Resolution vs Frame Rate

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***Abstract*—Nowadays, with a large number of 4K screens and fancy gaming monitors, we're trying to figure out if it's more important to focus on the resolution or the frame rates. According to the use cases, it is important to pick the right settings. This study looks into how people perceive videos with different combinations of resolution and frame rates. It focuses on comparing the perceived quality of videos with different resolutions and frame rates. The study uses an approach, using both subjective methods (by asking people for their opinions) and objective methods (by using tools to measure viewer perception) to understand the subtle differences in how viewers see the videos. The findings suggest that the choice of resolution and frame rate influences viewer perception of video quality. With the subjective assessments and objective measurements, we observed some differences in how viewers perceive videos. This study contributes to our understanding of the perceptual advantages associated with different video content configurations, providing insights for content creators and technology developers aiming to optimise viewer experience.**

Keywords—High Frame Rate(HFR), High Resolution, VCA, VMAF, Spatial/Temporal Complexity, FFMPEG, CRF, ACR, avrateNG, VQA

I. Introduction

Many devices and streaming services offer higher-resolution videos for entertainment. Resolutions, such as 4K and beyond, promise enhanced visual fidelity and immersion, particularly in applications where fine details are critical, such as cinematography. Although not many, we also see content in higher frame rates these days. Frame rates like 24fps, 25fps and 30fps are accepted worldwide and can be played on almost every available device today. High frame rate content is utilised in movies, especially for action scenes, animations, and special effects, to enhance the viewing experience and create smoother motion. High-frame rate cameras are employed in sports broadcasting to capture fast-paced action more accurately, providing viewers with clearer and smoother playback.

Also, VR and AR applications often require high frame rates to minimise motion sickness and create a more immersive experience for users. major VR headset manufacturers such as Oculus (owned by Meta, formerly Facebook) and HTC Vive often recommend a minimum frame rate of 90 fps for optimal performance and comfort in VR experiences.

Nowadays we see many screens which are capable of playing back much higher frame rates. It is also seen that higher frame rate videos result in reduced juddering or flickering effects observed in videos which have objects in motion. Due to this reason higher frame rates like 120fps are used in gaming [12]. Many video games now support high frame rates to provide more fluid and responsive gameplay, reducing motion blur and enhancing visual clarity.

We would like to explore the interplay between resolution and frame rates. High frame rate and resolution content can more accurately replicate real-world movements and details, leading to a more realistic viewing experience. This is beneficial for many applications where realism is crucial. Some studies [1] say that beyond 60fps the quality perceived by the people remains unchanged. We would like to find out how accurate are these studies. The motivation of this test is to find out whether it is a good idea to increase the frame rates of the content beyond a certain acceptable resolution. In other words, we would like to know if it makes sense to prioritise frame rate over resolution depending on the use case. Does it make sense to use higher frame rates and lower resolution or does it make sense to use lower resolution with higher frame rates? There are two ways to find out.

The testing process includes two types of assessments: subjective and objective.

The subjective part involves giving tests to viewers to get their direct opinions and preferences. The viewers rate every video on a scale of 5 ratings. Looking at the results of these tests helps us understand what people think are the good and bad points of the video formats.

In the objective tests, a set model predicts its ratings for the videos and tries to replicate human ratings. Subjective tests are often costly to implement and require a lot of time. At such times these VQA models can be used to find out the perceived quality. These models are generally trained with subjective datasets and it becomes fruitless to use them on newly developed encodings. But in our tests, we will use them on already known and tested formats.

The mix of subjective and objective results aims to give an understanding of how resolution and frame rate work together to affect what viewers experience. Here, we will try to understand beyond a certain acceptable resolution and for a relevant use case, whether it makes sense to increase the frame rate of the content.

Good quality videos from places like Ultra Video Group (UVG) Dataset [3] and LIV-YT-HFR [1, 4], recorded at 120 frames per second (fps) in 4K resolution, which is clear and sharp were obtained for this test. These videos were used as a strong base for the study. To look closely at how people see things, these original videos were changed into three different sizes—1920x1080, 2560x1440, and 3840x2160—and three different speeds—30, 60, and 120 fps. Having this wide range of sizes and speeds helps us study things in more detail and understand better how they affect what people see.

The conclusions were made by assessing the results from subjective tests. We also remarked on the performance of objective tests by comparing them with the subjective test results.

II. RELATED WORK

Previous studies have examined aspects of video quality perception, providing foundational insights into the interaction of resolution, frame rate, encoding paradigms and viewer experience. Research by Pavan C Madhusudana, Xiangxu Yu, Neil Birkbeck, Yilin Wang, Balu Adsumilli and Alan C Bovid (2021) [1] explored subjective and objective video quality assessment, emphasising factors like spatial resolution, temporal fidelity, and perceptual features. The research paper discussed the growing popularity of HFR videos, particularly in live-action and high-action streaming content like sports. To balance quality and bandwidth requirements, the researchers created a dataset called LIVE-YT-HFR. They conducted subjective VQA tests to evaluate video quality and compared existing video quality algorithms on this dataset. The study found that higher frame rates generally lead to better-perceived video quality, especially for videos with significant camera motion. They also found that the quality improvement diminishes above 60 frames per second. Objective video quality assessment models struggled to capture temporal artefacts caused by frame rate changes.

In “Perceptual quality assessment of high frame rate video”, Rasoul Mohammadi Nasiri, Jiheng Wang, Abdul Rehman, Shiqi Wang and Zhou Wang [10] try to find out the perceived quality increase with the increase in the frame rates, focusing on their impact and interactions with quantisation level, spatial resolution, spatial complexity, and motion complexity. They also did subjective tests with 336 test video sequences. They concluded that videos with lots of detail get a bigger boost from higher frame rates, especially if they're not of high quality. They also found that an increased frame rate does not affect the perceived quality with respect to the effect of motion.

In another research, “AVT-VQDB-UHD-1: A Large Scale Video Quality Database for UHD-1”, Rakesh Rao Ramachandra Rao, Steve Goring, Werner Robitza1, Bernhard Feiten and Alexander Raake [11] studied how the 4K UHD videos were perceived by people and compared their observations with a total of 8 SoA objective models(both reference models and no-reference models) like VMAF, PSNR, BRISQUE, etc. They used many metrics to compare these results with the subjective tests. They revealed that VMAF was effective despite limitations with lower frame rates, while traditional models like PSNR and SSIM show inferior performance.

Research by M. Claypool, K. Claypool and F. Damaa [12] provides information about the impact of high frame rates and high resolution on user performance in computer games. First-person shooter (FPS) games require a high level of concentration and critical decision-making. Any loss in display quality may lead to consequences in virtual lives. The researchers tested five frame rates (3, 7, 15, 30 and 60 fps) and 3 frame resolutions (640 × 480, 512 × 384, and 320 × 240). Upon plotting User Performance graphs on all the datasets, they concluded that frame rate has more impact than resolution on performance and overall enjoyment factor. They described performance benefits by mentioning that a frame rate of 60 fps provides a 7-fold increase in performance over a frame rate of 3 fps.

In one research [13], Qin Huang; Se Yoon Jeong; Shanglin Yang; Dichen Zhang; Sudeng Hu; Hui Yong Kim, Jin Soo Choi and C.-C. Jay Kuo made observations on how people perceive videos with different resolutions and frame rates highlight three main points: low frame rates create a juddering effect that disrupts smooth motion; viewers are drawn to moving objects, focusing their attention on the most noticeable parts of the video; complex backgrounds can make it harder for people to notice small changes in the video, a phenomenon known as the masking effect.

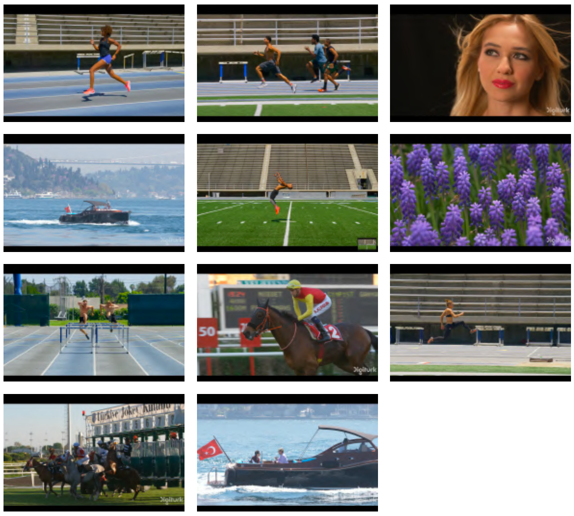

FIGURE 1: Sample frames from selected source sequences in UVG and LIV-YT-HFR datasets

Alex Mackin, Fan Zhang and David R. Bull, (2020) [9] investigated the impact of frame rate on viewer engagement, highlighting correlations with higher frame rates. This research explores the impact of HFR on video quality, an area previously under-explored due to limited HFR test content. The authors addressed this gap by introducing the BVI-HFR database, containing diverse scenes captured at 120fps. The authors explored temporal down-sampling methods to enable comparisons across different frame rates and discussed practical considerations of increased frame rates. Their findings suggest that higher frame rates can significantly impact visual quality up to 120 fps, with the choice of down-sampling methods affecting motion artefacts and encoded bitrates.

In 2017, Ma Li, Song Jianbin and Liu Hui [14] found out how the quality of user experience (QoE) can be enhanced by testing videos at various bit rates, resolutions and frame rates. They found that: to make videos play smoothly, it's important to pick the right frame rate, like 20 for simple videos and 25 for videos with fast motion; when the bandwidth is low, lower-resolution videos often look better than higher-resolution ones.

Another research was done by Dae Yeol Lee, Somdyuti Paul, Christos G. Bampis, Hyunsuk Ko, Jongho Kim, Se Yoon Jeong, Blake Homan and Alan C. Bovik in 2021 [15] where they conducted a comprehensive study to explore how combining space-time subsampling and compression impacts the perceptual quality of videos by collecting subjective opinion scores from nearly 15,000 participants, including evaluations on 4K 10bit videos with high frame rates. The findings suggest that while space-time subsampling results in information loss and quality degradation, it can be a beneficial tradeoff against increased compression within a fixed bit rate. Additionally, the evaluation of SoA quality models revealed their effectiveness in predicting quality under spatial subsampling and compression but highlighted challenges in predicting the effects of temporal subsampling, suggesting a need for further model refinement.

Building on this foundation, this study extends understanding by examining the relationship between resolution and frame rate using both subjective and objective evaluation methods.

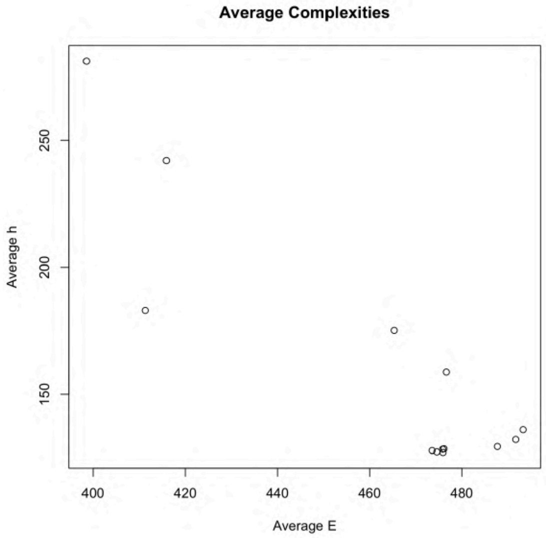

FIGURE 2. Average temporal complexity (E) vs average spatial complexity (h) plotted for 13 unaltered source sequences acquired from UVG and LIV-YT-HFR

III. Experiment - Design and Conduction

A. Source Content

To conduct both subjective and objective tests, pristine videos were sourced from two reputable platforms:

1. Ultra Video Group (UVG) Dataset [3]
2. Live YouTube High Frame Rate Database [1, 4]

These videos were in 3840 X 2160 (4k), 120 frames per second (fps) and were in unaltered condition.

To make sure we didn't just focus on one type of video, we purposely chose videos from lots of different categories. This included scenes with different kinds of lighting, how much movement there was, and how complicated the content was. Our aim was to test if the change in frame rate or resolution affected the quality at different complexities.

B. Source Characterisation

Considering the influence of video complexity on perceived quality, Video Complexity Analysis (VCA) [2] was conducted on the dataset.

Out of 13 available source datasets we selected 11 videos with different spatial and temporal complexities for the tests. This is because we wanted to test if videos with different complexities affect the perceived quality rating. FIGURE 2 shows the plot of the spatiotemporal complexities of the acquired dataset.

C. Encoded Videos

Using FFMPEG [5], we encoded the pristine videos selected into the following format for them to be played out for reference:

- Resolutions: 1920X1080, 2560X1440, 3840X2160
- Frame Rates: 30, 60, 120 frames per second
- Other Parameters: HEVC, Rec. 709, 10 bit, CRF 10

We used high-quality encoding to avoid loss of information during this process and tried to avoid changes in the results due to this process.

After testing the videos with VMAF, we found that the quality scores for videos encoded with a CRF 10 were consistently at or above 98%. Also, there were no times when frames dropped during playback on the screen. This suggests that the videos kept their quality very well when they were encoded with a CRF 10, meaning they were visually lossless.

The encoded videos were upscaled to 4K resolution and upsampled to 2160p to be able to play them on the available screen for the subjective tests. 11 videos used for the evaluation, were encoded into 8 formats as mentioned earlier. So, in total, we had 88 test dataset videos (FIGURE 1).

D. Subjective Test Conduction

Using the Absolute Category Rating (ACR) methodology, we evaluated the perceived quality of our test videos, with participants providing ratings on a predefined scale. Participants rated the quality using a predefined scale, typically from “Bad”, “Poor”, “Fair”, and “Good” to “Excellent". The platform used for ACR testing was avrateNG [6].

The testing environment was as per *ITU-T P.910* [7] recommendations for non-interactive subjective video quality assessment methods for multimedia applications. Participants were tested for near vision before the tests. They were also trained with 4 test videos before the actual tests.

In this test method, participants would watch a video and rate it immediately based on how they perceived its quality. All the participants were presented with video datasets to rate in a randomised order.

In total, we conducted tests with 30 participants, who were students of Technical Universität Ilmenau.

E. Objective Test Conduction

We used Video Multimethod Fusion (VMAF) [8] to conduct the objective analysis. As VMAF is a full reference-based method, the pristine video sourced from the original datasets serves as the reference and the encoded videos used for subjective tests, as mentioned earlier, were the distorted counterparts.

Although the main use of VMAF in our tests was to provide an estimate of the visual ‘losslessness’ of videos for them to be played back on the selected screen during subjective testing, we also did one round of objective tests to compare the model’s results with the subjective MOS scores.

For impartial testing and analysis, VMAF was done on the same videos which were used for testing.

IV. Observation and Results

A. Analysis of Subjective Tests

To check the reliability of the subjective scores, we performed outlier detection using the Pearson correlation coefficient (PCC). The ratings from users that are well-correlated with the MOS were considered more reliable, while those with low correlation might be outliers, possibly due to misunderstanding the rating task, random rating behaviour, or other factors. To our surprise, we found a large number of outliers and only a few participants were considered genuine. At a PCC lower than 0.60, we found 24 outliers leaving us with the scores of only 6 subjects to perform any analysis.

In discussions with the participants after their test, they mentioned that they found it difficult to find the differences in the qualities of the videos. This might be one of the reasons for such a large disagreement in the ratings among the participants.

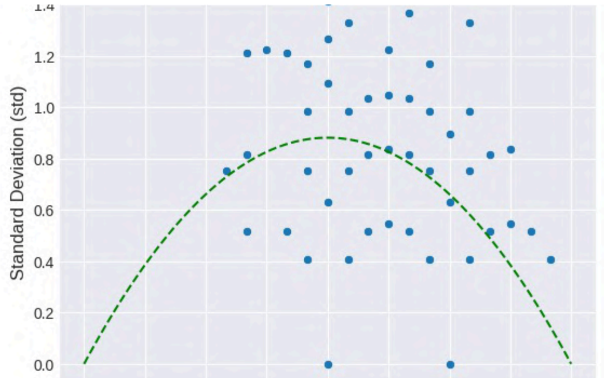

FIGURE 3: SOS plot for video quality (std vs MOS)

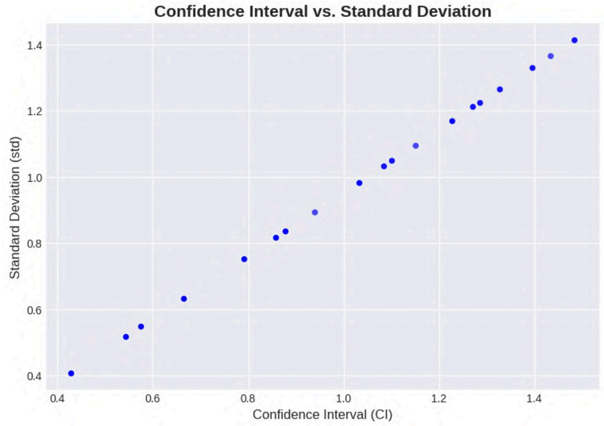

FIGURE 4: STD vs CI of MOS from subjective tests.

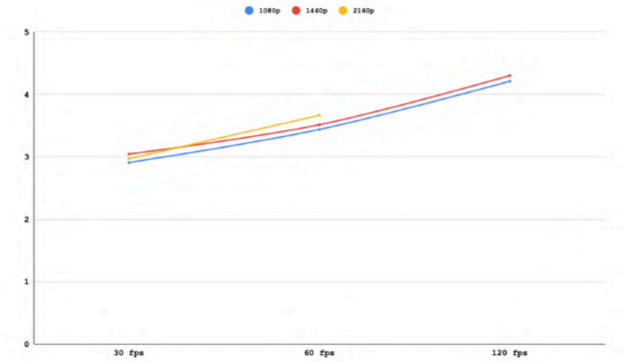

FIGURE 5: Perceived quality scores at selected resolutions and frame rates

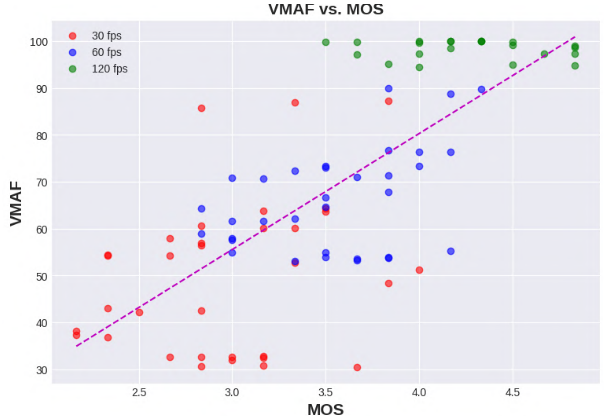

FIGURE 6: Comparison between VMAF and Subjective scores.

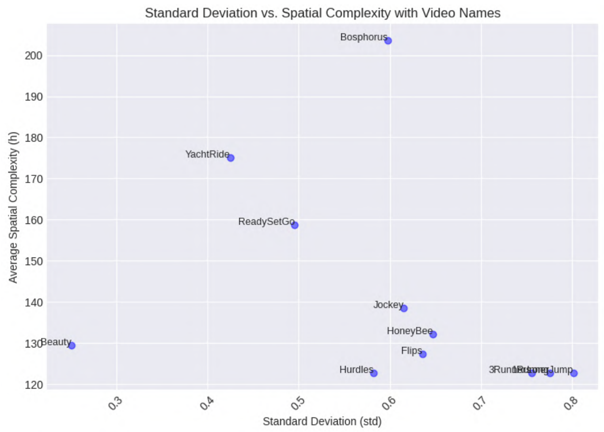

FIGURE 7: Spatial Complexity and Standard Deviation

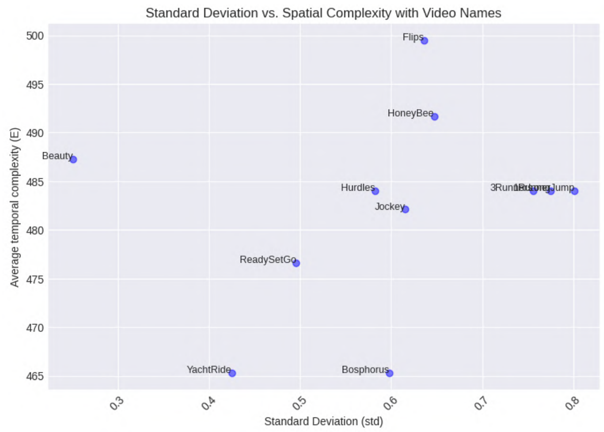

FIGURE 8: Temporal Complexity and Standard Deviation

At the lowest or the highest MOS scores, the standard deviation is generally low and it is acceptable to have greater disagreement among raters at MOS scores in the middle. But from FIGURE 3 we see that there is a clear lack of similarity among the participants in their ratings. Our data is becoming more variable (indicated by larger std.) making our confidence in determining the MOS also wider.

The points in FIGURE 4 appear to follow a linear trend, suggesting a direct proportionality between the standard deviation and the confidence intervals.

We calculated the Mean Opinion Score (MOS) of the available participants. FIGURE 5 shows the MOS of the datasets as a function of frame rate. It can be observed that as the frame rate increased from 30fps to 60fps, participants rated the videos higher. However, there is hardly any effect of resolution on the perceived video quality.

Upon further discussion, we decided to find any correlations between the spatial or temporal complexities with the subjective scores. FIGURES 7 and 8 depict the change in MOS with Spatial and Temporal complexities of the videos respectively. In most cases, with lower spatial complexities, the viewers' perception of visual quality varies significantly (FIGURE 7). Temporal complexities didn't seem to have any effect on the standard deviation.

TABLE 1: COMPARISON BETWEEN SUBJECTIVE SCORES AND

Matrics	Pearson	Spearman	Kendall
VMAF	0.735	0.706	0.528

B. Comparison between VMAF and Subjective Scores

FIGURE 6 shows the scatterplot of the correlation between VMAF scores and MOS of the available participants. We assume that VMAF did not perform as expected. To test the reliability of this model, we also found Pearson, Spearman and Kendall correlation coefficients.

This depicts a moderately positive correlation between the two scores. In [11] we learnt that this might have not happened if the frame rates remained constant. VMAF scores are affected by the introduction of frame rate variations. FMAF is a Full Reference (FR) model and it considers spatial variations in the frames caused by resizing/upscaling to score the videos.

V. Conclusion

A. Relationship Between Resolution and Frame Rate

People preferred the videos with 4k resolution the most. Even the videos which were 1080p with 30 frames per second got decent scores. Increasing from 1080p to 2160p resolution resulted in negligible changes in video quality. On the flip side, increasing the frame rates from 30fps to 120fps improved the video quality. Participants noticed less jittery movement and found the videos of better quality. This suggests that viewers were okay with them, especially if they were watched on a relatively acceptable screen size. As we increased the frame rate, the quality perceived increased as well. It is safe to say that the frame rate must be prioritised before Resolution.

B. Implications for Content Creation

Creating videos with higher resolution is usually easier. On the other hand, creating content with higher frame rates can be more expensive. Therefore, simple videos like educational tutorials might not need higher frame rates because they're not focused on fancy visuals. But for video games, sports, movies, and music videos, higher frame rates can make the experience more fun and engaging. So, creators may choose how to make their content based on what their audience wants and expects.

C. Limitations and Future Research:

In our study, we encountered several limitations that we would like to acknowledge. Our subjective tests resulted in a large number of outliers, indicating large variability in participants' responses. For the future, we would like to acknowledge considering a larger number of test participants to reduce the percentage of outliers.

As mentioned earlier, participants faced difficulty in differentiating the videos, a different subjective test methodology (eg. SAMVIQ) can be explored in which they are asked to compare two videos to score them. This way the results might have fewer outliers.

Our study was limited to only 3 frame rates. For future studies, we would like to account for frame rates lower than 30fps to test if the decrease in perceived quality below 30fps is significant or minute. Also, considering frame rates above 120fps might help in concluding if there is any appreciable difference in the quality.

In the future, we would also like to perform objective tests with more than one SoA model. In this case, VMAF performed moderately. Considering other models could have helped us in identifying which model is optimum if subjective tests are not possible.

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