes imperative to scrutinize the distinctive features and requisites specific to this application domain. By acknowledging the unique facets of cloud gaming, including the utilization of side information and other pertinent encoding parameters, developers can forge more efficacious solutions that elevate the holistic gaming experience while concurrently mitigating computational complexity entwined with the cloud gaming system. Thus, it becomes imperative to embark on further research and development initiatives that squarely address the distinctive demands and prerequisites of cloud gaming.

Numerous research endeavors have been dedicated to mitigating the computational intricacies associated with cloud gaming. One notable study delved into real-time video encoding, employing a runtime graphics rendering context to strategically select key frames and employ the innovative 3-D Warping algorithm to interpolate non-key frames internally. Another investigation capitalized on depth maps derived from the game engine to streamline the motion estimation process. Simultaneously, an alternative approach leveraged depth information to heighten the motion selection phase of the H.264/AVC codec. In a bid to optimize available resources, a distinct proposition advocated for parameter adjustments tailored to the cloud's capabilities. Furthermore, a pioneering study introduced a ranking method that adeptly curtailed processing power by eliminating less significant objects from the scene.

These multifaceted research studies have unveiled an array of techniques and algorithms that tackle the vexing challenge of computational complexity in cloud gaming. By judiciously integrating key frames, depth maps, and other encoding parameters, these approaches exhibit remarkable potential in optimizing the encoding process, ultimately elevating the overall gaming experience. Concurrently, developers can adroitly manage power consumption and abate computational complexities by adorning their toolkit with parameter adjustments aligned with the available cloud resources and employing a discerning ranking system to streamline scene processing. Continued research and development in this realm will undoubtedly propel the frontiers of cloud gaming, ushering in a new era of enhanced efficiency and optimized solutions for this rapidly burgeoning industry [18-22].

3. **Proposed Method.** The presented research introduces a fresh perspective on utilizing game engine side information in the context of cloud gaming. Unlike previous approaches, this novel method takes into account the macroblock location, making it more comprehensive and effective. Both foreground and background macroblocks are processed based on their respective locations, enabling a more refined analysis. The movement of each macroblock within a foreground object is carefully detected and compared to the predicted motion vector, resulting in three distinct scenarios: skipping the motion estimation process, performing it with restrictions, or following the normal process. Background macroblocks are also considered, and the motion estimation process is accelerated by leveraging a background motion vector for comparison against the predicted one.

By incorporating the optimization of motion estimation in both foreground and background macroblocks, this proposed idea offers a highly efficient and effective approach to handle game engine side information. The traditional block diagram of a cloud gaming system illustrates the division of gaming operations between the client and the cloud sides. On the client side, the focus is primarily on collecting user interactions and decoding the received bitstream from the server. On the other hand, the server side bears the responsibility of executing game logic, rendering game objects, and performing frame-by-frame encoding through the video encoder. However, this arrangement poses challenges in terms of power consumption, especially when catering to a large player base.

Furthermore, current server-side compression processes lack the utilization of valuable side information about game objects, despite its availability. This untapped information, which includes object sizes and locations, can greatly simplify compression operations if effectively employed. By harnessing this side information, complex encoding operations can be circumvented, leading to optimized compression, reduced computational complexity, and lower energy consumption. Consequently, the integration of available side information presents a promising opportunity to enhance the efficiency and sustainability of cloud gaming systems, offering cost-effective and environmentally friendly solutions. Continued research in this domain is essential to uncover additional avenues for optimizing cloud gaming systems, enabling improved performance and reduced energy consumption.

Based on the previous findings, a fresh approach is put forward to minimize computational time during the encoding process while upholding output quality. The proposed technique capitalizes on object information accessible at the encoder side, particularly in the context of HEVC, a prevalent video encoding standard built for high-resolution video sequences. However, the encoding complexity associated with HEVC presents a formidable obstacle. To overcome this hurdle, a groundbreaking method is presented in paper [16], focusing on expediting the HEVC intra prediction process. In this innovative approach, the number of comparisons in the Rate-Distortion Optimization (RDO) process is reduced by leveraging knowledge about neighboring blocks' content and direction. By exploiting the resemblance between candidate blocks and neighboring blocks, the technique effectively trims down the candidate block count, resulting in accelerated encoding. The key achievement lies in achieving faster intra prediction in HEVC without compromising video quality, thanks to the diminished number of RDO comparisons.

To implement this, the study embraces a swift H.265-HEVC encoding technique, as outlined in [16], to hasten the encoding process. Moreover, two distinctive paths are devised to detect and enhance the encoding process for both foreground and background macroblocks. Detailed insights into the enhanced H.265 codec adopted in this research can be found in [16], while subsections A and B delve into the specifics of the two paths. The primary objective of the proposed technique is to alleviate the computational complexity of the encoding process while upholding output quality. By leveraging object information available at the encoder side, the study strives to minimize bitrate escalation while significantly reducing computational time. This promising technique holds the potential to address the challenges faced by cloud gaming and enhance the overall gaming experience.

3.1. **Foreground Macroblocks.** To enhance the efficiency of the motion estimation process, the proposed methodology initiates by identifying the positional attributes of each macroblock and evaluating whether it resides within the confines of a game object, thereby classifying it as a foreground macroblock. Once a macroblock is designated as foreground, its motion is scrutinized to determine if it falls below the Low Threshold (L-Th), thereby denoting it as a closed macroblock. In cases where the motion exceeds L-Th, a more detailed analysis is conducted to ascertain whether it remains below the High Threshold (H-Th), leading to its classification as an average macroblock, or if it surpasses H-Th, categorizing it as a distant macroblock.

Subsequently, motion estimation is performed for each macroblock based on its respective classification. For close macroblocks, the motion estimation process is entirely bypassed. Conversely, average macroblocks undergo an enhanced motion estimation technique to ensure precise rendering. Lastly, distant macroblocks undergo the conventional motion estimation process to attain the desired level of accuracy. This approach facilitates a more streamlined and efficient motion estimation process while upholding the rendering quality of game objects at a superior level.

3.2. **Background Macroblocks.** The categorization of a macroblock (MB) as a background MB depends on its positional relationship with game objects. In situations where the game engine lacks information about the background MB and its motion, our proposed algorithm is designed to function effectively in the absence of such feedback. However, if the game engine does provide relevant information, the algorithm can be modified to leverage it, leading to improved processing time. Nevertheless, the novel technique employed in the proposed algorithm enables its operation without any game engine feedback.

To determine if a current background MB qualifies as a background MB in the previous encoded frame, the proposed approach first checks if it is positioned behind other objects and if it lies in the background of the reference frame. If the MB fails to meet the criteria for a background MB in the previous frame, a normal motion estimation (ME) is performed using the full search method. On the other hand, if it satisfies the criteria, a background ME is conducted for the current MB, taking into consideration the motion vectors of all MBs. For early MBs in a frame where motion vectors are not yet available, the normal ME is employed. Once a sufficient number of MBs have been processed, motion vectors are extracted and utilized in a manner similar to that of foreground MBs. This approach enables efficient motion estimation for background MBs, which typically have less detailed information compared to foreground MBs.

Figure 1 illustrates the step-by-step procedure followed by our algorithm at the video encoder side. This process is applied to each MB and encompasses all available modes for each MB. Depending on the specific scenario of the MB, motion estimation may be omitted for certain modes while being performed for others. The initial stage of the proposed algorithm involves verifying whether the MB lies within the boundary of a game object, followed by a subsequent test to determine the classification threshold for the MB.

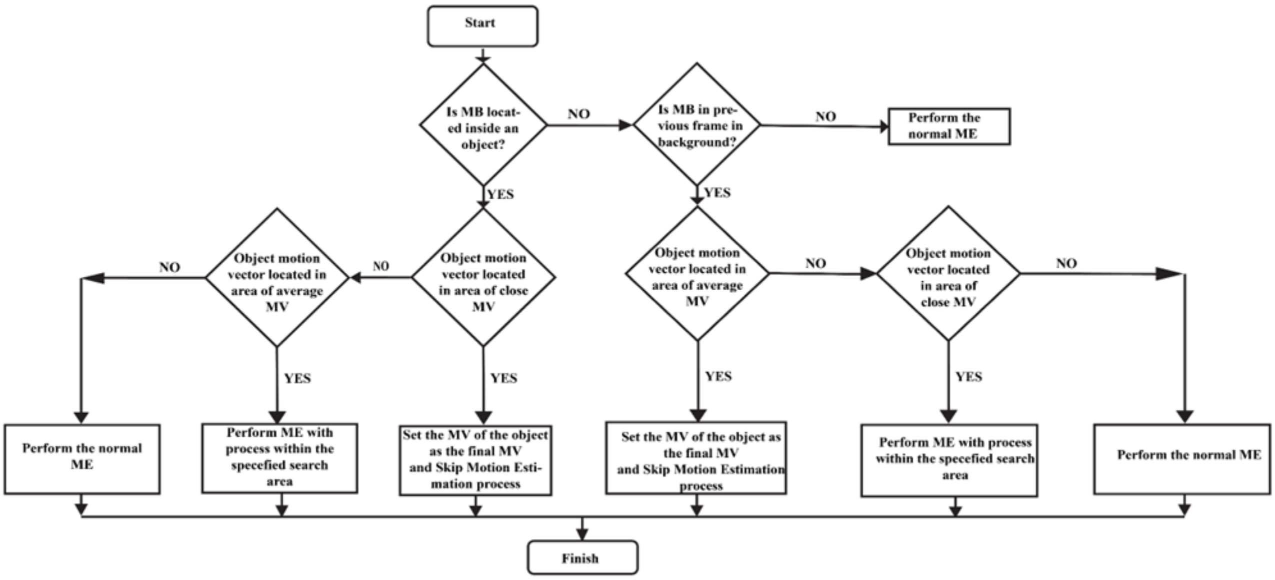

FIGURE 1. Flowchart of the proposed algorithm

The motion estimation (ME) selection process is contingent upon the threshold level, with the determination of the appropriate ME approach hinging on the presence of the macroblock (MB) within the background of a preceding frame and its exclusion from any game objects. In such cases, the algorithm assesses two distinct threshold values to determine the optimal ME technique. Conversely, if the MB is not identified through either of these methods, a regular ME is performed.

The threshold values hold great significance within the proposed algorithm, as they exert a considerable influence on its resulting output. These values can be predefined during the initial stages of implementation for a specific encoder, depending on factors such as the video type or the desired output characteristics. In Section 4, we elucidate the threshold parameters employed in our experimental analysis conducted with the HEVC codec.

4. **Experimental results.** A series of comprehensive experiments were undertaken to assess the effectiveness and performance of the novel algorithm proposed in this study. The experiments were carried out using the state-of-the-art HEVC video codec as the reference software. A diverse set of video sequences, encompassing a range of bitrates and resolutions, was utilized to ensure the robustness and applicability of the algorithm. The

specific configuration of the HEVC codec, including its key parameters, employed during these experiments is meticulously documented in Table 1.

In order to maintain the integrity of the experimental evaluation, a comprehensive comparison was conducted between the acceleration achieved through our novel algorithm and the latest advancements in the field as presented in prior research [12]. Furthermore, particular attention was directed towards acknowledging the potential trade-offs associated with the proposed algorithm, including the impact on bitrate increment and quality degradation. To ensure a comprehensive assessment, a combination of objective and subjective quality metrics was employed to quantify and evaluate the enhancements accomplished by our innovative approach.

TABLE 1. Parameter setting of the encoder

Profile	Baseline
Level	3
Number of coded frames	150
Number of reference frames	5
Search range	256
RDO	On
Quantization Parameters	24, 36, 38, 44 and 46

4.1. **Subjective Measurements.** The present study employed the Double Stimulus Continuous Quality Scale Method, as outlined by ITU-R [23], to conduct subjective quality assessment. Both subjective and objective methods were utilized, encompassing in-depth discussions on the participants' demographics, testing methodology, and evaluation procedures. To evaluate the performance of the proposed method, three popular games, namely Aquarium Toy, Death Ball Toy, and Truck Toy, were selected. The evaluation process involved comparing the conventional method using HEVC with our proposed method utilizing the improved HEVC [16].

Prior to the evaluation, comprehensive information and encoding settings for the selected games were meticulously chosen and evaluated. Subsequently, these parameters were transmitted to the video encoder, along with measurements of the game's background. However, it is important to note that no further information was extracted from the game engine. To capture the game video, the widely adopted software, FRAPS, was employed, employing a frame rate of 30fps and a quarter pixel motion estimation criteria.

For the video encoding process, the reference software of HEVC, incorporating the specified thresholds mentioned earlier, was utilized. Both the game capturing and encoding procedures were meticulously carried out, adhering to the aforementioned criteria. The initial phase of the study involved the participation of 40 individuals, specifically college students without prior experience in video compression or assessment. These participants were requested to provide demographic information through a questionnaire, and the collected data was presented in Table 2. This step aimed to ensure a diverse and representative sample population and to explore how demographic factors might influence the participants' subjective quality assessments.

In the subsequent phase, the participants were instructed to assess nine distinct sets of video sequences derived from three carefully chosen games. Each game underwent encoding at three distinct bitrates, as outlined in Table 3. The participants' task entailed assigning scores to their evaluations using the Double Stimulus Continuous Quality Scale

Method, as per ITU-R guidelines [23]. This standardized approach facilitated the collection of subjective ratings that faithfully reflected the participants' experiential perception of the video content.

The deliberate inclusion of multiple video sequences encoded at different bitrates served the purpose of thoroughly examining the effectiveness of the proposed algorithm across diverse conditions. Furthermore, the study's emphasis on recruiting a diverse range of participants ensured that the findings could be more broadly generalized and applied to a wider population.

Both the conventional encoding method and the proposed method were employed to encode each set of video sequences. To ensure accurate results, a 60-second video sequence consisting of 3600 frames was encoded for each bitstream. Participants were requested to

Table 2. Demographics of subjective participants

Gaming experience				
Bad	Poor	Fair	Good	Excellent
3	3	5	12	17
Weekly hours game play				
$\leq$5	6-10	11-20	21-30	>30
4	5	15	8	8
Gaming platform (already played on)				
PC	Console	Tablet	Cell phone	
2	10	13	17	

rate the quality of each set of video sequences on a scale ranging from Excellent to Bad which is (5-1), where Excellent indicates 5 and Bad indicates 1. To eliminate potential distortions resulting from scaling, the video sequences were presented at their original resolution. Furthermore, the viewing distance for participants was set at four times the screen size, following the recommendations outlined in [23]. The Mean Opinion Score

Table 3. Selected bitrates for MOS

Game Name	Bitrate 1 (Kbps)	Bitrate 2 (Kbps)	Bitrate 3 (Kbps)
AquariumToy	5500	3500	2500
DeathBallToy	4500	3500	2200
TruckToy	4200	3500	2700

(MOS) was adopted as the subjective quality metric in the final stage, encompassing both the conventional and proposed methods. MOS values were calculated by averaging the scores provided by participants for each combination of method and encoding setting. The comparative results for the MOS scores are presented in Table 4, providing a comprehensive analysis of the performance of the conventional and proposed methods across three different games, namely AquariumToy, DeathBallToy, and TruckToy. The comparison focuses on the average rate changes for each game including the three different bitrates. (Rate 1, Rate 2, and Rate 3) observed for each toy, where Rate 1 one represents the average MOS for the three bitrates of the game Aquarium Toy, Rate 2 and Rate 3 represent the games DeathBoyToy and TruckToy respectively.

For the conventional method, the average rates across all toys range from 4.63 to 4.96, with the highest rate achieved by the TruckToy. In contrast, the proposed method yields average rates ranging from 3.96 to 4.41, with the DeathBallToy obtaining the highest rate.

Notably, the proposed method consistently achieves lower rates than the conventional method across all three toys, resulting in an average rate change of -0.67%.

It is essential to highlight that the lower rates obtained by the proposed method indicate superior compression efficiency at the same quality level. A lower rate signifies a reduced number of bits required to represent the image or video. However, this efficiency comes at a slight cost in terms of quality, as evidenced by the -0.67% average rate change.

In summary, Table 4 serves as a concise and informative resource for comparing the performance of the conventional and proposed methods across various games. It provides valuable insights for researchers and practitioners in the field of video compression, enabling them to quickly assess the impact of the proposed method on different video content types. Furthermore, the empirical findings clearly illustrate the consistent performance of the proposed method across the range of bitrates employed in this investigation. On average, the proposed method exhibits a negligible decrease of less than 0.41 dB in quality when compared to the conventional full method, as indicated by both PSNR (Peak Signal-to-Noise Ratio) and dB (decibel) metrics. This outcome underscores the efficacy of the proposed approach, which primarily relies on motion estimation to determine the optimal block and utilizes entropy coding to calculate the residual between the current and reference blocks.

Table 4. Subjective results - MOS

	AquariumToy			**DeathBallToy**			**TruckToy**			**Average**
	Rate 1	*Rate 2*	*Rate 3*	*Rate 1*	*Rate 2*	*Rate 3*	*Rate 1*	*Rate 2*	*Rate 3*	**Change %**
Conventional	4.8	4.68	4.96	4.79	4.78	4.63	4.89	4.78	4.81	-
Proposed	3.96	4.11	3.97	4.41	4.12	4.1	4.31	4.08	4.23	-0.67

4.2. **Objective Measurements.** Figure 2 depicts the conventional compression method, while Figure 3 showcases the proposed method. In this study, the Torque2D game engine, as described in [24], was employed for testing purposes. The same three games utilized for subjective evaluation were also employed for objective testing. For each game, a specific object was selected and transmitted to the video encoder. Additionally, the background was considered in order to enhance efficiency, despite the absence of background information provided by the game engine. Game scenes were captured using FRAPS software [25] and subsequently transmitted to the encoder. The video capturing process operated at a frame rate of 60 frames per second, and the HEVC reference software with full search was employed for video encoding. Four thresholds, namely T1=22, T2=12, T3=8, and T4=4, were defined for the experiment. These thresholds were established after conducting an initial simulation process on a set of video sequences that were not included in the evaluation dataset.

To ensure an effective simulation process, it is crucial to encompass a diverse range of content types and bitrates. Furthermore, the threshold parameters for other video codecs should be adjusted based on the outcomes of the initial simulation process. Importantly, the threshold parameters cannot be modified once the simulation process is completed. The performance evaluation of the proposed method was conducted under various settings. Table 1 provides an overview of the parameter settings employed for the video encoder during the performance calculations. Specifically, the captured videos were encoded using Baseline with five different quantization parameter (QP) values, encompassing a total of 3600 coded frames.

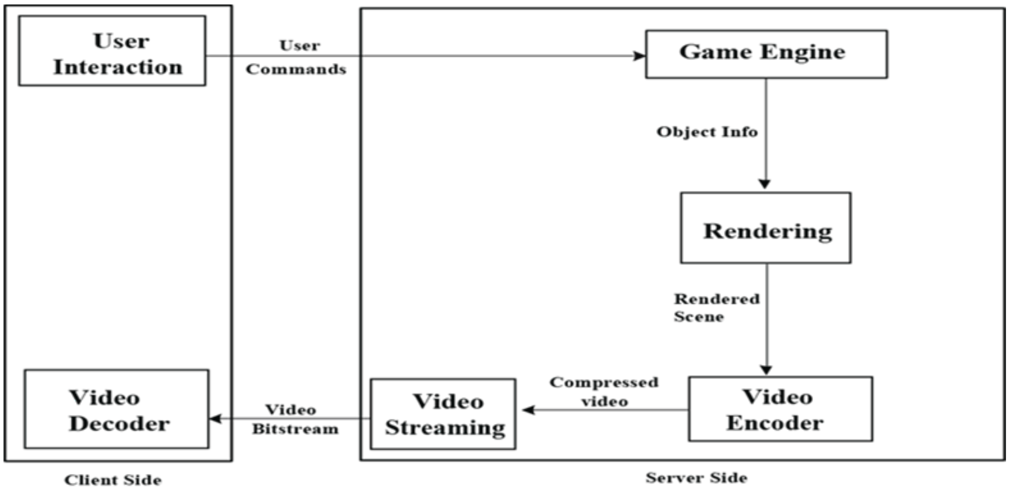

FIGURE 2. Conventional Compression Method

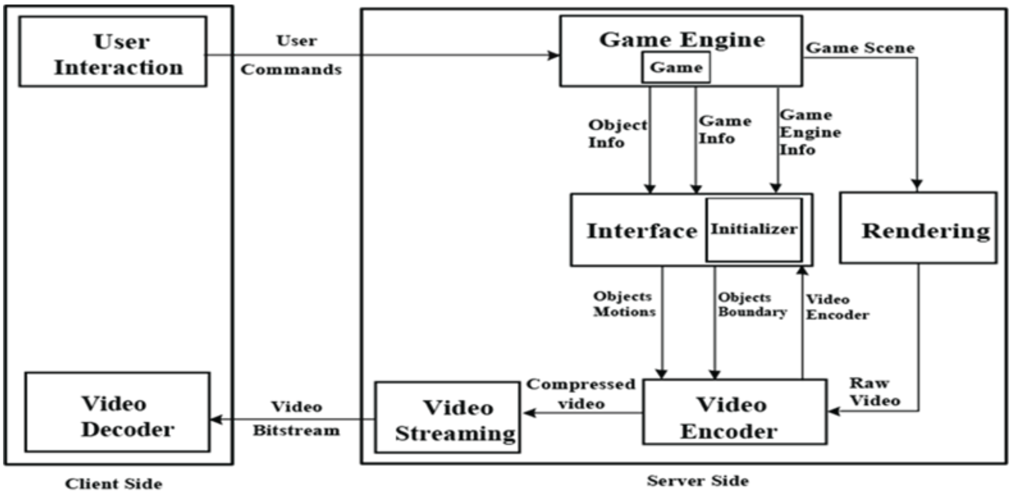

FIGURE 3. Diagram of the Proposed Method

The proposed approach exhibited a noteworthy improvement in speed compared to the conventional scheme. Figure 4 visualizes the total encoding time for three specific video scenes, demonstrating that the proposed method yielded a speedup of up to 9% for the selected QP values. Furthermore, Figure 5 illustrates the substantial acceleration of the motion estimation (ME) process achieved by the proposed method, attaining a speed increase of up to 33%. This performance notably surpassed that of the conventional encoding method. Figure 6 illustrates the Rate-Distortion (RD) performance of the proposed method, conventional method, and presents a comprehensive comparison between the two. Notably, the proposed method has achieved a commendable RD performance comparable to that of the conventional method, accompanied by a negligible increase in distortion. This achievement can be attributed to a strategic approach that prioritizes minimizing the impact of prediction errors on quality degradation. As a result, the proposed approach has incurred a minimal loss of less than 0.35 PSNR (Peak Signal-to-Noise Ratio), signifying its ability to maintain high fidelity. Additionally, the proposed method has demonstrated a significant speedup of up to 9% when compared to the conventional method. Taken together, these outcomes highlight the effectiveness of the

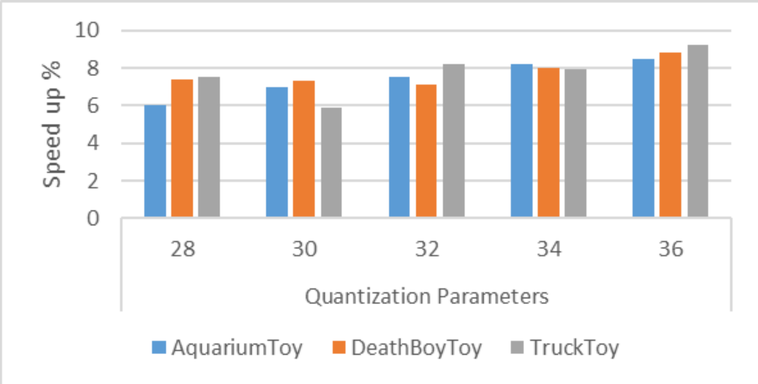

FIGURE 4. Encoding Time Speedup Compared to the Conventional Method

proposed method, as it strikes a balance between minimal distortion, considerable speed improvement, and a marginal loss in PSNR, which can be considered inconsequential.

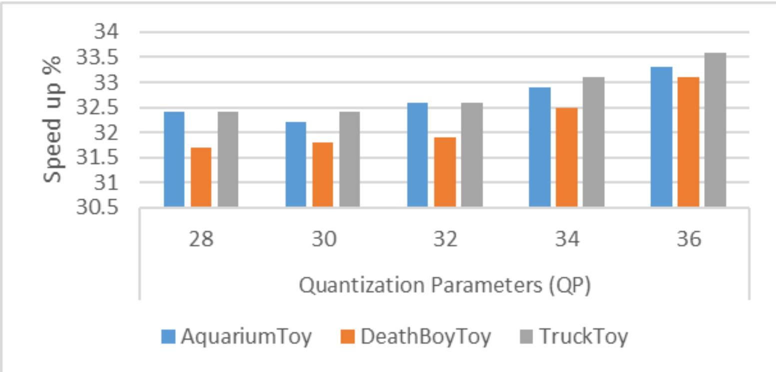

FIGURE 5. Motion Estimation Compared to the Conventional Method

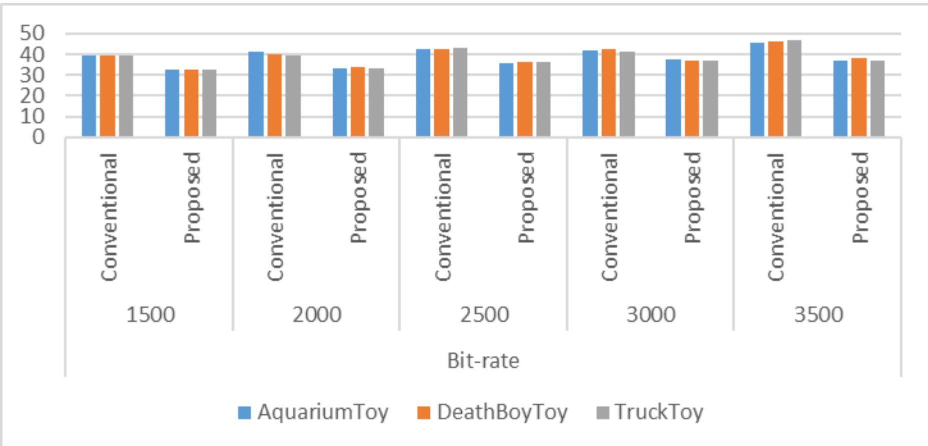

FIGURE 6. Rate Distortion Performance Compared to the Conventional Method

5. **Conclusion.** This study proposes a novel technique to improve the encoding process in cloud gaming. The proposed approach utilizes the game object information available within the game engine to speed up processing times. More specifically, this game object

information is integrated into the video encoder to skip motion estimation when feasible, leading to considerable acceleration. Additionally, the macroblocks are distinguished into foreground or background macroblocks, with the latter being subjected to specific measures to accelerate motion estimation and enhance quality. The experimental results demonstrate that the proposed technique can achieve up to a 33% acceleration in motion estimation and a 9% reduction in encoding time. One significant benefit of this method is its flexibility in application, as it can be used with any game object and video encoder with minimal modifications. However, further investigation may be required to support different types of game objects, including 3D objects, which could be a promising area for future research. Ultimately, the proposed technique can significantly enhance the cloud gaming experience for users by improving performance and reducing latency.

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