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Comparison of Subjective Quality Evaluation Methods for Omnidirectional Videos with DSIS and Modified ACR

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Abstract

In this paper, we compare the Double-Stimulus Impairment Scale (DSIS) and a Modified Absolute Category Rating (M-ACR) subjective quality evaluation method for HEVC/H.265-encoded omnidirectional videos. These two methods differ in the type of rating scale and presentation of stimuli. Results of our test provide insight into the similarities and differences between these two subjective test methods. Also, we investigate whether the results obtained with these subjective test methods are content-dependent. We evaluated subjective quality on an Oculus Rift for two different resolutions (4K and FHD) and at five different bit-rates. Experimental results show that for 4K resolution, for the lower bit-rates at 1 and 2 MBit/s, M-ACR provides slightly higher MOS compared to DSIS. For 4, 8, 15 MBit/s, DSIS provides slightly higher MOS. While the correlation coefficient between these two methods is very high, M-ACR offers a higher statistical reliability than DSIS. We also compared simulator sickness scores and viewing behavior. Experimental results show that subjects are more prone to simulator sickness while evaluating 360° videos with the DSIS method.

Introduction

Omnidirectional (360°) videos offer a much more immersive experience than traditional 2D video, by providing a higher Field of View (FOV) and enabling interactivity with the content. Users are free to explore any direction they want. When considering the increased FOV and high video resolution, it is obvious that there is a need to compress these videos efficiently in order to allow them to be transmitted over networks with as little bandwidth use as possible. While evaluating the effect of compression artifacts on the perceptual quality of the 360° videos may be approximated with objective metrics (e.g., based on PSNR-like measurements), these metrics are known to not necessarily correspond well to the quality as experienced by human subjects. Also, these metrics cannot incorporate human factors that may have an impact on the Quality of Experience (QoE) of viewers. Hence, it is important to not only develop methods to subjectively assess QoE but also ensure that such methods give valid and reliable results.

Despite several subjective tests having been conducted with omnidirectional video, according to the best of our knowledge, there are no works reported in the literature which explicitly *compare* different subjective evaluation methodologies on the same content. Hence, we conducted a study in which we compare the ITU-standardized *Double Stimulus Impairment Scale* (DSIS) and our previously proposed *Modified Absolute Category Rating* (M-ACR) method (c.f. [6]). The novelty of this paper, therefore, lies in comparing these two subjective test methodologies for evaluating 360° videos. In addition to that, we also investigated the impact of method choice on possible simulator sickness and the users' head movement behavior.

The remainder of the paper is organized as follows: We first give an overview of related work and then describe the experiments, including the technical setup, the video sequences, and the test methodologies themselves. In the following, we describe the detailed experimental results concerning video quality, simulator sickness and user behavior. Concluding remarks are given at the end of the paper.

Related Work

Unlike 2D videos, in omnidirectional videos users are free to explore in any direction they want. This freedom of exploration produces more challenges, especially in knowing what the most important regions are, where users focus more while watching the omnidirectional content. Previous studies were carried out to determine saliency maps or other representations of visual attention [12–15]. These studies provide insight in prioritizing the information present in the video sequences. In [5, 6] authors computed the mean view path for the yaw and pitch direction and also computed the saliency maps in [6].

Several objective metrics for evaluation of omnidirectional video quality have been reported in the state-of-the-art, such as Spherical PSNR (S-PSNR) [1], (WS-PSNR) [2], (AW-PSNR) [3] and CPP PSNR [4]. However, despite the usefulness of such metrics in automatically obtaining quality estimations, the only valid way to measure visual quality and Quality of Experience of VR technology consists in performing subjective studies with humans.

Different subjective quality evaluation methods for evaluating videos on computer screens or TVs have been standardized by the ITU-T [16, 17]. However, respective standards for omnidirectional videos do not exist yet, and methods for evaluating video quality have not been extensively studied so far. In [7], the authors evaluated the subjective quality of omnidirectional images by using the Absolute Category Rating (ACR). In [5], the authors adapted this method for long video sequences (60 s). In [6], we evaluated the subjective video quality of HEVC-encoded omnidirectional videos (10 s, encoding of equirectangular frames) and proposed a Modified ACR (M-ACR) scale for rating the quality of the videos. In [8], quality of High Dynamic Range (HDR) omnidirectional images were evaluated by using an alternate Pair Comparison (PC) method based on image toggling. Also, in previous subjective tests, only a Single Stimulus (SS) methodology has been used for evaluating the QoE / subjective video quality for omnidirectional videos.

Target bit-rates in MBit/s for different resolutions [6]

Resolution Class	R1	R2	R3	R4	R5
UHD	1	2	4	8	15
FHD	0.5	1	1.5	3.5	5.0

A challenging aspect in VR is simulator sickness. Described as similar to motion sickness [9, 10], it occurs due to the conflict between the sensory visual motion and vestibular system. In [5], we could show that resolution and content have an impact on simulator sickness, and that females experience higher simulator sickness than males [5]. This has also been stated in [11]. The *Simulator Sickness Questionnaire* (SSQ) [9, 10] is a quasi-standard method used to assess simulator sickness; we also employed it in the context of our proposed test design.

In order to properly validate and subsequently standardize a method for subjectively assessing omnidirectional video QoE – and quantify its impact on human well-being –, different approaches have to be tested and compared. This the main motivation for performing our studies, which we will describe in the following.

Experimental Setup

Description of the Dataset

The number of publicly available high-quality datasets for omnidirectional videos in an uncompressed format is limited [18]. As test dataset, we selected six different test sequences (1: `DrivingInCountry`, 2: `PoleVault_le`, 3: `Gaslamp`, 4: `Harbor`, 5: `KiteFlite`, 6: `Trolley`). They are the same as used in [6]. The video sequences are in YUV format, 4:2:0 color space with 8 bits per pixel. The frame rate and duration of each sequence are 30 fps and 10 s respectively.

For each test video sequence, two different resolutions were chosen: Full HD (1920×1080, FHD) and Ultra HD (3840×2160, UHD). Five different bit-rates were selected for each resolution, which corresponds to different quality levels, as shown in Table 1. In order to encode the test video sequences at the desired bit-rates, `ffmpeg`[1] with *libx265* was used. The *Video Buffering Verifier* (VBV) method has been used for encoding in a one-pass encoding scheme. It uses bit-rate constraints to restrict the target bit-rate by specifying both client-buffer size and a maximum bit-rate. *Libx265* is chosen over the `HM/JEM`[2] reference software mainly because of its faster encoding performance and better control over the bit-rate [6].

Test Environment and Equipment

In order to evaluate the degradations and compression artifacts in our 360° videos, we used an Oculus Rift (*Consumer Version 1*)[3]. The resolution and field of view (FOV) are 2160 × 1200 and 110° respectively. The Whirligig player (version 3.89) was used in order to display the 360° videos. The Oculus Rift was connected to a desktop PC equipped with an NVIDIA GTX980 graphics card and an Intel Core i7 processor.

[1]`https://ffmpeg.org/`

[2]`https://hevc.hhi.fraunhofer.de/svn/svn_HEVCSoftware/`

[3]`https://www.oculus.com/rift/`

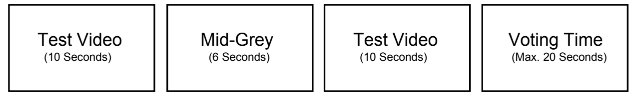

Figure 1. *Presentation of one stimulus for M-ACR test method [6]*

In order to reduce side effects such as simulator sickness and visual fatigue induced by VR, the subjective test was divided into four test sessions. The duration of each test session was no longer than ten minutes. Subjects were asked to fill out the SSQ after every test session and before the starting of the first test session. There are 16 questions in the SSQ; they assess the severity of different symptoms on a 4-point scale (None: 0, Slight: 1, Moderate: 2, Severe: 3). These symptoms are divided into the three different sub-categories (*Disorientation* (D), *Nausea* (N) and *Oculomotor* (O)) and *Total Score* (TS) contains the component from D, N and O and TS is computed based on [9].

At a given time, only two subjects were performing the subjective test. Each subject had to rate 60 test sequences (PVS, Processed Video Sequence), based on a full-factorial design with two resolutions, five bit-rates and six contents. Each content was viewed 20 times, since in DSIS, the reference sequence and test sequence are compared, and in our M-ACR method, each PVS is repeated twice (see the next section for more details).

After every full test session of one subject, for hygienic reasons, the lenses and HMD were cleaned. Subjects were sitting on a rotating chair so that they could explore any direction they wanted.

We developed a framework in Python which records the users' head movement while watching the content, in the three co-ordinates yaw, pitch and roll. Details of the framework can be found in [5, 6]. Before the start of the video, the subjects were instructed to position themselves in the center position so that yaw and pitch values in our head tracking system could be normalized to zero for this case.

Test Methodologies

Modified-ACR (M-ACR) Test Method

We proposed the Modified-ACR (M-ACR) test method in [6] for evaluating subjective video quality for short video sequences (10 s). Figure 1 shows the presentation of one stimulus for the M-ACR test method.

The test videos are shown twice, in between the test videos, a mid-grey screen was displayed for 6 s. Subjects were asked to rate the video quality on a five-point scale (5: Excellent, 4: Good, 3: Fair, 2: Poor, 1: Bad). The rating scale was projected at four azimuth angles on the HMD screen. Instruction were given to the subjects not to consider the ghost and stitching artifacts present in the video sequences.

30 subjects participated in the M-ACR subjective test. Out of 30, 15 were females and 15 were males. The age of the participants varied from 19 to 36 years with an average age of 25.62 and median of 25 years. Details for this test can be found in [6].

DSIS Method

The Double Stimulus Impairment Scale (DSIS) method is based on [19]. In DSIS, first, the source reference video is pre-

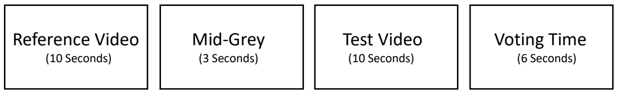

Figure 2. *Presentation of one stimulus for DSIS test method*

sented, followed by the PVS (i.e., a degraded variant of the reference video). See Figure 2 for a scheme of the method.

The reference videos are in raw YUV format, and hence cannot be played using the Whirligig player. Therefore, we encoded the reference video with the highest bit-rate or at the highest quality with HEVC so that no perceivable degradations were present in the reference video.

Subjects were asked to rate the degradations on a five-point scale (5: Imperceptible, 4: Perceptible but not annoying, 3: Slightly annoying, 2: Annoying, 1: Very annoying). The scale was displayed on the HMD screen at four different yaw angles as done in case of the M-ACR test method and described in [6]. Subjects were asked to rate the compression artifacts and impairments, but not to consider any ghosting and stitching artifacts present in the source. For collecting the ratings, the user had to say the number aloud and the experimenter would note down the rating. This process allowed the user to continuously wear the HMD throughout a test session and was the same as in case of the modified ACR method [6].

27 subjects participated in the DSIS subjective test. Out of 27, 11 were females and 16 were males. The age of the participants varied from 19 to 36 years with an average age of 25.07 and median of 24 years. All the subjects were screened for correct visual acuity and color vision using Snellen (20/25) and Ishihara charts. None of the subjects left the experiment in-between due to simulator sickness.

Results

In this section, the results of the subjective quality studies are analyzed and compared, with respect to quality, simulator sickness and behavior, for the two different test methodologies M-ACR and DSIS.

Subjective Quality Evaluation

For checking the reliability of the users, outlier detection was performed during the analysis. We computed the Pearson correlation coefficient between the raw scores of each user to the mean rating (Mean Opinion Score, MOS) value for each of the test conditions. Based on [20], a threshold of 0.75 was considered for detecting the outliers. In our experiment, only one user was found to be an outlier. We then computed MOS and associated confidence interval (CI, 95%) based on the ITU-R guidelines [21] for each test condition (resolution, bit-rate and content).

MOS Comparisons between M-ACR and DSIS

Figures 3 and 4 show the MOS for different bit-rates and for the M-ACR and DSIS methods for the two different resolutions 4K and FHD, respectively. At 4K resolution, for the lower bit-rates at 1 and 2 MBit/s, M-ACR provides slightly higher MOS than DSIS. For 4, 8, 15 MBit/s, DSIS provides slightly higher MOS. Figure 5 shows the average MOS values over all contents for different bit-rates for 4K and FHD resolution for DSIS. It is evident that 4K resolution generally leads to better-perceived quality than FHD resolution, except at 1 MBit/s. Due to the resolution limitation of the Oculus Rift, the perceived quality at 15 MBit/s is equal/slightly higher than at 8 MBit/s for UHD resolution for some contents and both the evaluation methodologies.

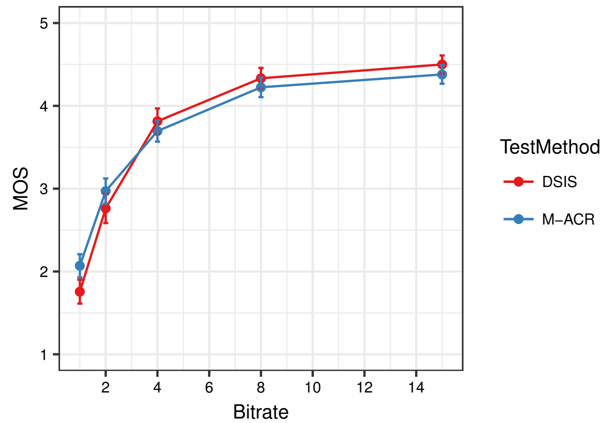

Figure 3. *Average MOS for different test methods at 4K resolution.*

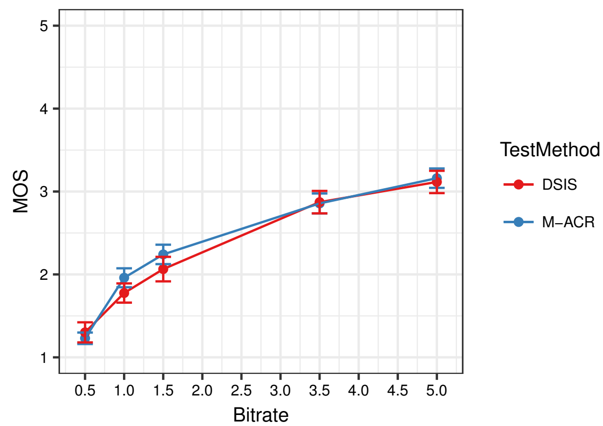

Figure 4. *Average MOS for different test methods at FHD resolution.*

Figure 5 also shows that DSIS has a larger range of MOS values – although only slightly –, and thus provides a higher subjective resolution power. M-ACR and DSIS differ in the evaluation and in the presentation method: DSIS evaluates the impairments present in the video, while M-ACR evaluates the absolute quality of the video. DSIS could therefore be more useful for assessing fine-grained or minutiae details, especially at 4K resolution. It is worth noting however that CI values are considerably higher in case of the DSIS method, as seen in Figure 6, where we plotted the CI corresponding to each MOS for all the PVSes.

Impact of Bit-Rate, Resolution and Content on DSIS Scores

In order to find out the impact of bit-rates, resolutions and contents on the users' ratings in the DSIS test, an ANOVA (Analysis of Variance) was carried out on the individual ratings given by subjects. Table 2 shows that all the independent variables bit-rates, resolutions and contents have a significant impact ($p < 0.01$) on the users' ratings. There is also an interaction effect between

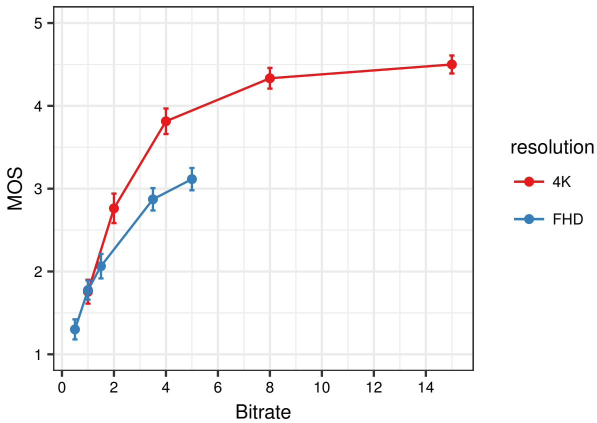

Figure 5. *Average MOS over all contents for DSIS test method.*

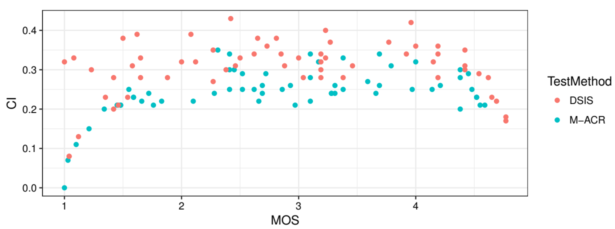

Figure 6. *CI vs MOS.*

MCI, MOS Range and MCI_{norm} for DSIS and M-ACR

	DSIS	M-ACR
MCI	0.136	0.118
MOS Range	3.198	3.149
MCI_{norm}	0.042	0.037

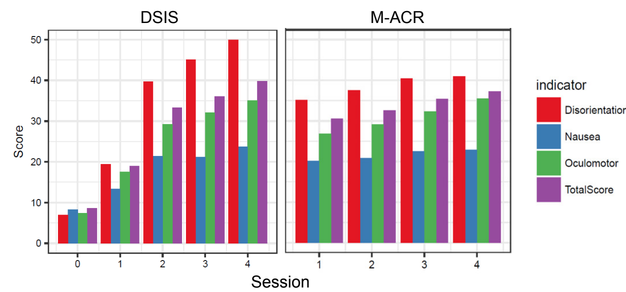

Figure 7. *Simulator sickness scores for all test sessions*

the bit-rate and resolution.

In order to find out which evaluation methodology is more reliable, we evaluated the statistical reliability based on [16]. For both these methods, we calculated MCI_{norm} as shown in equation 1.

$$\text{MCI}_{\text{norm}} = \frac{\text{MCI}}{\text{MOS Range}} \quad (1)$$

Here, MCI is the *Mean Confidence Interval*. *MOS Range* is the absolute difference between the highest and lowest MOS for each test method. Table 3 shows the MOS, MOS Range and MCI_{norm} for DSIS and M-ACR methods. Results indicate that M-ACR is slightly better than DSIS, as MCI and MCI_{norm} are smaller for M-ACR. Obviously, the Pearson correlation coefficient between these two methods is very high ($r = 0.992$).

ANOVA results on MOS vs. experimental factors.

	DF	Sum Sq	Mean Sq	F	p
resolution	1	21.878	21.878	64.244	< 0.001
bit-rate	1	30.900	30.900	90.739	< 0.001
content	5	7.980	1.596	4.687	< 0.01
resolution×bit-rate	1	3.794	3.794	11.142	< 0.01
resolution×content	5	0.523	0.105	0.307	0.90
bit-rate×content	5	1.318	0.264	0.774	0.57
resolution×bit-rate×content	5	0.147	0.029	0.086	0.99

Simulator Sickness

As explained in the Experimental Setup section, the duration of each test session was around ten minutes. We wanted to investigate if there is an increase in the simulator-sickness scores with an increase in test time, and with which methodology subjects are more prone to simulator sickness. For doing so, we used the SSQ to assess simulator sickness among subjects.

We compared the simulator sickness scores from [6] for the M-ACR method with our simulator sickness scores for the DSIS method, as shown in Figure 7. For the DSIS method, we computed simulator sickness scores for session 0, which were collected just after the pre-screening and before the training session. From the results it becomes clear that users are more prone to simulator sickness when evaluating 360° videos with the DSIS method, except for session #1. The possible reason could be due to the difference in the resolution / bit-rate of the reference stimuli and video under the test for DSIS. In the case of M-ACR, videos were also shown twice, but there is no change in the bit-rate / resolution of those videos.

Behavior Analysis

One advantage of omnidirectional video over conventional 2D videos consists of the increased FOV: users can look wherever they want and are provided with a highly immersive experience. In order to analyze the exploration behavior of the users, the head rotation data were recorded along the three single axes yaw, pitch and roll. In our analysis, we considered only the yaw and pitch direction, as users only minimally explored the roll axis. We considered the Rift's co-ordinate system for assigning negative and positive values for yaw and pitch. Pitching the head upwards and turning the head left would give positive pitch and yaw values respectively. Yaw and pitch values were measured at an interval of 0.19 s. Therefore, for the 10 s long video, about 54 values of pitch and yaw were recorded each.

Figure 8 shows the view path, averaged over all subjects, for different bit-rates and for both reference and video under test for

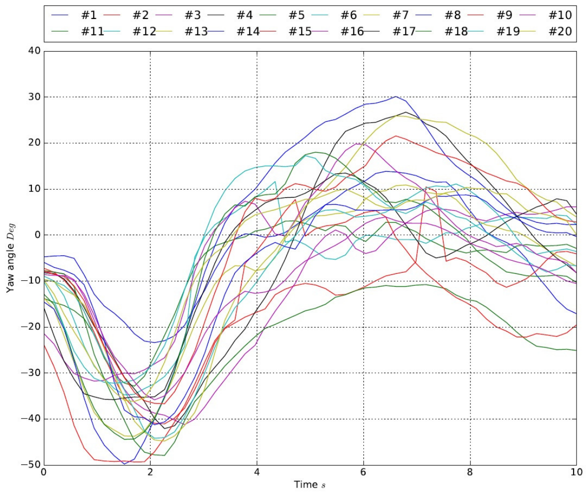

Figure 8. *Average Yaw value for video sequence 2 for DSIS method.*

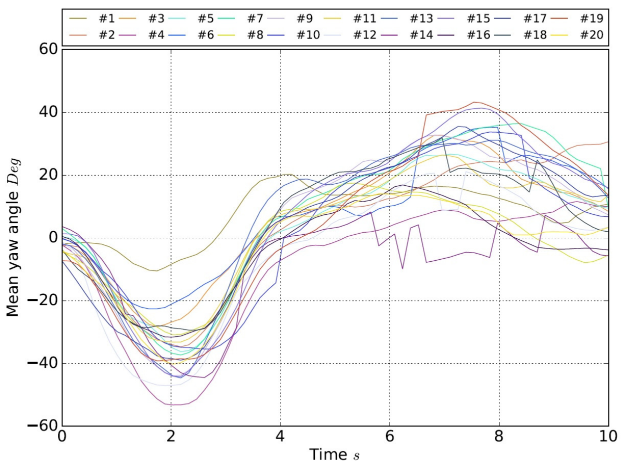

Figure 9. *Average Yaw value for video sequence 4 for M-ACR method.*

video sequence 2 (`PoleVault_le`). This video shows an athlete doing a pole vault with a lot of spectators in the surroundings. From Figure 8 it can be concluded that until 4 s, the mean view path is almost the same because approximately at 4 s, the sportsman is performing the jump. After the jump, users explored the different parts of the scene. Obviously, the exploration behavior in DSIS almost matches that for M-ACR, as can be observed when comparing Figures 8 and 9.

For video sequence 4 (`Harbor`), the exploration behavior of the users in both evaluation methodologies is quite random, as shown in Figures 10 and 11. This video sequence does not show a particular story, which could be a reason for the random exploration behavior – unlike video sequence 2, where subjects were trying to find interesting content in the video.

Conclusion

In this paper, we compared two subjective test methodologies (DSIS and M-ACR) for evaluating the subjective video quality for HEVC-encoded 360° videos. Results show a very high correlation between the scores obtained with the two methods (Pearson $r = 0.992$). Moreover, M-ACR provides slightly higher

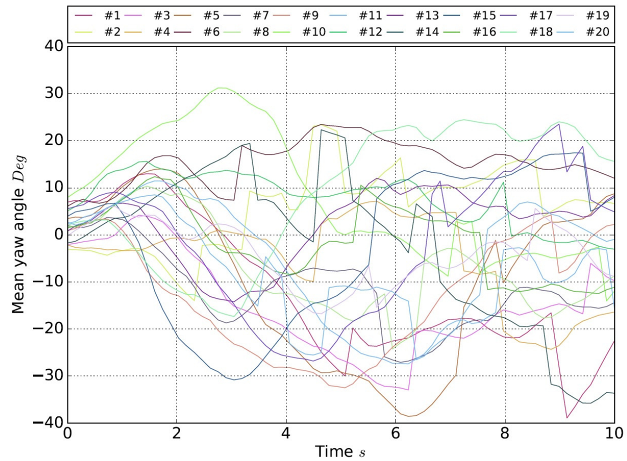

Figure 10. *Average Yaw value for video sequence 4 for M-ACR method.*

MOS compared to DSIS for lower bit-rates. For bit-rates above 4 MBit/s, DSIS provides slightly higher MOS at 4K resolution. Generally, users rate the perceived quality higher at 4K resolution than FHD, in both evaluation methodologies. An analysis also shows that M-ACR is statistically slightly more reliable than DSIS, and that DSIS has considerably larger CI values. We further analyzed simulator sickness; results show that subjects are more prone to simulator sickness in DSIS, except for the first viewing session. Finally, we analyzed head rotation data and compared results for M-ACR and DSIS for different contents. The results show similar exploration behavior in both methodologies and that the exploration range in yaw direction is higher than the pitch direction. From the analysis provided in this paper, it can be concluded that M-ACR appears to be the better choice, especially in light of the reduced simulator sickness scores.

Future work will address a more in-depth analysis of user behavior and its interplay with the applied test method. Further, we will include additional test methods in the comparison such as paired-comparison tests with binary answers of quality-preference for the two PVSs that build up each pair.

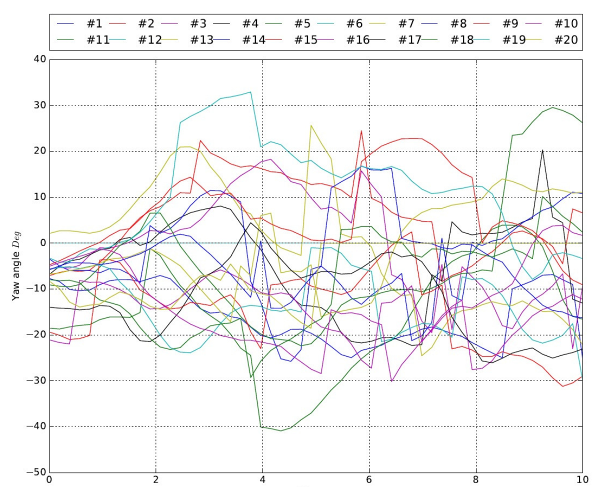

Figure 11. *Average Yaw value for video sequence 4 for DSIS method.*

Acknowledgments

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