STEP-MR: A Subjective Testing and Eye-Tracking Platform for Dynamic Point Clouds in Mixed Reality

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1 Introduction

STEP-MR builds upon our previous platform (Vats et al., 2023), improving on the subjective testing functionality and adding the ability to conduct eye-tracking tests along with heatmap generation. The platform continues to use Unity[1] and the Mixed Reality Toolkit (MRTK) 2[2] framework from Microsoft as its basis. Since the first version is already explained in the previous publication, this paper focuses majorly on the changes made to the platform since.

STEP-MR was also used for a study on subjective perception and saliency of dynamic point clouds, the result of which are available in (Nguyen et al., 2024). Finally, STEP-MR can be found at https://github.com/shivivats/MR-Subjective-Testing-Platform.

2 Proposed Platform

The architecture of STEP-MR is shown in Figure 1. We continue to utilize Holographic Remoting[3] from MRTK 2 to communicate between the workstation and the HoloLens 2. This allows us to perform the bulk of the computations on the former, while the latter serves primarily as an input/output device.

STEP-MR has three major functionalities: *(i)* point cloud previewing, *(ii)* subjective tests, and the newly added *(iii)* eye-tracking tests.

[1] Version 2021.3.19f1. https://unity.com/. Accessed: 06 July 2025.
[2] https://github.com/microsoft/MixedRealityToolkit-Unity. Accessed: 06 July 2025.
[3] https://learn.microsoft.com/en-us/windows/mixed-reality/develop/native/holographic-remoting-overview. Accessed: 06 July 2025.

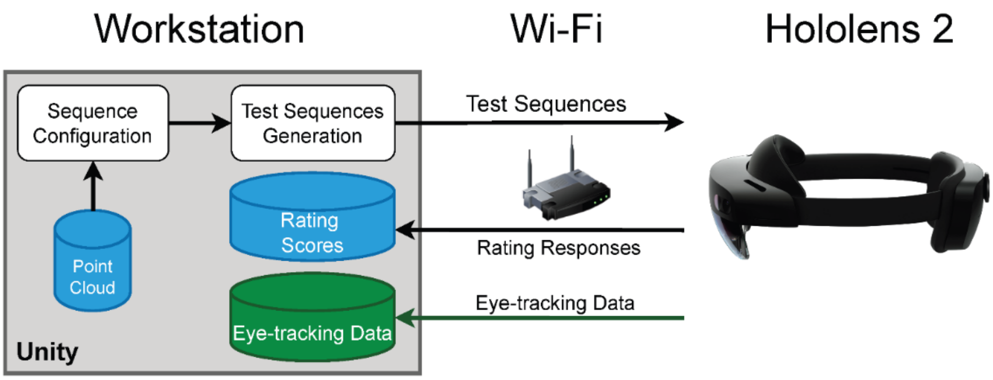

Figure 1. System architecture illustrating the use of Unity to configure point clouds (PCs) and the HoloLens 2 to display the dynamic PC sequences and relay user input back to Unity. Communication between Unity and the HoloLens 2 occurs via Wi-Fi.

2.1 Point Cloud Previews

The point cloud preview functionality has undergone only minor user-facing changes, namely *(i)* the quality slider has been replaced with buttons for ease of use, and *(ii)* the mesh option is removed, since we focused our research solely on point clouds. For working with meshes, the first version of STEP-MR can still be used.

Additionally, the back-end functionality of previewing scenes has been modified for demonstration purposes. To this extent, the controls of the configuration menu have also been bound to the keyboard, allowing the demonstration controller to adjust the point cloud (PC) configurations. This enables participants to experience the dynamic PC (DPC) content without needing to interact with the HoloLens 2 controls, which they might not be familiar with.

Finally, a general user experience change to the platform as a whole shows up when previewing scenes as well. The point cloud objects are now represented by Unity ScriptableObjects[4], allowing a PC's data to be stored in the Unity *Assets* folder, enabling easy reusability and adding even more modularity to the design.

2.2 Subjective Tests

Building upon the subjective testing functionality detailed in (Vats et al., 2023), STEP-MR now contains a set of buttons from 1 to 5 that allow the user to input their rating. The buttons replace the quality slider, a change that was made in response to participants' feedback indicating that the slider was difficult to use for people not accustomed to the controls of the HoloLens 2.

Since we wanted the second round of our subjective tests to include participants moving around the dynamic point cloud (DPC) sequences instead of remaining stationary, the quality rating buttons now appear in front of a participant's position the moment the sequence stops. This allows for immediate feedback from the participants. However, they are still required to go to a fixed location to start viewing the next sequence.

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[4] https://docs.unity3d.com/2021.3/Documentation/Manual/class-ScriptableObject.html. Accessed: 06 July 2025.

Additionally, the DPC frames are loaded dynamically into memory. When the subjective test begins, the order of the sequences is randomized and only the next five sequences are loaded into memory. The last played sequence is unloaded from memory, significantly reducing RAM usage. This optimization allowed STEP-MR to be run from a laptop with 32 GB of DDR5-4800 MHz memory compared to a workstation with 64 GB memory of similar speed for the previous round of tests, further adding to the ease-of-use and modularity of the platform.

More information on the subjective testing methodology and how STEP-MR was used to perform the tests is found in (Nguyen et al., 2024).

2.3 Eye-Tracking

The eye-tracking functionality is the most significant addition to STEP-MR. It consists of error measurement, point cloud viewing, fixation map generation, and heatmap visualization. A brief overview of these functionalities is given below. The eye-tracking testing methodology and data processing workflow are further described in (Nguyen et al., 2024).

Error Measurement. Since the tool GazeMetrics (B. Adhanom et al., 2020) is not available for the HoloLens 2, we implemented this functionality ourselves. Nine 5 cm large spherical markers are placed 2 m away from the participant and displayed for 3 s each. The participant is asked to look at the markers as soon as they appear. The error data is stored as a CSV file per participant. The positioning and duration of the markers can be customized by the platform user.

Point Cloud Viewing. This functionality involves playing back the DPC sequences for the participant to walk around and observe. To minimize bias, the order of the sequences and the PCs' rotation at the start of a sequence are both randomized. The participant's gaze origin and gaze direction are saved every frame to a CSV file per PC. Users of STEP-MR can control which PCs are displayed and how much the rotation of the PC is randomized.

Fixation Map Generation. The fixation maps are generated by processing the eye-tracking data using both Unity C# and MATLAB code. The MATLAB scripts are available in the GitHub repository, and are heavily based on the work done in (Zhou et al., 2023) whose authors also collaborated with us on our work with the subjective tests (Nguyen et al., 2024).

Firstly, the eye-tracking data is processed in a separate Unity scene. The Dispersion Threshold Identification (I-DT) (Salvucci & Goldberg, 2000) method is used, and the parameters for it are made available to STEP-MR users to customize. The results from this step are stored in a folder on the disk which the MATLAB scripts then access to further process the data into fixation maps.

Heatmap Visualization. The fixation maps are loaded back into the Unity scene for data processing. PCs are played back as DPCs in the highest quality, and fixation heatmaps are visualized on the PC objects per frame. Screenshots of the heatmaps are captured from the front, back, left, and right views of the PCs. Users can customize the heatmap colors to suit their preferences.

3 The Demonstrator

First, the participant will be able to use the PC preview scene mode to display and interact with various DPCs in different representations via the HoloLens 2. The presenter will help the participant by controlling the DPC sequences using the keyboard as needed.

Secondly, the participant will gain insight into the workings of the subjective testing functionality, by participating in a short test. The test will consist of a handful of DPC sequences, allowing the participant to experience the full workflow, from viewing the sequences to rating the DPCs based on the participant's observations.

Finally, the participant will experience the eye-tracking tests, starting with the error measurements, viewing some DPC sequences, and then being able to see the heatmap of their eye movements after a short wait.

4 Conclusion and Future Work

This paper has described STEP-MR, a platform for subjective and eye-tracking testing of dynamic point clouds in MR environments. Users of STEP-MR can preview different configurations of PCs, configure and perform subjective quality tests with DPC sequences and configure, perform and analyze the results of saliency tests via eye-tracking. Potential future work involves implementing double-stimuli tests and recording eye-tracking data during the subjective tests.

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References

B. Adhanom, I., Lee, S. C., Folmer, E., & MacNeilage, P. (2020). GazeMetrics: An Open-Source Tool for Measuring the Data Quality of HMD-based Eye Trackers. *ACM Symposium on Eye Tracking Research and Applications*, 1–5. https://doi.org/10.1145/3379156.3391374

Nguyen, M., Vats, S., Zhou, X., Viola, I., Cesar, P., Timmerer, C., & Hellwagner, H. (2024). ComPEQ-MR: Compressed Point Cloud Dataset with Eye Tracking and Quality Assessment in Mixed Reality. *Proceedings of the 15th ACM Multimedia Systems Conference*, 367–373. https://doi.org/10.1145/3625468.3652182

Salvucci, D. D., & Goldberg, J. H. (2000). Identifying fixations and saccades in eye-tracking protocols. *Proceedings of the 2000 Symposium on Eye Tracking Research & Applications*, 71–78. https://doi.org/10.1145/355017.355028

Vats, S., Nguyen, M., Van Damme, S., van der Hooft, J., Vega, M. T., Wauters, T., Timmerer, C., & Hellwagner, H. (2023). A Platform for Subjective Quality Assessment in Mixed Reality Environments. *2023 15th International Conference on Quality of Multimedia Experience (QoMEX)*, 131–134. https://doi.org/10.1109/QoMEX58391.2023.10178443

Zhou, X., Viola, I., Alexiou, E., Jansen, J., & Cesar, P. (2023). QAVA-DPC: Eye-Tracking Based Quality Assessment and Visual Attention Dataset for Dynamic Point Cloud in 6 DoF. *2023 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 69–78. https://doi.org/10.1109/ISMAR59233.2023.00021