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RESEARCH ARTICLE

Towards Efficient Video Codec for 360-degree Video Streaming over Broadband Network

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Abstract

Objectives: This study presents the compression efficiency analysis of AV1, H.265/HEVC, and VVenc based on the Peak Signal-to-Noise Ratio (PSNR) and Video Multimethod Assessment Fusion (VMAF) objective quality metrics. **Methods:** The study utilizes video sets from publicly available databases and YouTube. The video sets were compressed using High Efficient Video Codec (HEVC/H.265) and Versatile Video Encoder (VVenc) based on Common Test Conditions (CTC) for fixed-quality encoding at different rates. For STV-AV1, we use quantization parameters which result in the rate nearly the same as that of CTC. The encoders' performance was evaluated using PSNR and VMAF objective metrics. Rate-distortion curves were constructed, and Bjøntegaard delta metric was computed to obtain bitrate saving/overhead between encoders. **Findings:** The superiority of the Versatile Video Encoder (VVenc) over STV-AV1 was unchallenged in eight out of twelve encoded 360-degree videos. The maximum bitrate saving of 72.6% and minimum of 12.8% is attained by the VVenc encoder compared to SVT-AV1. For the case of the HEVC encoder, the maximum and minimum bitrate overhead of 89.5% and 19.2% is required for it to achieve video quality similar to that of VVenc encoded video. Based on bit-rate saving, the SVT-AV1 encoder is the second most performing, especially for 6K and 5K resolution videos. It is further observed that the HEVC encoder outperforms VVenc and SVT-AV1 only in two video scenes, with average bitrate savings of 34.1% and 1.3%, respectively. Even though the popularity of HEVC still exists in most encoded 360-degree videos, the open-source STV-AV1 showed better results by outshining the HEVC in eleven out of twelve 360-degree video sets. The VVenc, an open-source version of H.266 surpasses other encoders, however, up to this moment, most of the Virtual reality platforms do not support the H.266 format. **Novelty:** High-resolution 360-degree video requires high-speed network infrastructure to transmit video packets. Therefore, a bandwidth-efficient video encoder must be selected to ensure an adequate immersive experience. It is well known that the HEVC encoder performance is far better than its predecessor X.264 yet, most publicly available 360-

degree databases and published research works are based on video sequences encoded by using X.264 and few utilize the HEVC encoder. However, based on findings, STV-AV1 outshines HEVC with average bitrate saving of 11.6%, 34.9%, and 58% in 8K, 6K, and 4K resolution respectively making it a suitable candidate for encoding high-resolution 360-degree videos.

Keywords: 360-degree videos; Video codecs; Peak signal-to-noise ratio; Video multimethod assessment fusion; Bandwidth

1 Introduction

Over the last few years, multimedia services have notably increased in entertainment, learning, and social interaction applications. While traditional video streaming has become common across societies, virtual reality (VR) has emerged as a technology that offers a more immersive viewing experience. However, compared to 2D/3D videos, VR video demands a significant amount of storage capacity. Moreover, for a more immersive experience, a high frame rate is desirable, resulting in a high video bitrate, affecting the required bandwidth [(1)]. This creates the need for a bandwidth-efficient video encoder, which reduces video file size while maintaining nearly the same visual quality as that of the original video scene.

Recently, several video codecs, such as Alliance for Open Media Video 1(AV1), VP9, H.256/HEVC, Joint Exploration Model (JEM), Essential Video Coding (EVC), and Versatile Video Codec (H.266/VVC) have been introduced. These codecs aim to enhance video compression, storage, transmission over the network, and playback. While multimedia enthusiasts anticipate an upgraded version of the loyalty-free AV1 codec from Alliance for Open Media, a proprietary codec, VVC, has been available since 2020, promising significant improvements over its predecessor H.265/HEVC [(2)]. Nevertheless, the VVC is not widely adopted due to license requirements and hardware support issues [(3)], nevertheless, the Versatile Video Codec Test Module (VTM), an open-source version, is freely available for research purposes.

Extensive studies reported the performance comparison of video codecs based on 2D videos. In [(4)], a trade-off between data rate and distortion regarding the Peak Signal-to-Noise Ratio (PSNR) metric for video sequences compressed at different levels using HEVC and VVC was reported. Even though the computation complexity of VVC is 10 to 16 higher than that of HEVC, it is argued that VVC achieves a bit-rate reduction of 44% compared to HEVC. The performance evaluation of HEVC and VVC based on PSNR and bitrate distortion metrics was conducted in [(5)]. Depending on spatial resolution and video content, VVC outperforms HEVC, showcasing improved quality ranging from 32% to 43%. Researchers in [(6)] compared the performance of VVC, AV1, and EVC on video sequences ranging from 720p to 4K resolution. VVC claimed to surpass AV1 and EVC with the expense of computational cost, as reported in [(7,8)]. Moreover, authors in [(9)] evaluated VP9, VVC, AV1, and HEVC compression efficiency. The result reveals that, on average, AV1 attained a bit-rate reduction of 24% than VP9. In addition, a slight difference in bitrate saving of around 3.9% is observed for AV1 and VVC, with the latter being superior.

The use of PSNR and Video Multi-Method Assessment Fusion (VMAF) metrics to assess the performance of HEVC, AV1, VP9, and VCC is reported in [(10)]. The resolution range of the test video was from 480p to UHD with varied frame rates. While VVC outshines all other codecs, a narrow performance margin between AV1 and HEVC is reported. Similar compression superiority of VVC over other codecs for test video sequences possessing UHD resolution was reported in [(11)]. Researchers in [(12)] focused on 2D video sequences to evaluate the compression efficiency of AVC, AV1, HEVC, and VVC using Structural Similarity Index (SSIM), VMAF, and PSNR objective metrics.

It was urged that VVC outshines other codecs regarding Bjøntegaard delta rate for all investigated test sequences. Thus, a bandwidth-efficient video codec will not only conserve storage space but optimize network resources, ensuring that video segments of acceptable visual quality are transmitted at a low bitrate.

The perceived quality of 360-degree video streaming is influenced by user, system, and context-related factors[13]. From the system point of view, video codecs from developers are based on different compression efficiency and implementation which may result in different perceived quality[14]. However, fewer studies analyzed video codec type as a distortion of the perceived 360-degree video quality[15]. Moreover, most of the available 360-degree video databases[16–18] are developed based on the single encoder (X.264/HEVC) implementation thereby providing limited information on the impact of encoder performance on the compressed 360-degree video quality. Therefore, the contribution of this work is three-fold:

a) Develop a 360-degree video database comprised of a wide-range video resolution, compressed under different quantization parameters using three (VVenc, HEVC, and STV-AV1) codec technologies

b) Analyze the encoder performances using PSNR and VMAF objective metrics.

c) Discuss the encoder performance in terms of bitrate saving.

The remainder of this paper is structured as follows: Section 2 focuses on methodology, where the dataset used, rate control parameters, and objective quality evaluation are described. Section 3 deals with result analysis, and a conclusion is drawn in Section 4.

2 Methodology

In this work, we use the 360-degree video sets from YouTube and the scenes reported in[19], which are publicly available for research [https://bthse-my.sharepoint.com/:u:/g/personal/mew_bth_se/EZE_PZ1j7RhFnKwujDtNLN4ByPYjcCAm5gx-O66M3c097w?e=oez38w]. We limit the video's duration and discard the audio part in all YouTube downloaded scenes. Figure 1 illustrates a preview of the 360-degree videos used in while Figure 2 describes the performance evaluation workflow. Moreover, video features are tabulated in Table 1.

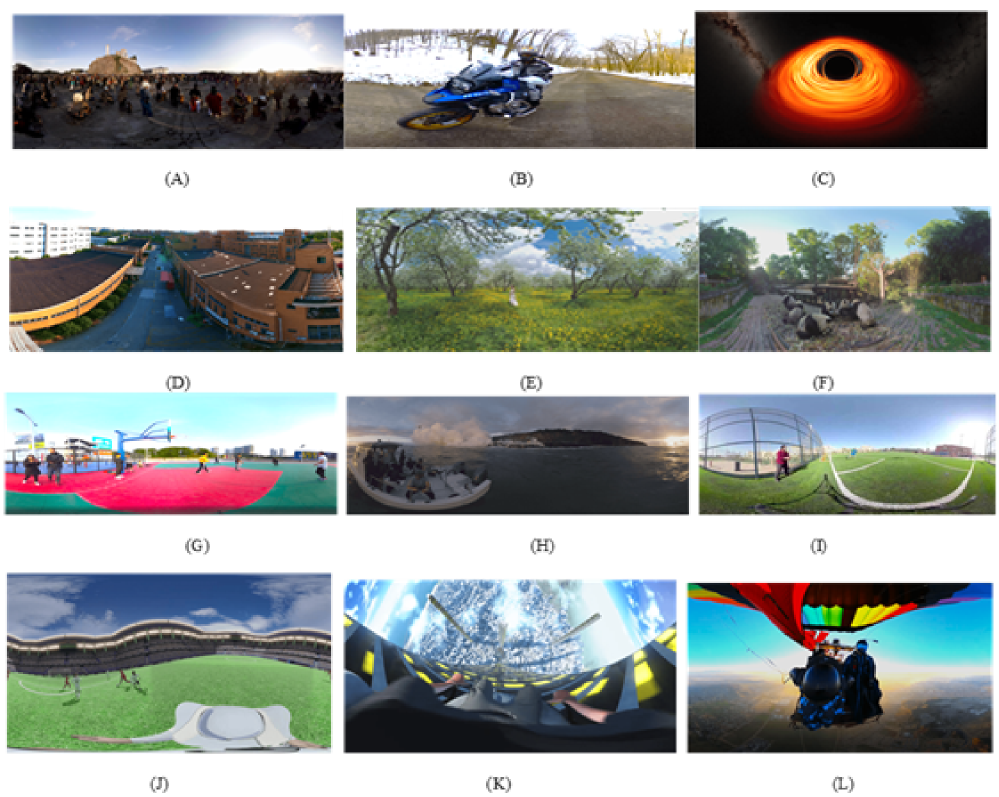

Fig 1. 360-degree videos

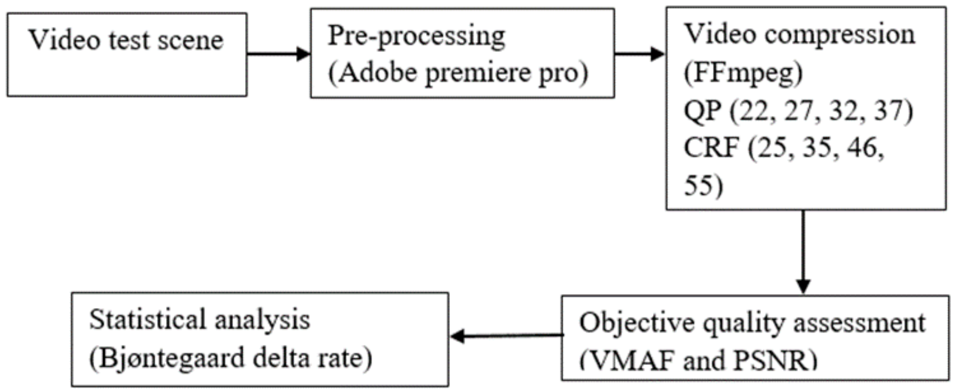

Fig 2. Performance evaluation workflow of encoders

Table 1. Description of 360-degree video scenes

Video Index	Video name	Source/YouTube ID	Resolution	Duration (s)	Frame-rate
(A)	Alcatraz	[19]	7680 x 3840	10	29.97
(B)	360 Riding in Winter	2-HWPpTUtMw	7680 x 3840	41	29.99
(C)	Black hole	lCbPu6dhBBs	7680 x 4096	20	29.97
(D)	Aerial view	1pLTwFPlbHzTh5z74UI6aA2wywSaHimqG	7680 x 3840	29	30
(E)	Blooming Apple Orchard	[19]	6144 x 3072	10	29.97
(F)	Panda	[19]	6144 x 3072	10	29.97
(G)	Outdoor basketball	CzByRYeBZ1Y&list=PLmjwCk5juJ-8oyjf0D84f8F1RqnUi6BjH&index=17	5760 x 4320	20	60.05
(H)	Formation Pace	[19]	4096 x 2048	10	29.97
(I)	Football Experience Demo	znD22BY4kCQ	3840 x 2160	32	29.99
(J)	Football	pxH4_6TWsc4	3840 x 2160	30	30.01
(K)	Skydive	gukQrib2E3Q	3040 x 2160	15	30
(L)	Falling from Building	ZZyBG6UsvoQ	2560x 1440	51	30

2.1 Video dataset and experiment configurations

The test scenes were created by compressing the reference videos using the FFmpeg tool. The quantization parameter (QP) and constant rate factor (CRF) metrics were used in HEVC and AV1, respectively. For the VVC encoder, we utilize an open-source VVenc tool[20]. The choice of QP values for both HEVC and VVenc encoders was based on Common Test Conditions (CTC) reported in sources[10] and[11]. To ensure fair assessment, for the AV1 encoder, we selected constant quality parameters that resulted in bitrates closely resembling those achieved by VVenc and HEVC encoders, as reported in[10,11] were used in the AV1. Taking four compression levels across three codecs over twelve 360-degree reference videos resulted in 120 video sets.

Moreover, we only defined a preset value for the three codecs while other default software configurations were used. For the VVenc encoder, we turned off a default rate control mode, which normally limits the video bitrate to around 200kbps. This adjustment allowed the VVenc encoder to select the bitrate based on the supplied quantization parameter. To achieve improved PSNR and VMAF results, the parameter –subjopt in the VVenc encoder was disabled. Table 2 illustrates the codec types, quantization/constant quality parameters, and presets for the three encoders.

Table 2. Video codec type, version and presets

Codec name	Codec version	QP/CRF	Presets
VVenc	1.9.1	22, 27, 32,37	medium
STV-AV1	2.2.0	25, 35, 46, 55	preset 8
HEVC	3.6	22, 27,32,37	medium

2.2 Objective video quality assessment

2.2.1 VMAF

Even though VMAF was originally designed for 2D videos with resolution from 480p up to 1080p, recent development extends its capability to quantify quality on 8K resolution videos[12]. Moreover, conditions such as viewer distance from a display, content type, and improved compression efficiency are accommodated. Moreover, in[21], the authors urged that the VMAF metric can be used to evaluate 360-degree videos without needing adjustment. Therefore, this study uses VMAF as a visual quality assessment metric.

2.2.2 Peak signal-to-noise ratio

PSNR stands as the most used objective quality metric. However, the rate-distortion curves obtained by comparing the encoder compression capability at different compression parameters do not give a clear mathematical meaning regarding the encoder compression efficiency. Due to that reason, Bjøntegaard delta rate (BD-BR), which utilizes the PSNR results, is used to evaluate encoder performance in terms of bitrate saving and quality of compressed video scenes[22,23].

On the other hand, methods such as Weighted to spherically uniform PSNR (WS-PSNR) and Crasters Parabolic Projection (CPP-PSNR) can be used to evaluate the video quality. However, the former evaluation method correlates well with traditional PSNR, while the latter is suitable for cross-format distortion measurements[24]. Moreover, authors in[25] argued that PSNR can be used as an appropriate measure for 360-video quality assessment as it possesses a high correlation with subjective score compared to WS-PSNR, CPP-PSNR, and Spherical PSNR with/without interpolation. Therefore, this study uses the PSNR metric as an objective quality metric for evaluating the encoder's performance over 360-degree videos.

3 Results and discussion

Table 3 summarizes PSNR BD PSNR-BR saving for VVenc vs. AV1, VVenc vs. HEVC, and AV1 vs. HEVC for each investigated 360-degree video sequence. It should be noted that the positive BD-BR value indicates bitrate saving while the negative value shows the bitrate overhead required to achieve a nearly similar $PSNR_{611}$ value. Figure 3 depicts the rate-distortion (R-D) curves for the video set at different resolutions.

For all four 360-degree 8K resolution videos, the VVenc codec outperforms AV1 and HEVC regarding video quality, as presented in Figure 3**A-D**. The maximum and minimum bitrate saving of 54.2% and 32.4% is attained by the VVenc encoder compared to the AV1 encoder. Compared to the HEVC encoder, the VVenc encoder achieves the maximum and minimum bitrate savings of 82.3% and 52.4%. Moreover, AV1 outshines the HEVC encoder with maximum and minimum bitrate savings of 29.8% and 5.3%.

Based on the observations, we can report that the VVenc encoder is better suited for encoding 360-degree videos of 8K resolution than AV1 and HEVC encoders. Even though this work focuses on 360-degree videos, the encoder performance results align with findings reported in[11] and[12] thus VVenc and STV-AV1 are primarily developed for high-resolution scenes.

Table 3. BD PSNR Bitrate saving (%)

Video codec	Video Index											
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
VVenc vs. AV1	32.4	40.2	54.2	53.4	-49.2	-14.8	-13.1	43.7	12.8	31.6	24.3	72.6
VVenc vs. HEVC	65.1	52.4	59.8	82.3	-34.1	19.2	27.8	85.3	84.5	81.8	89.5	69.8
AV1 vs. HEVC	29.8	9.5	5.3	29.1	40.7	58.8	66.4	54.7	77.9	37.3	62.3	-1.3

An un-doubtful performance of SVT-AV1 over VVenc is observed in Figure 3 **(E, F, and G)**. To achieve similar video quality as that of SVT-AV1 encoded videos, a bitrate demand of 49.2%, 14.8%, and 13.1% is required when videos with index E, F, and G are encoded using a VVenc encoder. However, it is observed that video scenes with index G attained a better visual quality when encoded by VVenc than STV_AV1, as presented in Figure 4 **G**.

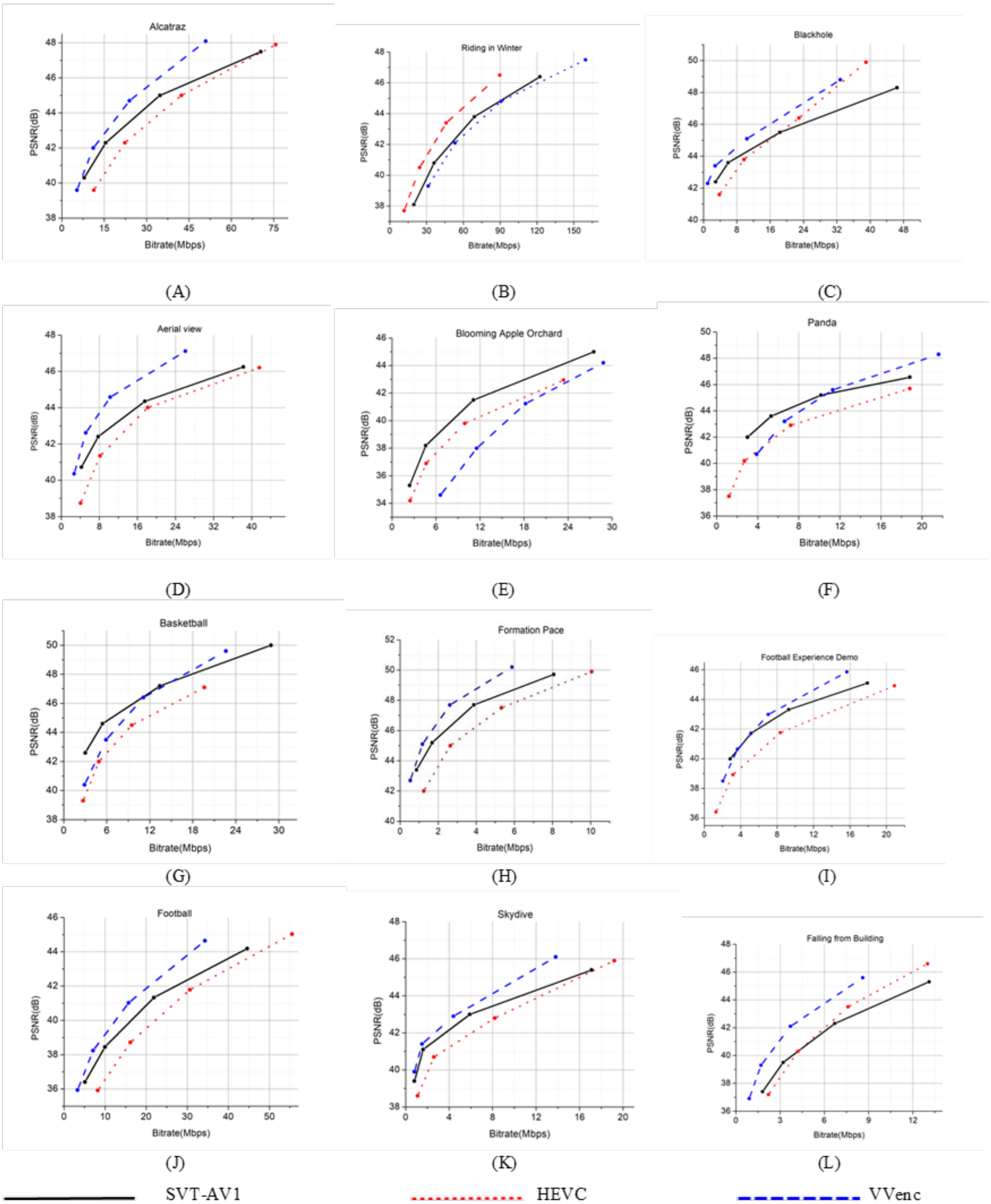

Fig 3. PSNR R-D curves of SVT-AV1, HEVC and VVenc for all 360-degree video sequence

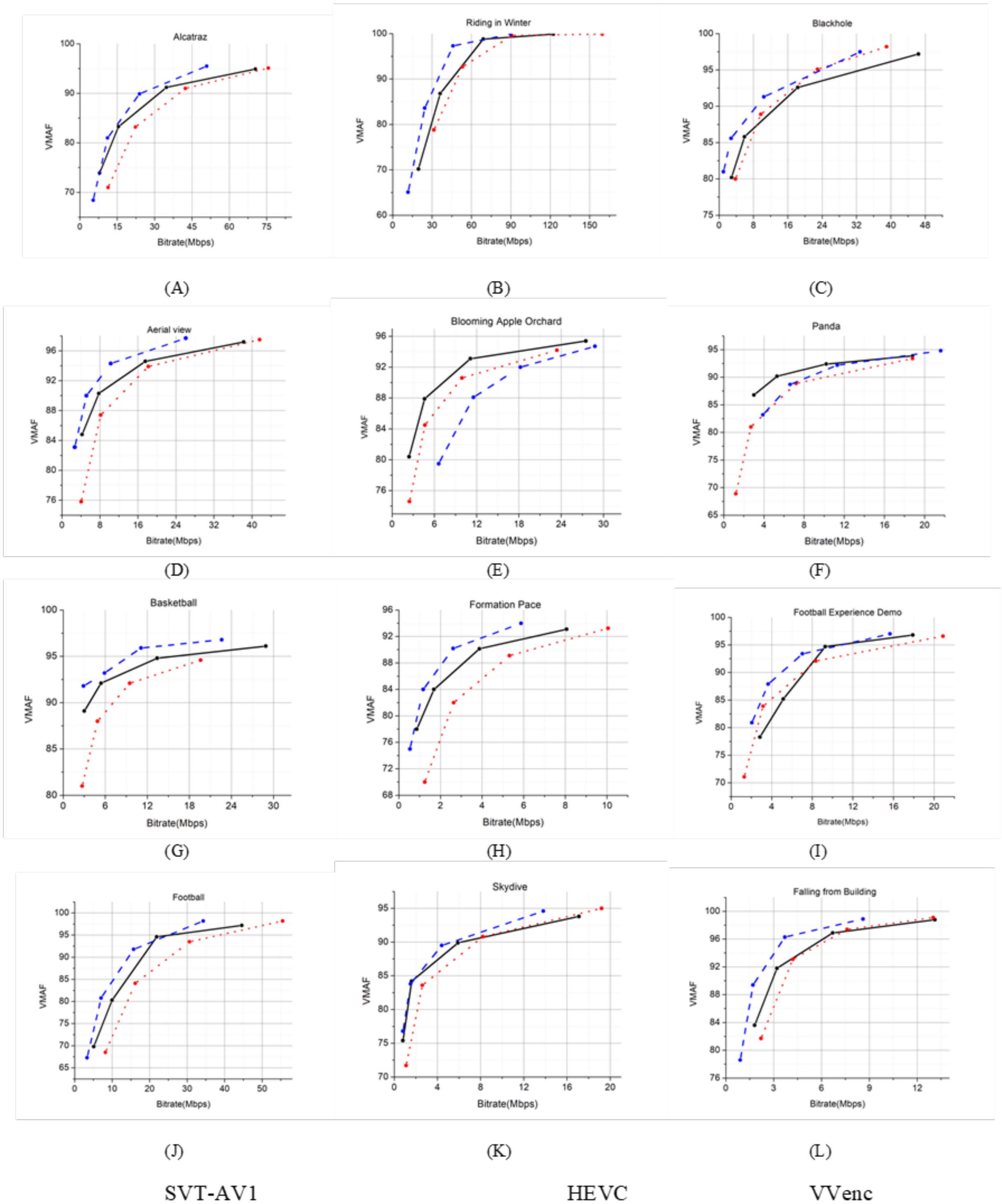

Fig 4. VMAF R-D curves of SVT-AV1, HEVC and VVenc for all 360-degree video sequences

Likewise, the HEVC encoder requires a bitrate gain of 40.7%, 58.8%, and 66.4% to attain an equivalent $PSNR_{611}$ rating similar to the STV-AV1 encoder on 6K and 5K video scenes. It is further observed that HEVC outshines the VVenc encoder in one of 6K resolution video (Video-index E) with a bitrate saving of 34.1%. Conversely, STV-AV1 achieved bitrate savings of 49.2%, 14.8%, and 13.1% compared to VVenc on video scenes E, F, and G. However, video scenes encoded by VVenc resulted in better visual quality than STV-AV1 with the expense of higher bitrate as presented in Figure 4**F and 4G**. Even though further investigation will give a clear picture of SVT-AV1 superiority, particularly on 6K and 5K 360-degree videos, up to this end, we can report that the AV1 encoder is well tailored to encode 6K and 5K videos compared to VVenc and HEVC encoder.

In addition, for Ultra High Definition (UHD) 360-video scenes, a bitrate gain of 43.7%, 12.8%, 31.6%, and 24.3% is required for SVT-AV1 to achieve similar visual quality as that of VVenc in video scenes with index H, I, J, and K respectively. On the other hand, HEVC required a bitrate gain of 85.3%, 84.5%, 81.8%, and 89.5% compared to VVenc on similar video scenes. In line with findings reported in [10–12] and [9] where the average bitrate saving of VVenc over HEVC is between 40% and 70%, the improvement reported in this work is attributed to the version of VVenc and the configuration parameters used. SVT-AV1 emerged as the second performing encoder, with a bitrate saving of about 54.7%, 77.9%, 37.3%, and 62.3% compared to the HEVC encoder. The results contradict findings reported in [7] where HEVC outshines STV-AV1. The poor performance of STV-AV1 over HEVC is mainly due to the encoder version and preset value used in [7]. For better bitrate saving, preset 8 is used in this study as proposed in [26].

Figure 3**L** illustrates the encoder's performance for a video shot at UHD 360 degrees with a resolution of 2560x1440p.VVenc encoder continues to outshine both SVT-AV1 and HEVC encoder with bitrate savings of 72.6% and 69.8%, respectively. Even though HEVC emerged as the second-performing encoder in bitrate saving, SVT-AV1 surpassed the HEVC encoder by providing better visual quality, as illustrated in Figure 4 **L**.

4 Conclusion

This study discusses the performance analysis of three video codecs: AV1, VVenc and HEVC. The superiority of the VVenc encoder over STV-AV1 was unchallenged in eight out of twelve encoded 360-degree videos. The maximum bitrate saving of 72.6% and minimum of 12.8% is attained by the VVenc encoder compared to SVT-AV1. For the case of the HEVC encoder, the maximum and minimum bitrate overhead of 89.5% and 19.2% is required for it to achieve video quality similar to that of VVenc encoded video. The SVT-AV1 encoder is the second most popular, especially for 6K and 5K resolution videos compared to VVenc. Moreover, SVT-AV1 outshines HEVC with average bitrate saving of 11.6%, 34.9%, and 58% in 8K, 6K, and 4K resolution respectively. It is further observed that the HEVC encoder outperforms VVenc and SVT-AV1 only in video scenes of index E and index I, with average bitrate savings of 43.4% and 1.3%, respectively.

The future work involves exploring the encoder performance over vast data sets to increase the robustness of the comparison outcomes by considering various aspects such as camera motion and video content complexity. Moreover, we would like to conduct a subjective investigation over Head-Mounted Display and compare user perceptions and results of objective metrics.

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