Quality of Experience Evaluations for Multi-cloud Streaming

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Abstract

Point clouds are widely used in immersive multimedia systems because they can be acquired in real time using sensors like LiDAR (Light Detection and Ranging) or Time-of-Flight (ToF) cameras, which makes them ideal for building realistic and interactive 3D experiences. However, their large size introduces challenges for compression and streaming, especially in complex scenes with multiple objects viewed through head-mounted displays (HMDs). This paper presents two experimental applications developed for two recent underinvestigated HMDs: the Apple Vision Pro and Meta Quest 3. The first application allows users to view compressed dynamic point clouds and rate their perceived visual Quality of Experience (QoE) using a simple hand-based interface. The second application focuses on complex 3D scenes with multiple point clouds and supports the development of an adaptive streaming algorithm that optimizes the QoE based on the user's view and system constraints. These tools aim to support future research on immersive content delivery in extended reality (XR), with possible applications in tourism and cultural heritage.

Introduction

Point clouds (PCs) are a key content format in immersive applications thanks to their ability to represent 3D scenes with high realism and freedom of exploration. Each point in a PC includes geometric and visual attributes that enable a full six degrees of freedom (6DoF) experience. However, the size of PC data is typically very large, which makes compression essential. Two standard methods have been defined by MPEG: Video-based Point Cloud Compression (V-PCC) and Geometry-based Point Cloud Compression (G-PCC) (Graziosi et al., 2020).

Although these techniques reduce data volume, they also introduce visual artifacts that can affect the user's Quality of Experience (QoE). Several studies have investigated this trade-off, but mostly by showing single compressed point clouds on 2D screens or on a limited set of head-mounted displays (HMDs) such as Oculus Rift (Subramanyam et al., 2020; Viola et al., 2022), HoloLens (Nguyen et al., 2024; Fan et al., 2024; Nguyen et al., 2023), HTC Vive (Wu et al., 2021; Gutierrez et al., 2023; Alexiou et al., 2020), and Meta Quest 2 (Van Damme et al., 2023). There is still a lack of studies that consider new-generation devices like the Apple Vision Pro and Meta Quest 3. At the same time, current solutions do not consider scenes composed of multiple PCs, which are common in real applications such as virtual tourism, cultural heritage, or remote collaboration. These multi-object scenes require more advanced streaming strategies. While some recent works proposed adaptive streaming methods that prioritize parts of a PC based on the user's attention (Li et al., 2020 & 2023; Wang et al., 2023), they typically assume the presence of a single PC and do not address the problem of dynamically managing multiple PCs with different levels of detail (LoD).

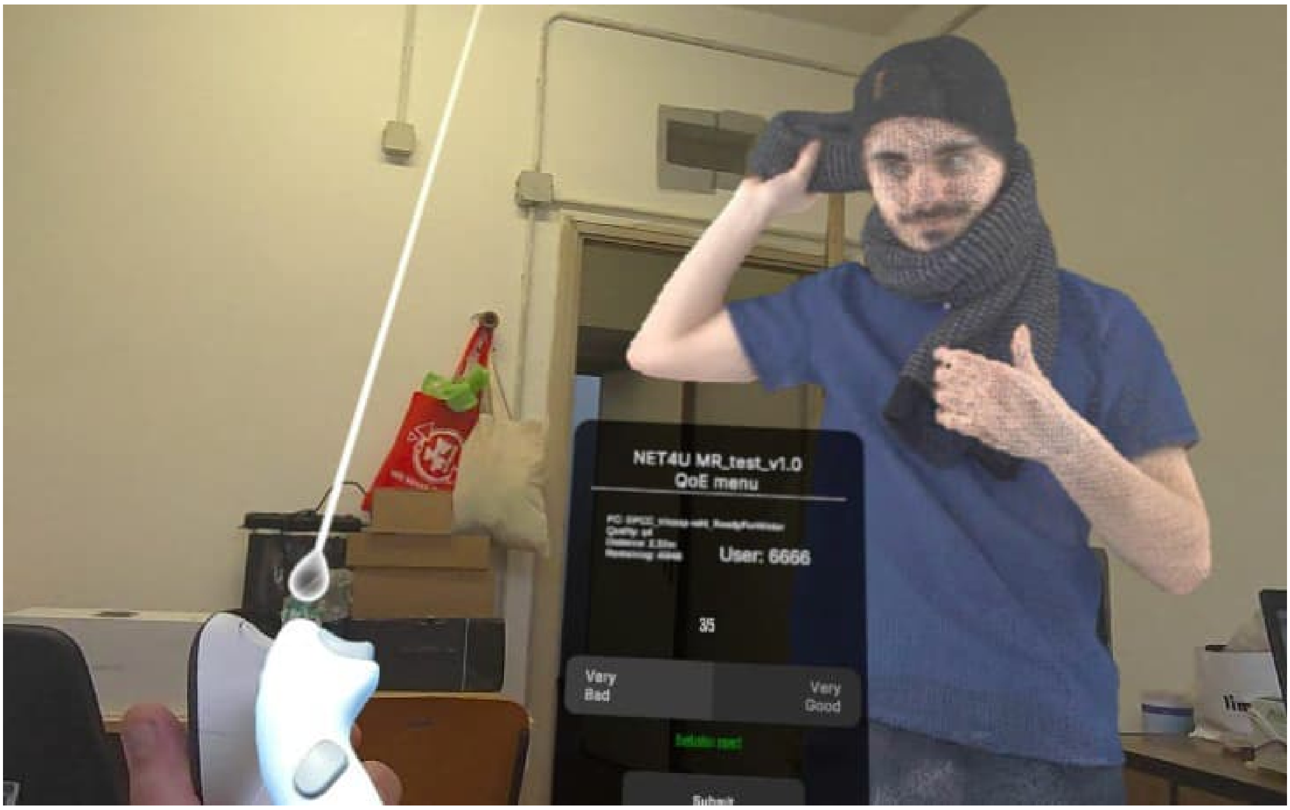

Figure P 21*. A point cloud displayed in XR mode using the Meta Quest 3.*

In this work, we propose a twofold contribution. First, we developed an application to display and evaluate compressed PCs on the Apple Vision Pro and Meta Quest 3 HMDs. This app allows for subjective assessments on devices that have not yet been considered in previous studies. Second, we developed an additional application, compatible with the two HMDs, designed to render scenes that include multiple PCs compressed at different LoDs and placed at various distances from the user's point of view. This app supports the development of a new adaptive streaming algorithm that adjusts the quality of each object based on user's attention, network conditions, HMD's rendering capabilities, and object distance from the user's point of view. Together, these tools provide a framework for studying QoE in complex immersive environments and improving the efficiency of streaming in extended reality (XR) applications.

Application 1: QoE Evaluation of Compressed Point Clouds on Modern HMDs

The first application allows to understand how users perceive the quality of 3D dynamic PCs. The PC is shown on two of the most advanced headsets currently available: the Apple Vision Pro and the

Meta Quest 3. To this aim, we used the public dataset ComPEQ-MR[19], which includes a variety of PCs previously used for quality assessment in mixed reality scenarios (Nguyen et al., 2024). The PCs selected from the dataset were compressed using the two MPEG-standard methods: G-PCC and V-PCC (Graziosi et al., 2020). To present this content in an immersive environment, we developed a custom cross-platform application in Unity (showed in Figure P 21), compatible with both Apple Vision Pro and Meta Quest 3.

The application was designed to support natural hand interaction without requiring physical controllers. Users can move freely within the XR scene, observe the dynamic PC content, and provide a subjective quality rating using a 5-point Absolute Category Rating (ACR) scale. The interface allows intuitive and direct selection of scores using hand gestures. This setup enables the collection of QoE scores in realistic XR conditions on under-investigated HMDs, contributing to a more comprehensive understanding of how compression impacts user experience in next-generation immersive systems.

Application 2: Streaming of Multiple Point Clouds with Adaptive Quality

The second application focuses on scenes that contain multiple PCs shown at the same time. This type of setup reflects real use cases, such as virtual tours or remote visits to museums and cities. Thus, we created a new dataset that includes 3D PCs of selected artworks (sound stones) by the Sardinian artist Pinuccio Sciola, as illustrated in Figure P 22. These artworks were acquired using high-resolution photogrammetry to preserve both texture and geometric details. After the acquisition, the PCs were compressed using the V-PCC and G-PCC methods, each at different LoD. The compressed PCs were then placed in virtual scenes, with some PCs positioned in the foreground and others in the background. These scenes were used to build new applications for Apple Vision Pro and Meta Quest 3, allowing users to explore complex environments.

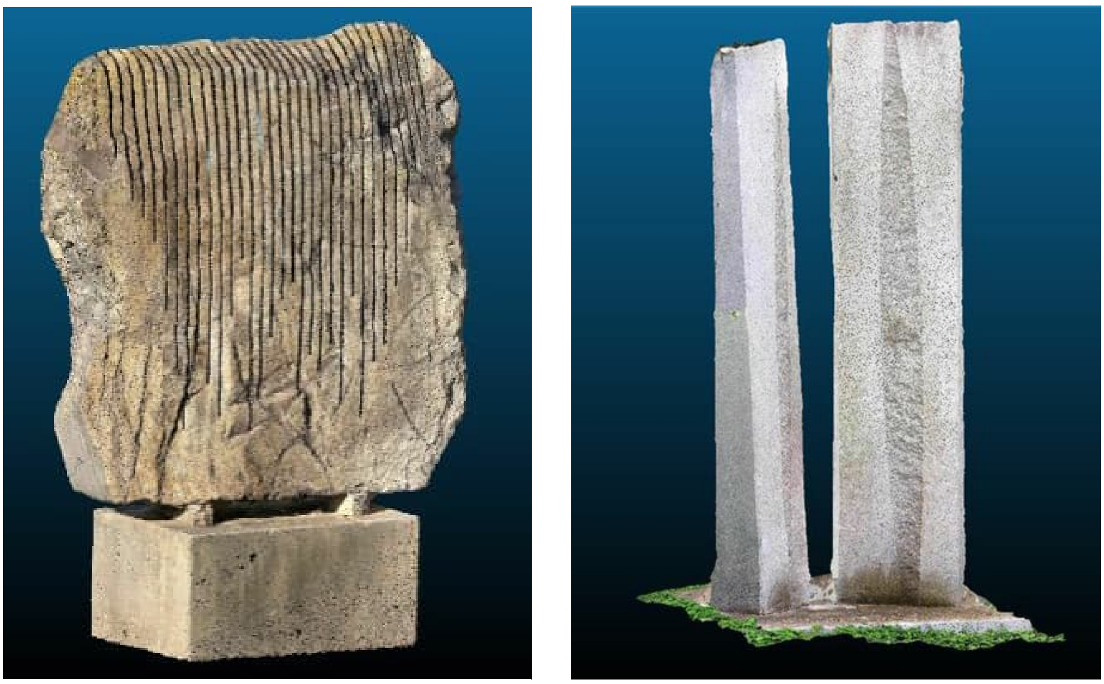

Figure P 22. *Two PCs representing the selected sound stones created by the artist Pinuccio Sciola.*

[19] https://ftp.itec.aau.at/datasets/ComPEQ-MR/

The goal of this application is to support the development of a new adaptive streaming algorithm. This algorithm will adjust the quality of each point cloud based on the user's field of view, the number of visible objects, the available network bandwidth, and the rendering capacity of the HMD. The idea is to show high quality PCS only where needed, reducing bandwidth usage while keeping the experience smooth and immersive.

Conclusions

This work presents two experimental applications designed to explore how PC compression and scene complexity affect QoE in XR environments. In both cases, we developed apps for Apple Vision Pro and Meta Quest 3, which are currently among the most widespread HMDs. The first application focuses on the evaluation of single dynamic PCs, allowing users to rate visual QoE using hand gestures. The second application introduces more complex scenes with multiple PCs and supports the design of a new adaptive streaming algorithm. These tools create a solid base for future subjective studies on new-generation headsets and for improving immersive streaming in real use cases such as virtual tourism.

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