Assessing Visual Defect Saliency on 3D Meshes Through Gaze-Based Metrics

Le Mans Université · UMR IRISA · LIUM Laboratoire d'Informatique Le Mans Université · Inria

Sonain Jamil[1] Julien Pettré[2] Sébastien Iksal[1] Erwan David[1]

[1] LIUM, Le Mans Université, France · [2] Univ Rennes, Inria, CNRS, IRISA, France

01 Context & Motivation

- Immersive 3D content is central to **technology-enhanced learning, training & simulation** — where visual realism affects engagement and performance. [1]
- Unintended **geometric artifacts may act as local distractors**, diverting attention and adding cognitive load. [2]
- Mesh quality is still often judged by **explicit ratings & global metrics** that miss *localized* perceptual effects. [3, 4]

OPEN QUESTION

How do localized geometric distortions translate into *measurable perceptual disruption* during interactive viewing?

02 State of the Art

MESH QUALITY ASSESSMENT

Often **subjective ratings & global similarity metrics** — good for overall quality, but blind to *localized* effects during interaction. [3, 4]

GAZE & VISUAL SALIENCY

Attention is sensitive to structural irregularities; mesh distortions & saliency cues shift gaze — yet **defect-level analysis under free interaction stays limited** . [5, 6]

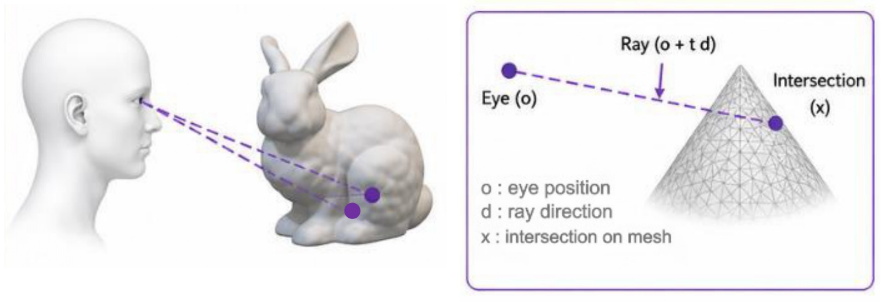
GAZE IN 3D & SURFACES

Image-plane & fixed-viewpoint methods can't anchor gaze to geometry under rotation; recent toolboxes (Salient360!, Plume) map gaze onto **surfaces**. [7-10]

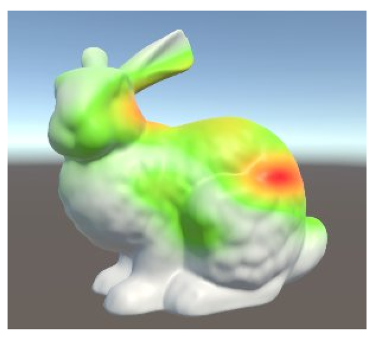
THE GAP → OUR APPROACH

Localized, defect-level, interaction-aware gaze analysis anchored to mesh geometry — combining **surface projection** with **vertex-level AOIs**.

OBSERVATION & PROJECTION



Gaze rays are casted from observer and intersect the mesh surface. Intersection points are used for surface-based analysis.



GEOMETRIC DISTORTIONS

Same object with different types of distortion

03 Approach

Surface-based gaze projection. Eye-tracking samples are mapped onto the **visible 3D mesh surface** as the user freely rotates and zooms — keeping attention analysis **view-consistent** and geometry-anchored, unlike image-plane or fixed-viewpoint methods [8]

- **Vertex-level AOI encoding.** Defect regions are marked on vertices (mesh-colors [11]); AOI hit when a gaze raycast intersects a defect vertex.

04 Study Design

22 participants — 17 Males, 4 Females, 1 Undisclosed; 18-21 years old, M = 19.32, SD = 0.87

27 textureless meshes [5]

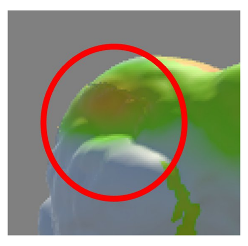
4 defect types — SI Self-intersection, SM Smoothing, LP Low-polygon, SE Semantic, + unmodified meshes

135 stimuli (27 × 5) seen in **one of the 5** conditions

Apparatus. Tobii Pro Fusion @ 120 Hz · 2560×1440 @ 60 Hz · 60–65 cm chin rest · stimuli in Unity · **10s of free interactive viewing** (rotate & zoom) per mesh. The full protocol lasted **~20 min** ; a "gaming-habit" questionnaire was administered to control for video-gaming effects.

05 Results

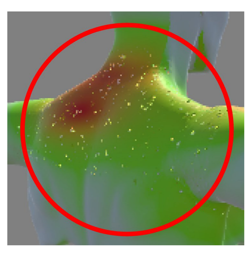
Median AOI metrics, modified vs. matched normal · Wilcoxon signed-rank



Self-intersection SI

STRONG CAPTURE

3.5× more fixations, longer dwell time & more refixations → sharp geometric inconsistency reliably grabs gaze.



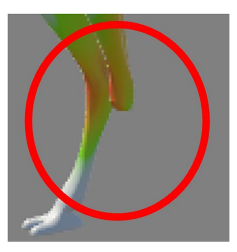
Smoothing SM

NO EFFECT

Low-polygon LP

SCANPATH SHIFT

Fewer fixations, plus shorter forward-saccade sequences (FSSL ↓, p=.013) [12] → disrupts how gaze flows, not where it lands.



Semantic SE

NO EFFECT

DEFECT	FIX. M/N (count)	p	TFF M/N (s)	p
Self-intersection	7 / 2	<.001 ★	2.83 / 3.15	.250
Smoothing	3 / 2	.110	3.35 / 3.38	.724
Low-polygon	0 / 1	.006 ★	3.23 / 3.96	.978
Semantic	0 / 0	.320	4.38 / 5.29	.987

★ **significant** ($p < .05$)
FIX = fixation count on defect AOI · **TFF** = time-to-first-fixation on AOI (s)
M = modified, **N** = matched normal.
Saccade amplitude & direction *stayed stable across all conditions.*

06 Two Levels of Disruption

WHERE — FIXATIONS

Self-intersections capture attention *locally*.

Strong geometric inconsistencies draw repeated fixations to the defect region.

HOW — SCANPATHS

Low-polygon defects disrupt *gaze flow*.

Without attracting fixations, they shorten forward-saccade sequences [12] → altering exploration patterns over time.

TAKEAWAY Gaze can **differentiate the perceptual effect** on visual attenton of mesh defects in **2 out of 4** geometric defect types.
→ **Data for perceptually-grounded QoE** of interactive 3D content, with direct implications for simulation fidelity in education & training.

07 Future Directions

SALIENCY MODELS vs. GAZE

Benchmark computational **saliency predictions against measured gaze** → testing whether models can flag defects automatically.

VR REPLICATION · N = 40

We just finished running a 40-participant VR study → weighing the gain of a full **VR set-up against a simpler desktop** protocol.

DEFECT STRENGTH THRESHOLD

Parametrically vary **defect strength** to locate the per-defect threshold at which gaze begins to react.

TOP-DOWN TASK · IN SITU

Vary **top-down task demands** and test **in situ** within real learning scenarios → beyond free viewing.

REFERENCES

[1] J. Radianti et al., "A systematic review of immersive virtual reality applications for higher education: design elements, lessons learned, and research agenda," *Computers & Education*, 2020.

[2] G. Makransky & G. B. Petersen, "The cognitive affective model of immersive learning (CAMIL): a theoretical research-based model of learning in immersive virtual reality," *Educational Psychology Review* , 2021.

[3] G. Lavoué & R. Mantiuk, "Quality assessment in computer graphics," in *Visual Signal Quality Assessment: Quality of Experience (QoE)* , Springer, 2014.

[4] Y. Nehmé et al., "Visual quality of 3D meshes with diffuse colors in virtual reality: subjective and objective evaluation," *IEEE TVCG*, 2020.

[5] G. Lavoué, F. Cordier, H. Seo & M.-C. Larabi, "Visual attention for rendered 3D shapes," *Computer Graphics Forum* , 2018.

[6] J. Guo, V. Vidal, A. Baskurt & G. Lavoué, "Evaluating the local visibility of geometric artifacts," in *Proc. ACM SIGGRAPH Symp. Applied Perception* , 2015.

[7] M. Abid, M. P. Da Silva & P. Le Callet, "Towards visual saliency computation on 3D graphical contents for interactive visualization," in *IEEE ICIP*, 2020.

[8] M. Maurus, J. H. Hammer & J. Beyerer, "Realistic heatmap visualization for interactive analysis of 3D gaze data," in *Proc. ETRA*, 2014.

[9] E. David et al., "The Salient360! toolbox: handling gaze data in 3D made easy," *Computers & Graphics* , 2024.

[10] C. Javerliat, S. Villenave, P. Raimbaud & G. Lavoué, "Plume: record, replay, analyze and share user behavior in 6DoF XR experiences," *IEEE TVCG*, 2024.

[11] C. Yuksel, J. Keyser & D. H. House, "Mesh colors," *ACM Trans. Graphics (TOG)*, 2010.

[12] E. J. David, P. Lebranchu, M. Perreira Da Silva & P. Le Callet, "What are the visuo-motor tendencies of omnidirectional scene free-viewing in virtual reality?," *Journal of Vision*, 2022.

SCAN FOR PAPER

sonainjamil@ieee.org

erwan.david@univ-lemans.fr