https://doi.org/10.2352/ISSN.2470-1173.2019.12.HVEI-219

Impacts of internal HMD Playback Processing on Subjective Quality Perception

Frank Hofmeyer, Stephan Fremerey, Thaden Cohrs, Alexander Raake
Audiovisual Technology Group (AVT), Technische Universität Ilmenau, Ilmenau, Germany
E-Mail: [frank.hofmeyer, stephan.fremerey, thaden.cohrs, alexander.raake]@tu-ilmenau.de

Abstract

In this paper, we conducted two different studies. Our first study deals with measuring the flickering in HMDs using a self-developed measurement tool. Therefore, we investigated several combinations of software 360° video players and framerates. We found out that only 90 fps content is leading to a ideal and smooth playout without stuttering or black frame insertion. In addition, it should be avoided to playout 360° content at lower framerates, especially 25 and 50 fps. In our second study we investigated the influence of higher framerates of various 360° videos on the perceived quality. Doing so, we conducted a subjective test using 12 expert viewers. The participants watched 30 fps native as well as interpolated 90 fps 360° content, whether we also rendered two contents published along with the paper. We found out that 90 fps is significantly improving the perceived quality. Additionally, we compared the performance of three motion interpolation algorithms. From the results it is visible that motion interpolation can be used in post production to improve the perceived quality.

Introduction

Nowadays, various affordable Head-Mounted Displays (HMD) are available in the market and more and more 360° video contents are released, e.g. on YouTube. (cf. [6]). Regarding 360° video or Virtual Reality (VR), the end user's Quality of Experience (QoE) is influenced directly or indirectly by many technical and perceptional factors. There are possible problems along the whole processing pipeline concerning video capturing, encoding, transmission, decoding and consumption.

Even the way how a 360° video is processed and displayed at the end user's HMD system is influenced by many conditions like the video characteristics, the used video player, the underlying VR framework like e.g. SteamVR, the graphics card and the graphics driver.

For this reason, in most subjective evaluations the end-to-end chain for 360° video streaming is considered as a black box as we also are doing in this study. This is reasonable because Virtual Reality (VR) systems like HMDs or their connected frameworks are still changing a lot due to new technologies and developments.

During selection of suitable contents for our former conducted subjective tests, we found out that most publicly available 360° video material has a framerate lower than 50 fps. The common used framerate for these contents is 30 fps. Furthermore, we observed that in some videos moving objects are stuttering significantly, especially when they are passing by the camera. Apparently the stutter intensity depends on the speed and the direction of the movements.

Starting from this identified problem, we analyzed the video processing in the end-to-end chain of a 360° video pipeline. Additionally we investigated the HTC Vive Pro, which we also used in some of our conducted tests (cf. [3]). Usually, HMDs panels like e.g. Oculus Rift, HTC Vive and HTC Vive Pro have a refresh rate of 90 Hz.

Regarding e.g. the human critical fusion frequency (cf. [5], [2], [9]) this seems very beneficial but it is also very problematic because most of all 360° videos are not matching this framerate. This is leading to the fact that software players and HMD systems are required to compensate this framerate mismatch.

Therefore objective measurement tools are needed to reveal the implications of video processing in HMD related players and panel technologies. Moreover, it is required to analyze whether motion interpolation (MI) is a suitable technology to improve the QoE of low framerate 360° contents. Within this study, we will focus on the following three research questions:

- To what extent the internal playback processing of the HMD is influencing the content shown to the user?
- Can MI be used to improve the quality of 360° videos?
- If MI should be used: which algorithm could be recommended to achieve a higher QoE? Is this content dependent?

To investigate the identified research questions we conducted several tests. In our first test, we are physically measuring the HMD video playout using a self-developed measurement setup and several software 360° players. As a second step, within a subjective test we initially displayed two computer generated imagery (CGI) contents rendered at different source framerates to expert viewers. Then we analyzed to what extent the general perceived video quality is affected by the different framerates. In the second part of the subjective test, we displayed four 30 fps 360° videos and the interpolated versions of the video with 90 fps framerate in a pair comparison test. Here, we used three different MI algorithms.

The paper is organized as follows. The following section describes the physical measurement setup. After discussing the results of the objective measurements, in the subsequent section the subjective test design will be presented, motivated by the results from our measurements. Afterwards, the results of the subjective test are discussed. In the last section we will conclude our work and identify some future work.

Related work

We already conducted a series of subjective tests for investigating 360° video QoE. Our work focuses on perceived 360° video quality [12], methods to evaluate user behavior [4], used streaming algorithms or methods [13], test methods [11] or content analysis, e.g. saliency in [7].

In the literature, a series of subjective tests investigating 360° video QoE can be found. For example, Schatz et al. investigated the influence of stalling in the context of 360° video streaming [10]. Furthermore, Xu et al. analyzed the exploration behavior of the subjects, where they also investigated the perceived video quality [15]. Zhou et al. compared the quality for omnidirectional images using various resolutions and encoding settings [19]. Other studies in the area of QoE evaluation for omnidirectional contents were done by Tran et al. [14], Zhang et al. [18] and Yang et al. [16].

There is also literature available dealing with the influences of framerate on the QoE. Mackin, Zhang, and Bull conducted a subjective study using standard 4K video content with various framerates up to 120 fps. They found out that the framerate has a significant impact on the perceived quality [8].

Regarding influences of framerate on the quality of 360° videos, we were not able to find appropriate literature. This is probably also related to the fact that 360° contents mostly are not available in framerates higher than 60 fps, usually only 30 fps.

Flicker Test

Our first approach is to measure how head-mounted displays (HMDs) are handling different input framerates using various 360° video players. Our VR system used in this study consists out of SteamVR v1.6 on a newly installed Windows 10 system with typical high-quality VR specs (Intel Core i7 CPU, Nvidia GTX 1080, NVMe M.2 SSD). Further, we use the latest versions of popular 360° video players: GoPro VR player[1], Virtual Desktop[2] and Whirligig[3]. To analyze the way how HMDs are handling videos with different framerates, we developed our own test system consisting of special test videos (flicker test sequences) and special sensor hardware to show what the HMD displays to the user.

Test Stimuli

Our developed flicker test stimuli consists of black and white frames, where every uneven frame is white and every even frame is black. The resolution of this video sequence is 3840 x 2160 px. As next step, we rendered such sequences with 25, 30, 50, 60 and 90 fps using *ffmpeg*. For excluding any artifacts related to encoding and providing a smooth playback, we encoded the video stimuli with *libx265* encoder and a Constant Rate Factor (CRF) of 0. 90 fps was selecte as highest framerate because the panel of the HTC Vive Pro has a fixed refresh rate of 90 Hz as well as other popular HMD systems like e.g. the Oculus Rift. To measure the actual playback of our HMD system, we developed an analog frontend consisting of a photodiode, a transimpedance amplifier and a buffer, compare Figure 1. The photodiode has a spectral range adapted to the human eye and its sensitivity is 9 nA/lx, which results in a dynamic range of 100,000 lux. With this setup we are able to measure flickering up to 100 kHz.

Test Method

While playing the test sequences in a dark environment, our tool is placed above the HMD display and detects every single frame by its photodiode. As a result all changes from black to white can be seen on an oscilloscope and recorded via data logger. We used a LeCroy MSO 104MXs-B Mixed Signal Oscilloscope with 1 GHz bandwidth and a sample rate up to 10 GS/s. A combination of five test videos, three 360° video players with different video backends was analyzed.

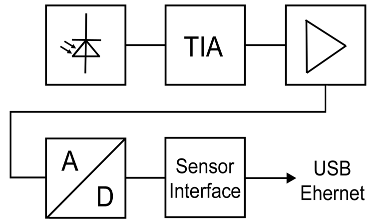


Figure 1. *Physical Measurement Setup;*

For identifying repeating waveform patterns, we conducted short time and long time measurements. Furthermore, we repeated our measurements at least thrice to ensure stability of our results. Altogether we collected more than 80 data sets.

Results

Figure 2 shows the measurement result of the 90 fps flicker test sequence with our common setup Vive Pro HMD and Whirligig player. On the X-axis the time in seconds is shown while the Y-axis shows the relative intensity from 0 to 100%. As mentioned before, the flicker test sequence only consists of repetitive black and white frames. In the diagram every peak of the signal (highest relative intensity) is representing a white frame. The troughs with the lowest relative intensity stand for black frames. From the results it is visible that the 90 fps video fits perfect to the fixed 90 Hz refresh rate of the Vive Pro panels. Every 0.1 seconds 9 frames are recorded in a uniform way, while no frame manipulation can be noticed. While playing the test video, the HMD displayed a homogeneous grey picture without any breaks or stuttering. Due to the high light intensity and the HMD's FOV the critical flicker frequency (CFF) is increased (cf. [2], [9], [5]), so flickering was slightly perceptible. This result can be considered as a reference for the following measurements.

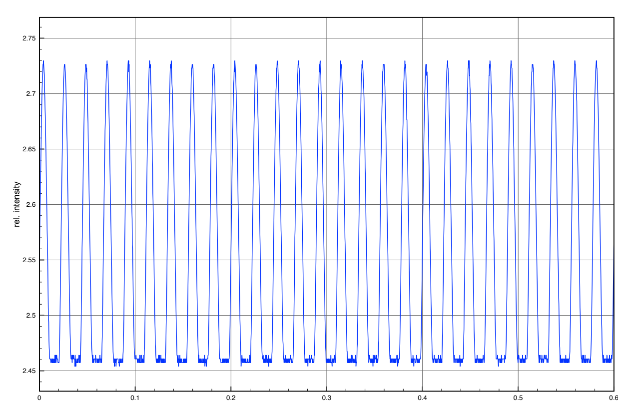


Figure 2. *HTC Vive Pro, Whirligig player, 90 fps*

As it can be clearly seen in Figure 3, the test sequence with 25 fps evokes a complete different waveform pattern. The du-

[1] http://www.kolor.com/gopro-vr-player/download

[2] https://store.steampowered.com/app/382110/Virtual_Desktop

[3] http://www.whirligig.xyz/new-page-3

ration of the black and white frames is fluctuating. This occurs because the VR system has to adapt the 25 fps video to the 90 Hz panels of the HTC Vive Pro with an uneven multiplication factor of 3.6. Due to the so-called sample-and-hold effect[4] even OLED panels suffer from motion blur. If it is not possible to increase the refresh rate of the panel, the only way to reduce this kind of motion blur is to insert additional black periods between the refreshes, also called black frame insertion (BFI).

From the plots it is apparent that the VR system uses BFI. According to the duration of the white frames, two or three black periods (flickering) are inserted. All these factors lead to characteristic motion artifacts that can be perceived by the user as e.g. stuttering and flickering of the video.

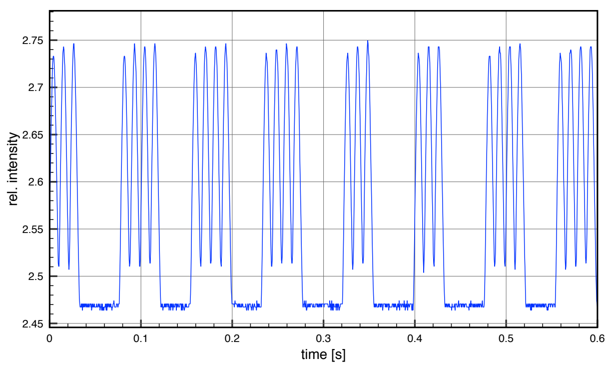


Figure 3. *HTC Vive Pro, Whirligig player, 25 fps*

On the basis of an integer multiplication factor of 3, the 30 fps test video leads to a very uniform plot (cf. Figure 4). Every frame has the same duration and every white frame has the same amount of additional black periods between the refreshes. Because of the long display duration of 33 ms per black frame the periodic changes from black to white can still be seen.

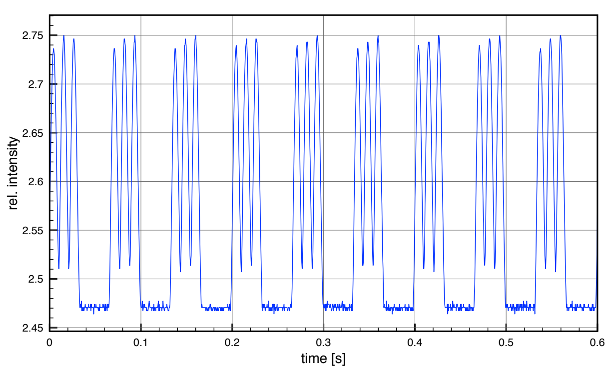


Figure 4. *HTC Vive Pro, Whirligig player, 30 fps*

The 50 fps test video shows an unequally distributed waveform pattern (cf. Figure 5). The duration of the black and white frames is fluctuating because the VR system has to adapt the 50 fps video with to a refresh rate of 90 Hz using an uneven multiplication factor of 1.8. It is noticeable, that some white frames have a BFI and some of them not.

[4]https://www.blurbusters.com/faq/oled-motion-blur

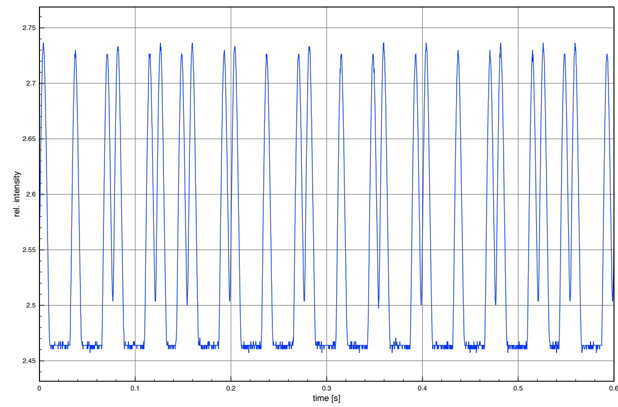


Figure 5. *HTC Vive Pro, Whirligig player, 50 fps*

With a multiplication factor of 1.5, the 60 fps test video leads to a quite uniform plot (see Figure 6). Every frame has the same duration and every white frame has the same amount of additional black periods between the frame refreshes. Because of the short display duration of approximately 16.7 ms per frame, flickering is hardly visible.

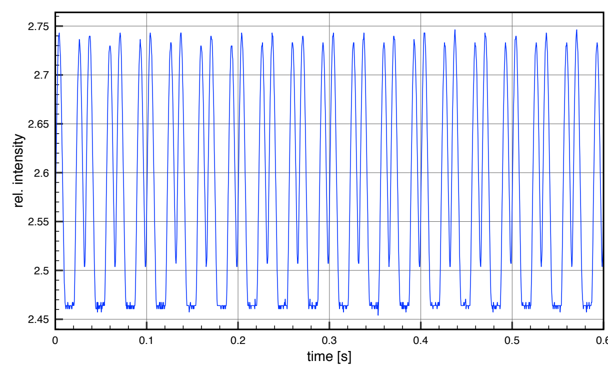


Figure 6. *HTC Vive Pro, Whirligig player, 60 fps*

With the Virtual Desktop player we had similar results. The layout and the way BFI is used were basically identical. Compared to Whirligig, Virtual Desktop needed up to 50% less GPU and CPU workload for playout.

The GoPro VR player was tested with two different video backends: VLC using libVLC to decode the video and DirectShow with the LAV Filter codec pack. According to the GoPro VR Documentation[5] the use of DirectShow is deprecated but still allowed. With both options we had severe flickering and stutter issues, leading to the fact that we won't use this player for future tests.

In summary we developed a measurement tool for analyzing the video output of typical VR and 360° video setups. We can be sure that our VR system runs stable without any dropped frames. Furthermore we are able to identify and to describe frame manipulation effects (e.g. BFI) of HMDs.

[5]http://www.kolor.com/wiki-en/action/view/GoPro_VR_Documentation

Subjective Test

Based on the previously performed physical measurements it is required to perform a more detailed analysis with test subjects to finally find out how different framerates have an influence on the perceived quality. Therefore we designed a subjective expert test, while participants were video and audio QoE experts. We used two self-rendered CGI videos, *Moonrise* and *Starfield*. These contents are also publicly available at [6]. We decided to use CGI content, because in this case we can control the real framerate and the characteristics of the resulting videos. The videos were played out using Whirligig player because it also provided good results in our flickering test.

In the subjective test we also wanted to investigate, whether the usage of motion interpolation (MI) algorithms leads to better results for real 360° videos, mostly only available in 30 fps. For that we selected 4 360° videos from YouTube with 30 fps framerate, 20 s duration and 3840 x 1920 px resolution. As it is visible from the SI/TI plots in Figure 7 the contents are representing different categories of motion. Source Content (SRC) 2 does not have much motion. SRC 3 and 4 with a moderate amount of motion are leading to typical stuttering effects. We also decided to integrate one content with a high amount of motion, where people are dancing around the camera (SRC 5).

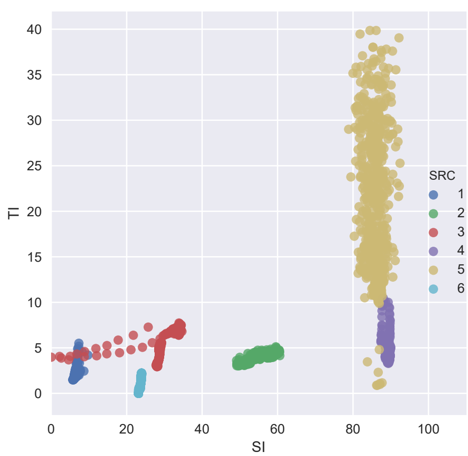


Figure 7. *SI/TI values of used contents*

Test Stimuli

In Figure 8, the rendered CGI contents are shown. The 20 s long SRC *Moonrise*, where a moonrise in the desert at night is shown, is only used in the training phase of our test to make them sensitive for framerate variations. We rendered the SRC using Blender 2.79[7] using Cycles[8] and a panoramic camera with an equirectangular lens type. While rendering the sequence, it especially was important that the attention of participants is directed to the movement of the moon. For preventing additional movement artefacts by head movements, we payed attention that subjects can perceive the whole movement of the moon without turning their head. In total, we used two different Processed Video Sequences (PVS) of *Moonrise* in the training phase: 30 fps and 90 fps.

[6]https://git.io/fhSUR
[7]https://www.blender.org
[8]https://www.cycles-renderer.org

In the next CGI test sequence *Starfield*, SRC6, the predominant stimulus in this 30 s long sequence is the movement of the objects – stars. These movements are very linear and predictable to prevent physical stress of test participants.

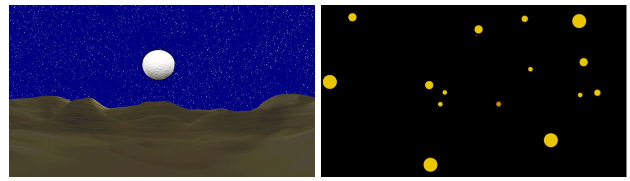


Figure 8. *Moonrise (left) and Starfield (right) test sequence*

To reduce the chromatic aberration, caused by the Fresnel lenses of the HMD, we changed the color of the stars from RGB (255,255,255) to RGB (200,136,000). This lowers the color contrast ratio significant from 21:1 to 7:1 and reduces color fringes. We created this content using the described Blender setup. We rendered five different videos with 25/30/50/60 and 90 fps with a resolution of 3840 x 1920 px. For every version it was required to adjust the animation to ensure a constant speed value of the stars.

To exclude any influence from the encoding, at first all SRCs were converted using the same settings used for the flicker test sequences and rescaled to a resolution of 3840 x 1920 px. To investigate whether the usage of MI can improve the perceptual quality, we interpolated all contents to 90 fps using three different MI methods. Two MI methods are included in *ffmpeg*, whether we used a simple blending of the frames and *mci* (motion compensated interpolation), while overlapped block motion compensation was activated. As third MI technology, we used v0.2.3 of *butterflow*[9], which is combining pixel-warping and blending for rendering the intermediate frames.

Test method

After pre-screening the subjects for accurate vision and color charts using Snellen (20/25) and Ishihara charts, they had to fill in a consent form. After introducing the subjects to the test procedure, the HMD was correctly mounted on the head. In addition, the interpupillary distance (IPD) was set to a default value of 62 for female and 65 for male participants (cf. [1]). At first, both PVS of the training sequence *Moonrise* were played out, while subjects had to rate the general perceived visual quality using the Absolute Category Rating (ACR) scale. At next, all 5 PVS of the *Starfield* content were played out, while subjects had to again rate the quality using the ACR scale. In the last part of the test, pairs of videos were played out to the subjects. At first, the reference video in 30 fps was shown, while afterwards the interpolated version using the respective MI algorithm was displayed. After each pair, participants had to decide, whether they would prefer the first or the second video or if they have no preference. To reduce symptoms of simulator sickness after half of the PVS, subjects had the possibility to make a short break. All playlists in the test were randomized.

Results

12 subjects participated in the test, while one was female, 11 male and the average/median age was 33/35.

[9]https://github.com/dthpham/butterflow

In Figure 9 the Mean Opinion Scores (MOS) with 95% Confidence Intervals (CI) are shown for the content *Moonrise*. From the plot, it is clearly visible, that the 90 fps version of the content is leading to a significant better quality (4.5 MOS) than the 30 fps version (2.0 MOS). This probably is related to the fact that in the 30 fps content people can perceive the stuttering of the moving moon, leading to a worser quality rating. For 90 fps most of the subjects perceived the movement as smooth, leading to a good perceived quality. All in all it can be concluded that stuttering has a strong influence on the QoE.

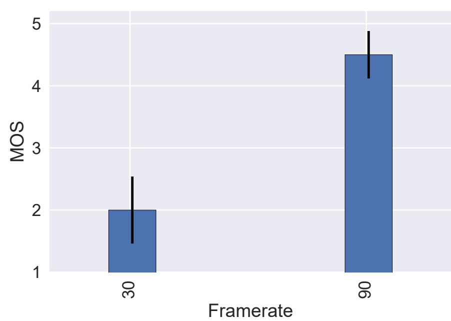


Figure 9. *MOS results for content Moonrise*

In Figure 10, the MOS with 95% CI are shown for the different framerates of the content *Starfield*. Like in Figure 9, it is definitely visible that the 90 fps content was again clearly stated as best quality by all subjects, reflected in a high MOS (4.7). This also can be supported by the fact that most of the subjects were surprised by the smoothness of the moving stars while watching that video. This is probably related to the fact of that in lower fps versions the stars are stuttering. This is especially visible for stars near to the camera, which are "splitted" to multiple stars. The 25 and 30 fps contents only were rated with "poor" (2.2 and 2.6 MOS), while 50 and 60 fps were rated as "fair" (3.1 and 3.3). To be concluded, subjects were able to see clear differences between the single framerates of the *Starfield* content, while the 90 fps version was clearly stated as the best. This is visible for both CGI contents, despite of the low number of subjects.

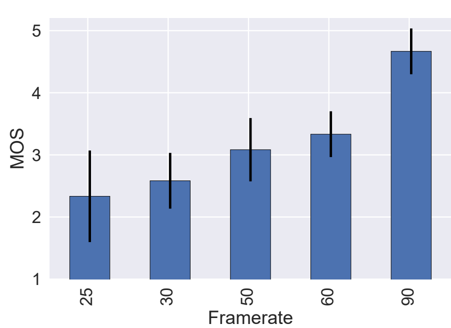


Figure 10. *MOS results for content Starfield*

In Figures 11, 12 and 13, the results of the comparison between the SRC in 30 fps and the interpolated 90 fps version using the mentioned MI algorithms are shown for all SRCs.

In 11 the preference of butterflow versus the reference video is plotted. It is visible, that the butterflow interpolated version was

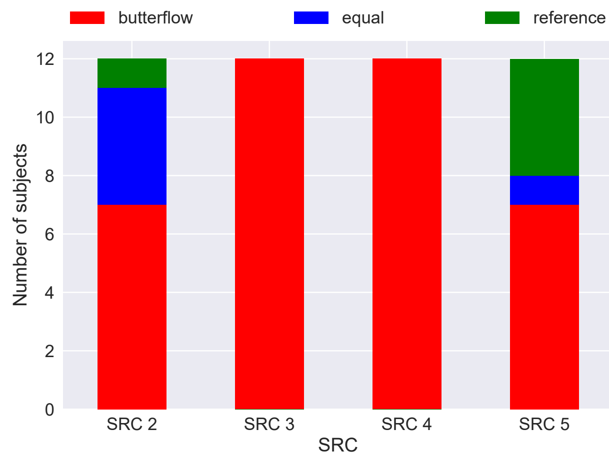


Figure 11. *Reference vs butterflow*

always preferred over the source video, even though differences can be perceived in between the SRCs. For SRC 2, the difference is not so clearly visible. A few participants were not able to see a difference between the two versions of the video. This probably can be related to the fact that compared to the other videos the amount of motion was relatively small. In SRC 3 and 4, leading to typical stuttering effects especially when objects or persons are passing by the camera, there is a very clear preference for the interpolated version of the video. For SRC 5, where fast and sudden movements were included, there is not such a clear preference for the 90 fps version, interpolated using the *butterflow* filter. One possible reason could be that due to the MI, so-called mosquito artifacts or noise are introduced, visible as "clouds" around moving objects. Due to Zeng et al., mosquito noise is having a strong negative impact on video quality (cf. [17]), leading to the fact that the reference video with no mosquito artifacts but stuttering effects is often preferred. Summarizing, for improving the perceived quality of most 30 fps 360° contents, the *butterflow* filter could be applied, increasing the framerate of the video. For SRC 2, differences are not as visible as for the other SRCs, while for higher motion videos the *butterflow* filter does not give as good results as for SRC 3 and 4.

Figure 12 shows the preference of the interpolated video using blending frames versus the reference video. From the plot, it can be deduced that the preference for the interpolated video is not clearly visible, irrespective of the shown content. The minority of participants preferred the interpolated version of the content over the reference video. This probably is related to the fact that blending leads to blurred images, leading to either a preference of the reference video or an equal rating of the shown pair. It can be summarized, that *ffmpeg blend* is not leading to a significant better quality. It is rather decreasing the quality than improving it and should not be used for MI of 360° contents.

In Figure 13 the preference of the interpolated video using *ffmpeg mci* versus the reference video is shown. From the results it is clearly visible that for most of the contents the interpolated version is preferred over the reference video. Because of the slow camera movements, for SRC 2 the preference of the interpolated video is not as clearly visible as for the other contents. For SRC 5, the interpolated video is also clearly preferred. From the results it

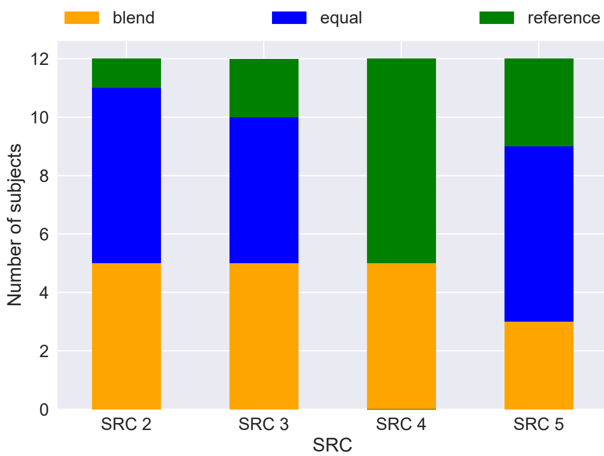


Figure 12. *Reference vs blend*

also can be concluded that *ffmpeg mci* is more suitable for interpolating fast movement contents than *butterflow*, which is especially visible for SRC 5 in Figure 13.

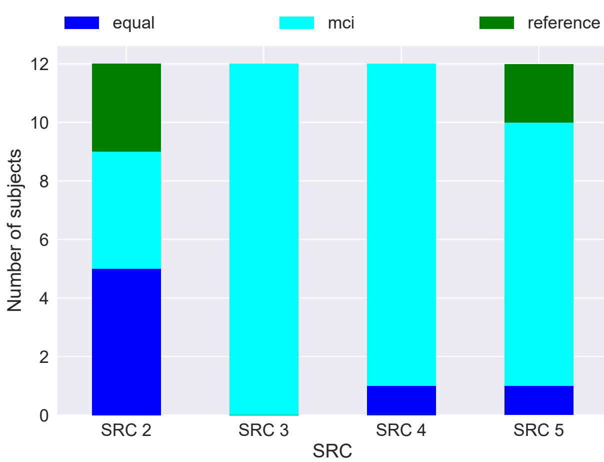


Figure 13. *Reference vs mci*

Conclusions and Future Work

Within the paper, we conducted two studies: One objective measurement and one subjective test using HTC Vive Pro. In the objective measurement, using an oscilloscope and a photodiode, we found out that on our system the Whirligig and Virtual Desktop player are offering a smooth playback for 90 fps content without dropped frames or flickering. However, on the used system using Virtual Desktop the workload for decoding the 360° videos is up to 50% lower compared to the Whirligig player. In addition, we found out that the playback of 25, 30, 50 and 60 fps content is leading to frame fluctuation and frame manipulation (BFI). This is related to the fact that the content is displayed on the 90 Hz panel of the HTC Vive Pro, while the interpolation is done. We also recognized that for the GoPro VR Player more often frame drops are occuring.

In our second study, we found out that the native 90 fps versions of two CGI contents are clearly preferred over lower framerate versions of the content. In the second part of the subjective test, we investigated whether MI could be used for improving the overall quality of 30 fps 360° videos. From the results it is significantly visible that MI is a tool to clearly improve the video quality and reduce typical stuttering artifacts in 30 fps 360° videos. We also found out that *ffmpeg mci* should be preferred over *butterflow* for interpolating 30 fps to 90 fps content, especially for contents with a high amount of motion. However, for videos with low motion the difference between the interpolated and the reference video is not clearly visible.

In the future, we will compare different MI technologies among each other to find out which algorithm can be used for given SRCs with various movement characteristics to reduce stuttering. For doing so we want to conduct a test using naive participants.

References

[1] N. A. Dodgson. "Variation and extrema of human interpupillary distance". In: *Stereoscopic Displays and Virtual Reality Systems XI*. Vol. 5291. International Society for Optics and Photonics. 2004, pp. 36–47.

[2] E. S. Ferry. "ART. XXVI.–Persistence of Vision". In: *American Journal of Science (1880-1910)* 44.261 (1892), p. 192.

[3] S. Fremerey et al. "Are people pixel-peeping 360° videos?" In: *Electronic Imaging, Human Vision Electronic Imaging*. 2019.

[4] S. Fremerey et al. "AVtrack360: an open dataset and software recording people's head rotations watching 360° videos on an HMD". In: *Proceedings of the 9th ACM Multimedia Systems Conference*. ACM. 2018, pp. 403–408.

[5] R. Granit and P. Harper. "Comparative studies on the peripheral and central retina: II. Synaptic reactions in the eye". In: *American Journal of Physiology-Legacy Content* 95.1 (1930), pp. 211–228.

[6] HTC Corporation. *Das neue VIVE Pro*. https://www.vive.com/de/pro-eye/. 2019.

[7] P. Lebreton and A. Raake. "GBVS360, BMS360, ProSal: Extending existing saliency prediction models from 2D to omnidirectional images". In: *Signal Processing: Image Communication* (2018).

[8] A. Mackin, F. Zhang, and D. Bull. "A Study of High Frame Rate Video Formats". In: *IEEE Transactions on Multimedia* (2018).

[9] T. C. Porter. "Contributions to the study of flicker. Paper II". In: *Proceedings of the Royal Society of London* 70.459-466 (1902), pp. 313–329.

[10] R. Schatz et al. "Towards subjective quality of experience assessment for omnidirectional video streaming". In: *Proc. 9th Int. Conf. Qual. Multimedia Exp.(QoMEX)*. 2017, pp. 1–6.

[11] A. Singla, W. Robitza, and A. Raake. "Comparison of Subjective Quality Evaluation Methods for Omnidirectional Videos with DSIS and Modified ACR". In: *Electronic Imaging* 2018.14 (2018), pp. 1–6.

[12] A. Singla et al. "Measuring and comparing QoE and simulator sickness of omnidirectional videos in different head mounted displays". In: *Quality of Multimedia Experience (QoMEX), 2017 Ninth International Conference on*. IEEE. 2017, pp. 1–6.

[13] A. Singla et al. "Subjective Quality Evaluation of Tile-based Streaming for Omnidirectional Videos". In: *10th ACM Multimedia Systems Conference*. Amherst, MA, USA, 2019.

[14] H. T. Tran et al. "A subjective study on QoE of 360 video for VR communication". In: *Multimedia Signal Processing (MMSP), 2017 IEEE 19th International Workshop on*. IEEE. 2017, pp. 1–6.

[15] M. Xu et al. "A subjective visual quality assessment method of panoramic videos". In: *2017 IEEE International Conference on Multimedia and Expo (ICME)*. IEEE. 2017, pp. 517–522.

[16] J. Yang et al. "3D panoramic virtual reality video quality assessment based on 3D convolutional neural networks". In: *IEEE Access* 6 (2018), pp. 38669–38682.

[17] K. Zeng et al. "Characterizing perceptual artifacts in compressed video streams". In: *Human Vision and Electronic Imaging XIX*. Vol. 9014. International Society for Optics and Photonics. 2014, 90140Q.

[18] B. Zhang et al. "Subjective and objective quality assessment of panoramic videos in virtual reality environments". In: *Multimedia & Expo Workshops (ICMEW), 2017 IEEE International Conference on*. IEEE. 2017, pp. 163–168.

[19] R. Zhou et al. "Modeling the impact of spatial resolutions on perceptual quality of immersive image/video". In: *3D Imaging (IC3D), 2016 International Conference on*. IEEE. 2016, pp. 1–6.

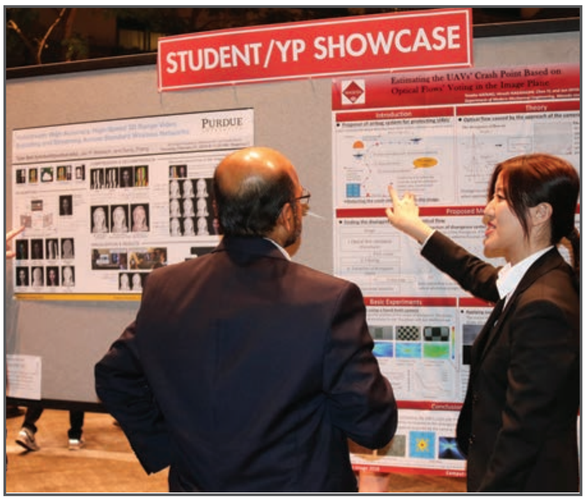
JOIN US AT THE NEXT EI!

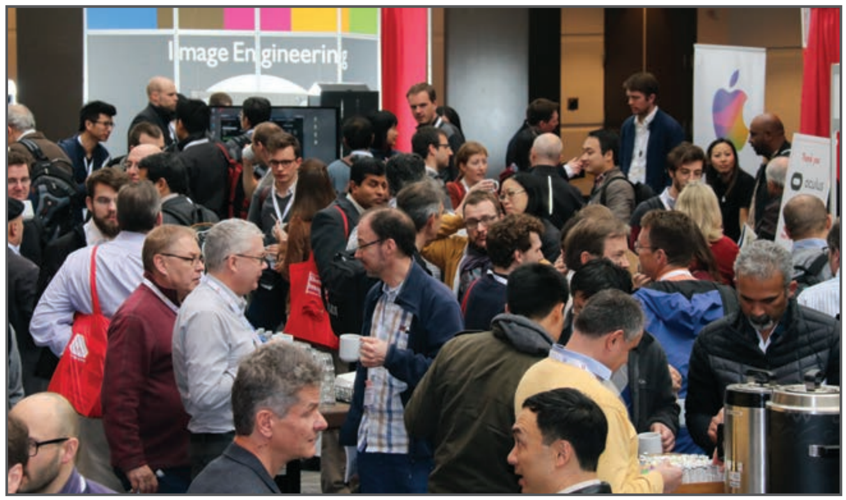
IS&T International Symposium on

Electronic Imaging

SCIENCE AND TECHNOLOGY

Imaging across applications . . . Where industry and academia meet!





• SHORT COURSES • EXHIBITS • DEMONSTRATION SESSION • PLENARY TALKS •
• INTERACTIVE PAPER SESSION • SPECIAL EVENTS • TECHNICAL SESSIONS •

www.electronicimaging.org

IS&T
imaging.org