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# Introduction

This document aims to collect and document quality metrics and methodologies for immersive visual media. According to the QUALINET White Paper on Definitions of Immersive Media Experience (IMEx) [1], immersive media can be defined as:

*a high-fidelity simulation provided and communicated to the user through multiple sensory and semiotic modalities. Users are emplaced in a technology-driven environment with the possibility to actively partake and participate in the information and experiences dispensed by the generated world.*

The ISO/IEC 23090 MPEG-I (Coded Representation of Immersive Media) series of standards currently comprises 22 parts where part 1 provides a technical report on architectures for immersive media [2].

# MPEG AG 5 Workshop on Quality of Immersive Media: Assessment and Metrics [3]

The scope of this workshop is *(i)* to raise awareness about MPEG efforts in the context of quality of immersive visual media and *(ii)* invite experts (outside of MPEG) to present new techniques relevant to this workshop.

Quality assessments in the context of the MPEG standardization process typically serve two purposes: *(1)* to foster decision-making on the tool adoptions during the standardization process and *(2)* to validate the outcome of a standardization effort compared to an established anchor (*i.e.,* for verification testing).

* Date: October 5, 2021
* Time slot: 1500-1700 UTC

**Program/Speakers**:

15:00-15:10: **Joel Jung** & **Christian Timmerer** (AhG co-chairs): Welcome notice

15:10-15:30: **Mathias Wien** (AG 5 convenor): **MPEG Visual Quality Assessment: Tasks and Perspectives**

**Abstract**: The Advisory Group on MPEG Visual Quality Assessment (ISO/IEC JTC1 SC29/AG5) has been founded in 2020 with the goal to select and design subjective quality evaluation methodologies and objective quality metrics for the assessment of visual coding technologies in the context of the MPEG standardization work. In this talk, the current work items, as well as perspectives and first achievements of the group, are presented.

15:30-15:50: **Aljosa Smolic: Perception and Quality of Immersive Media**

**Abstract**: Interest in immersive media increased significantly over recent years. Besides applications in entertainment, culture, health, industry, etc., telepresence and remote collaboration gained importance due to the pandemic and climate crisis. Immersive media have the potential to increase social integration and to reduce greenhouse gas emissions. As a result, technologies along the whole pipeline from capture to display are maturing and applications are becoming available, creating business opportunities. One aspect of immersive technologies that is still relatively undeveloped is the understanding of perception and quality, including subjective and objective assessment. The interactive nature of immersive media poses new challenges to estimation of saliency or visual attention, and to the development of quality metrics. The V-SENSE lab of Trinity College Dublin addresses these questions in current research. This talk will highlight corresponding examples in 360 VR video, light fields, volumetric video and XR.

15:50-16:00: Break/Discussions

16:00-16:20: **Jesús Gutiérrez: Quality assessment of immersive media: Recent activities within VQEG**

**Abstract**: This presentation will provide an overview of the recent activities carried out on quality assessment of immersive media within the Video Quality Experts Group (VQEG), particularly within the Immersive Media Group (IMG). Among other efforts, outcomes will be presented from the cross-lab test (carried out by ten different labs) in order to assess and validate subjective evaluation methodologies for 360º videos, which was instrumental in the development of the ITU-T Recommendation P.919. Also, insights will be provided on the current plans on exploring the evaluation of the quality of experience of immersive communication systems, considering different technologies such as 360º video, point cloud, free-viewpoint video, etc.

16:20-16:40: **Alexander Raake: Perceptual evaluation of Immersive Media - from video quality towards a holistic QoE perspective**

**Abstract**: Immersive visual media spans from higher-resolution video with increased field of view to fully interactive extended reality (XR) systems based on VR, AR, or MR technology. Here, quality and Quality of Experience (QoE) evaluation are key to ensure valuable experiences for the users and thus successful technology developments. The talk presents some work in ITU-T SG 12 on the assessment of immersive media, and corresponding contributions and other related research activities by the Audiovisual Technology (AVT) group at TU Ilmenau. In the first part of the talk, the quality model series P.1203 and P.1204 for resolutions of up to 4K/UHD1 will be presented, with a primary focus on the bitstream-based models P.1203.1 and P.1204.3. Besides their application to 2D video, their usage for gaming-video and 360° video quality assessment are addressed. In the second part, the talk discusses aspects of QoE for immersive media that go beyond visual quality. Research is presented on the exploration behavior of users for 360° video, showing the influence due to the content as well as the task given to the subjects. Furthermore, some recent work on presence and cybersickness evaluation for 360° video is discussed. The talk concludes with an outlook on using indirect methods and cognitive performances as evaluation criteria for audiovisual IVEs.

16:40-17:00: **Laura Toni: Understanding user interactivity for immersive communications and its impact on QoE**

**Abstract**: A major challenge for the next decade is to design virtual and augmented reality systems for real-world use cases such as healthcare, entertainment, e-education, and high-risk missions. This requires immersive systems that operate at scale, in a personalized manner, remaining bandwidth-tolerant whilst meeting quality and latency criteria. This can be accomplished only by a  fundamental revolution of the network and immersive systems that has to put the interactive user at the heart of the system rather than at the end of the chain. With this goal in mind, in this talk, we provide an overview of our current researches on the behaviour of interactive users in immersive experiences and its impact on the next-generation multimedia systems. We present novel tools for behavioural analysis of users navigating in 3-DoF and 6-DoF systems, we show the impact and advantages of taking into account user behaviour in immersive systems. We then conclude with a perspective on the impact of users behaviour studies into QoE.

17:00: Conclusions and Discussions

The video and slides of this workshop are publicly available at [3].

# 360-Degree Video

## General

For 360-degree video, JVET maintains an output document “Algorithm descriptions of projection format conversion and video quality metrics in 360Lib” that comprises a set of 360-degree video quality metrics supported in 360Lib. See Section 4 of [4] for further details, specifically related to the following PSNR-based quality metrics:

* Weighted to Spherically uniform PSNR (WS-PSNR)
* Spherical PSNR w/o interpolation (S-PSNR-NN)
* Spherical PSNR with interpolation (S-PSNR-I)
* Crasters Parabolic Projection PSNR (CPP-PSNR)

Further details can be found in Section 4 of [4].

ITU-T P.919 defines “subjective test methodologies for 360° video on head-mounted displays” [5].

## VIVA-Q: Omnidirectional Video Quality Assessment based on Voronoi Patches and Visual Attention

VIVA-Q is a novel quality metric for 360-degree video, which makes 2 contributions [6][7]. The first is to take care of the spherical distortions introduced by 360-degree imaging. This is done through subdivision of spheres into patches using spherical Voronoi diagrams. Each patch is further processed in the planar domain, applying a standard video quality metric of choice (e.g., PSNR, SSIM, MS-SSIM, VMAF). Per patch quality scores are then pooled (e.g., averaged Eq. 1(a)) to compute an overall quality score. This part of the processing corresponds to the VI part of the acronym and is illustrated in Figure 1. Figure 2(a) shows an example of computed per patch VMAF scores.

Diagram

Description automatically generated with low confidence

Figure 1 - Voronoi-based quality assessment framework, showing patch extraction and patch metric score calculation.

Eq. 1

The second contribution relates to incorporation of visual attention or saliency into the metric and corresponds to VA in the acronym. Viewers are looking only at a portion of the content (viewport), when watching 360 content in most cases. Visual importance of different regions also varies, due to content and also position in the sphere, e.g., content along the equator is often more visually important than content at the poles. These properties of user behavior can be represented in visual attention or saliency masks (Figure 2(b)), which can be collected in user studies or estimated (saliency estimators e.g., based on deep learning). If such VA information is available, it can be incorporated into the metric. For that, we compute a VA weight for every patch from the visual attention or saliency map, as shown in Figure 2(b). The final VIVA score is then computed via some pooling of the weighted VI patch scores (e.g., averaged Eq. 1(b))

A picture containing graphical user interface

Description automatically generated

Figure 2 - Visualization of the VMAF patch scores, visual attention map, and the visual attention patch weights ν\_(i,k). Please refer to the color bars beside the figures for the used color code.

VI and VIVA metrics have been evaluated in detailed validation experiments, where it has been shown that they outperform other metrics in terms of correlation with subjective scores. Both contributions, VI as well as VA, independently provide improvements. Further details including experimental results can be found in [6][7]. Detailed slides with visualizations are included in the input container [7]. Directions to related code and data can be found on the project page: <https://v-sense.scss.tcd.ie/research/voronoi-based-objective-metrics/>

# MPEG Immersive Video (MIV)

## Objective evaluation

Evaluation with objective metrics is used in the MIV project to decide on adoption of proposals. The proposed method is typically compared to a so-called “anchor”, which follows precise common test conditions, as defined in [13].

The objective evaluation follows this process: intermediate views, corresponding to a location and orientation that have a source view (*i.e.* that were captured by a camera), are produced by the renderer, from the decoded texture and depths. All such views, and only such views are considered for the objective evaluation, which allows to use full-reference objective metrics. This limits however the evaluation to be performed on a restricted number of camera locations and orientations.

At the beginning of the project, intermediate views on non-captured positions were computed from original content, to serve as a reference for intermediate views synthesized after decoding. This appeared however to be a weak process, given that the references were containing synthesis artifacts, and that the process couldn’t allow to evaluate the improvements of a proposed renderer.

The proposal is compared with the anchor results, by reporting the scores for the following metrics:

* WS-PSNR, applied to omni-directional and perspective views. For perspective views WS-PSNR reduces to regular PSNR.
* VMAF, using the 4K model,
* IV-PSNR [14], a full-reference metric based on the PSNR, with two major changes: 1- “pixel shift”, that considers that edges of the objects in the synthesized view may be shifted due to rounding errors, and 2- “global color shift”, that considers that different input views may have various color characteristics.

The comparison of proposals with the anchors is expressed in terms of BD rate computed on low and medium bitrate rate-distortion curves. The average over each source view of the metric between the intermediate view synthesized from decoded atlases and the original/non-compressed source views is considered, along with the total bitrate required to encode the views (including depths) for all frames.

The texture QPs defined for the anchor are defined per sequence, to reach a specific bitrate range (from 50Mbps to 5Mbps). When the proposed method implies bitrate changes compared to the anchor, it might happen that the computed BD-rate returns a zero value, due to insufficient overlap of the two bitrate vs. metric curves. When this situation occurs for a specific sequence, the proponent should:

* Generate, for the proposal and this sequence specifically, a new point corresponding to a QP0 or QP6 to fall back in the desired bitrate range and allow the BD-rate computation to provide a realistic result. QP0 and QP6 are defined as:
* Report in the template the results corresponding to the 5 consecutive QPs that have the largest overlap with the target bitrate range (for instance, QP0, QP1, QP2, QP3, QP4).

When the BD-rate computation still returns a zero value, with the process described above, no average over all sequences will be calculated for this metric.

## Subjective evaluation

The MIV group currently has limited confidence in the three objective metrics described above. To take decisions on adoptions the group systematically relies on a so-called “informal viewing session”, held during a meeting.

Each sequence is synthesized according to a set of pose traces. A pose trace, as represented in the figure below, specifies for each frame the position and orientation of the viewport to synthesize. The purpose is to mimic natural viewing on a head-mounted display while using offline tools and a 2D monitor.

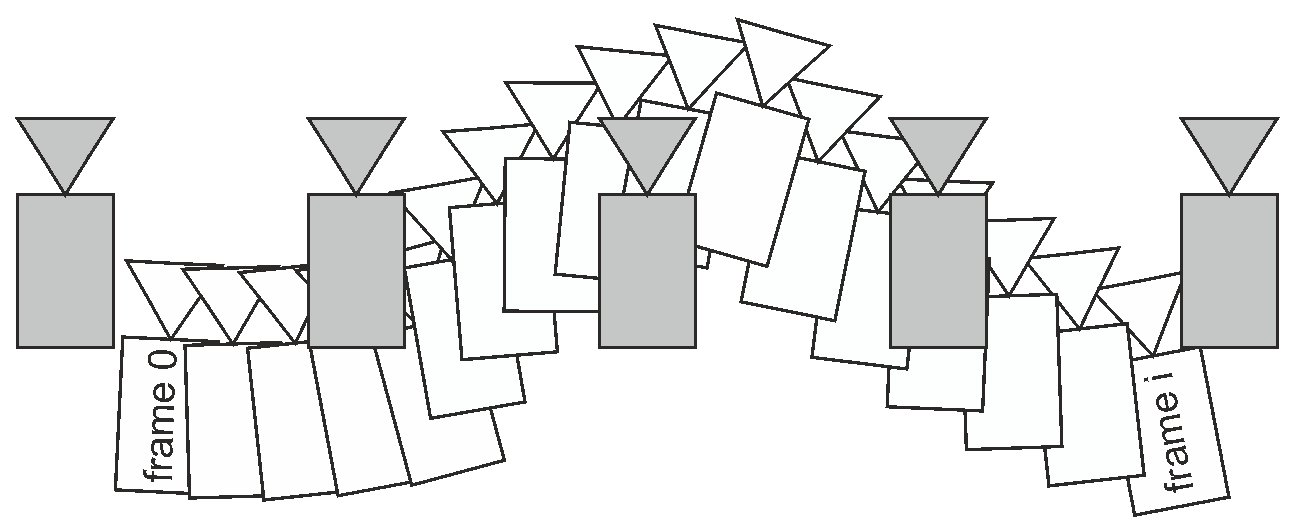


Fig. 1. The concept of pose trace (gray – input views, white – intermediate views).

Because of the large difference in visual comfort between a viewer that voluntarily initiates head motion versus a viewer watching the same viewport on a 2D monitor, pose traces have a small amount of motion. For each sequence there are three pose traces which are meant to represent a diversity of natural head movement compliant with the overall dimension of the capture rig.

The TMIV decoder is configured to extend the video to 300 frames (10 seconds length) by mirroring the 97-frame sequences, that the MIV common test conditions require to process by proponents.

For adoption of a proposed method, the proponent must:

* Be able to show any pose trace of the proposed method, during an informal viewing session.
* Be able to show, during the presentation of the contribution, any pose trace, in a side-by-side mp4 format including the anchor, and make it clear what the bitrate and pixel-rate differences with the anchor are.

The informal viewing session itself generally consists in watching several side by side pose trace, and experts commenting on noticeable artifacts. The process is not intended to provide any score or ranking, but rather to decide whether the proposal improves the anchor or not. This is currently done without meeting any recommendation on viewing conditions, in a non-blind way, with comments shared publicly among the viewers. It is obviously a process that can be significantly improved, to provide more reliable conclusions.

# Point Cloud Content

## Introduction

This section comprises a collection of quality metrics and evaluation methodologies for point cloud content.

## A color-based objective quality metric for point cloud contents [8]

**Abstract**: In recent years, point clouds have gained popularity as a promising representation for volumetric contents in immersive scenarios. Standardization bodies such as MPEG have been developing new compression standards for point cloud contents to reduce the volume of data, while maintaining an acceptable level of visual quality. To do so, reliable metrics are needed in order to automatically estimate the perceptual quality of degraded point cloud contents. Whereas several objective metrics have been developed to assess the geometrical impairment of degraded point cloud contents, fewer publications have been devoted to evaluating color artifacts. In this paper, we propose new color- based objective metrics for quality evaluation of point cloud contents. Our work extracts color statistics from both reference and degraded point cloud contents, in order to assess the level of impairment. Using publicly available ground-truth data, we compare the performance of our proposed work with state-of-the- art metrics, and we demonstrate how the color metrics are able to achieve comparable results with respect to widely adopted solutions. Moreover, we combine color- and geometry-based metrics in order to provide a global quality score. The novelty of our works resides in simultaneously taking both degradation types into account, while being independent of the rendering process. Results show that our solution is able to overcome the limitations of focusing on only one type of degradation, achieving better performance with respect to current metrics.

## A reduced reference metric for visual quality evaluation of point cloud contents [9]

**Abstract**: Point cloud representation has seen a surge of popularity in recent years, thanks to its capability to reproduce volumetric scenes in immersive scenarios. New compression solutions for streaming of point cloud contents have been proposed, which require objective quality metrics to reliably assess the level of degradation introduced by coding and transmission distortions. In this context, reduced reference metrics aim to predict the visual quality of the transmitted contents, while requiring only a small set of features to be sent in addition to the streamed media. In this paper, we propose a reduced reference metric to predict the quality of point cloud contents under compression distortions. To do so, we extract a small set of statistical features from the reference point cloud in the geometry, color and normal vector domain, which can be used at the receiver side to assess the visual degradation of the content. Using publicly available ground-truth datasets, we compare the performance of our metric to widely-used full reference metrics. Results demonstrate that our metric is able to effectively predict the level of distortion in the degraded point cloud contents, achieving high correlation values with respect to subjective scores.

## Towards 6dof http adaptive streaming through point cloud compression [10]

**Abstract**: The increasing popularity of head-mounted devices and 360° video cameras allows content providers to offer virtual reality video streaming over the Internet, using a relevant representation of the immersive content combined with traditional streaming techniques. While this approach allows the user to freely move her head, her location is fixed by the camera's position within the scene. Recently, an increased interest has been shown for free movement within immersive scenes, referred to as six degrees of freedom. One way to realize this is by capturing objects through a number of cameras positioned in different angles, and creating a point cloud which consists of the location and RGB color of a significant number of points in the three-dimensional space. Although the concept of point clouds has been around for over two decades, it recently received increased attention by ISO/IEC MPEG, issuing a call for proposals for point cloud compression. As a result, dynamic point cloud objects can now be compressed to bit rates in the order of 3 to 55 Mb/s, allowing feasible delivery over today's mobile networks. In this paper, we propose PCC-DASH, a standards-compliant means for HTTP adaptive streaming of scenes comprising multiple, dynamic point cloud objects. We present a number of rate adaptation heuristics which use information on the user's position and focus, the available bandwidth, and the client's buffer status to decide upon the most appropriate quality representation of each object. Through an extensive evaluation, we discuss the advantages and drawbacks of each solution. We argue that the optimal solution depends on the considered scene and camera path, which opens interesting possibilities for future work.

## Objective and Subjective QoE Evaluation for Adaptive Point Cloud Streaming [11]

**Abstract**: Volumetric media has the potential to provide the six degrees of freedom (6DoF) required by truly immersive media. However, achieving 6DoF requires ultra-high bandwidth transmissions, which real-world wide area networks cannot provide today. Therefore, recent efforts have started to target efficient delivery of volumetric media, using a combination of compression and adaptive streaming techniques. It remains, however, unclear how the effects of such techniques on the user perceived quality can be accurately evaluated. In this paper, we present the results of an extensive objective and subjective quality of experience (QoE) evaluation of volumetric 6DoF streaming. We use PCC-DASH, a standards-compliant means for HTTP adaptive streaming of scenes comprising multiple dynamic point cloud objects. By means of a thorough analysis, we investigate the perceived quality impact of the available bandwidth, rate adaptation algorithm, viewport prediction strategy and user's motion within the scene. We determine which of these aspects has more impact on the user's QoE, and to what extent subjective and objective assessments are aligned.

# Annex A – Classification of contributions per N19512

**Editor’s note**: This annex maintains the Classification of contributions per N19512 [12].

Since the area of Quality of Immersive Media is broad, a first attempt to classify the input contributions is given in this section. This could help in the understanding of what topics are covered by the inputs, where the major emphasis has been placed and what are the current hot topics in the area. Possibly, this classification will also help in shaping the future goals of the AHG.

In the following table the items have been clustered with a colour according to whether the work was target to immersive 3DoF or 6DoF video or generic 2D video. Further, columns for indicating whether the work is about subjective and objective quality assessment have been added.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Document number** | **Title** | **Subjective quality assessment** | **Objective quality assessment** | **3DoF** | **6DoF** | **Notes** |
| M54398 | Test Plan for Quality Assessment of 360-degree Video. Phase 1: Short sequences | X |  | X |  | Based on a new forthcoming ITU-T standard (P.360) |
| M41303 | [MPEG-I Quality] Similarity Ring Metric (SRM) for Subjective Evaluation of 360-Degree Video | X |  | X |  | Metric to assess within- or between-subject correlation during test sessions. |
| M54771 | Predicting Tolerance to Velocity Mismatch Between Virtual and Physical Head Rotation in Virtual Reality | X |  | X |  | Metric for human virtual velocity loss and tolerance. |
| M54344 | Objective Metric for Predicting the Perceptual Quality of Immersive Video |  | X | X |  |  |
| M54451 | Comparing the Quality of Highly Realistic Digital Humans in 3DoF and 6DoF: A Volumetric Video Case Study | X |  |  | X | Comparison of V-PCC and an octree-based anchor codecs. |
| M54361 | On quality evaluation for MIV (MPEG Immersive Video) activity | X | X |  | X | Subjective assessment was not formal.  Specific for MPEG MIV |
| M54479 | A Subjective Study for Volumetric Video Compression Comparing Textured Meshes and Coloured Point Clouds | X |  |  | X | Comparison of textured meshes and coloured point clouds. There is lack of quality metrics. |
| M54315 | Report of CE on Immersive Media Metrics for PCC Distribution |  | X |  | X | Metrics for PCC distribution |
| M54381 | [DNNVC] Learned Visual Quality Assessment for Image and Video Compression |  | X | - | - | Deep learning-based quality metrics for generic 2D video and images. |

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