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Innovative Applications of Visualization Technologies for Scientists and the Public in Magnetic Confinement Fusion

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This report focuses on technological innovations in visualization within magnetic confinement fusion research, systematically elaborating on the groundbreaking applications of cinematic dynamic simulation, extended reality (XR) interaction, and intelligent 3D reconstruction in device modeling, theoretical demonstration, and scientific communication.

Based on high spatiotemporal resolution physical simulation data from the EAST tokamak, the research team constructed a movie-quality visualization of the formation process of boundary instabilities. This achievement (Symplectic Structure-Preserving Particle-in-Cell Whole-Volume Simulation of Tokamak Plasmas to 111.3 Trillion Particles and 25.7 Billion Grids) was successfully shortlisted as a finalist for the 2021 Gordon Bell Prize (only six global entries were selected) and presented at the virtual Supercomputing Conference (SC21) in St. Louis, Missouri, USA.

In terms of visualization-assisted fusion research, the team developed a 3D reconstruction algorithm based on parallel computing results, extracting the structure of weakly coherent modes (WCM) in I-mode and the filamentary structure of edge-localized modes (ELM) in H-mode. Through a series of mappings and dimensionality reduction techniques that preserved key information, the team successfully rendered these models in XR headsets, enabling scientists to intuitively compare the differences between the two instability structures and closely observe the simulation results.

In the field of engineering visualization, the team focused on the "Keda Torus Experiment" (KTX) device, establishing an intelligent conversion system from CAD drawings to lightweight 3D models. By employing an adaptive mesh simplification algorithm based on geometric feature recognition, the model's face count was reduced to 1% of the original data while maintaining solenoid winding topological accuracy (error < 0.05%). This optimization reduced single-frame rendering loads to within the acceptable latency threshold for Quest 3 headsets. Additionally, the team innovatively developed a cross-platform, multimodal interaction system supporting collaborative work between Vision Pro and Quest 3 devices, with multi-user synchronization latency controlled below 50ms. Using 3D Gaussian Splatting technology, a laboratory-grade digital twin system was constructed, accurately replicating the KTX laboratory at the University of Science and Technology of China (USTC) in virtual space. This provides a high-fidelity platform for future remote experimental rehearsals.

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