XDE (eXtensible Dynamics Engine) - Real-Time Simulation for Advanced Teleoperation

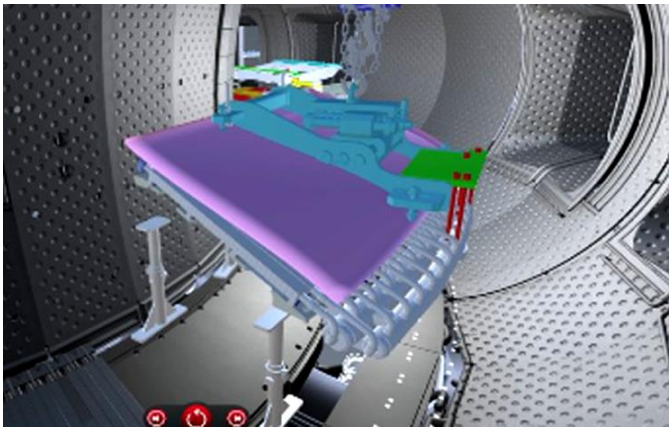
The eXtensible Dynamics Engine (XDE) is a high-performance real-time simulation platform developed by the CEA for precise teleoperation in nuclear fusion reactors. Combining a rapid physical simulation engine with ROS protocols, XDE enables responsive robotic manipulation, enhanced by Extended Reality (XR) for augmented visualization and real-time data overlays. These features improve situational awareness and reduce operator cognitive load. With its modular architecture, XDE is advancing toward physical validation, positioning itself as a powerful solution for nuclear decommissioning and other high-risk applications.

Description of the technology

The eXtensible Dynamics Engine (XDE), developed by the CEA IRFM, is a sophisticated real-time physical simulation platform crafted to address the demands of fusion environments, such as those in the ITER and WEST tokamaks. Unlike conventional simulation engines, XDE is designed specifically for real-time interactions in hazardous and complex settings, where spatial accuracy, responsiveness, and safety are paramount. XDE achieves this by delivering ultra-fast cycle times in the order of milliseconds, which enables fluid manipulation and haptic feedback, essential for teleoperation in high-risk, remote scenarios.

At its core, XDE integrates a physical simulation engine with ROS (Robot Operating System) protocols, which enhances its flexibility in robotic applications. This configuration allows seamless interoperability with various robotic systems, facilitating precise control and movement in real time. In applications within the nuclear fusion sector, XDE's capabilities extend to both operational procedures and maintenance tasks, where fine motor control and spatial awareness are required to interact with intricate systems under extreme environmental pressures, such as radiation and heat. Within the framework of the WEST and ITER projects, XDE has been pivotal for testing and validating the handling of critical components, like the ICRH antennas and the Test Blanket Systems (TBS), through digital simulations and early prototyping.

XDE further distinguishes itself by incorporating Extended Reality (XR) elements, which empower operators with advanced visualisation tools and real-time data integration. By combining virtual overlays and augmented visual feedback, the engine supports operators in navigating confined and visually challenging environments with increased confidence and accuracy. This XR component enables virtual barriers, collision avoidance features, and interactive guides that act as digital assistants, ensuring that complex tasks are performed with reduced human error and enhanced situational awareness. These features address a common challenge in teleoperation: the cognitive strain associated with remote manipulation in visually compromised or spatially restricted environments.



Extended reality device at the IRFM to check the feasibility of assembling components in the West tokamak enclosure and to train operators. @CEA

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Description of the technology

Another distinctive feature of XDE is its modular and extensible architecture, which allows it to adapt and scale to diverse teleoperation needs. The system can incorporate additional modules or interfaces, enhancing its utility across various tasks, from real-time spatial mapping to strategic planning. As XDE progresses through its development phases, particularly with ongoing support from CEA's robotic platform, the technology is evolving to include enhanced user-interface capabilities that further streamline operator interaction.
Furthermore, XDE has been developed with stringent safety protocols, allowing it to operate autonomously in confined, high-radiation spaces. The system's precise simulation capabilities make it invaluable for creating virtual mock-ups of fusion environments, enabling operators to test and refine handling procedures in a controlled, risk-free setting before actual implementation. This virtual testing phase is especially crucial for nuclear applications, as it allows teams to anticipate and mitigate potential issues without exposure to hazardous conditions, thus preserving both equipment integrity and personnel safety.

Through its combination of real-time dynamics, XR integration, and modular flexibility, XDE represents a powerful tool for the fusion industry and beyond, addressing the need for safe and efficient remote handling in some of the world's most demanding environments. As it advances to physical validation, XDE is positioned to redefine teleoperation standards, merging the precision of simulation with the robustness needed for industrial applications.

Example of VR studies carried out at IRFM: Simulation of an intervention in a constrained environment (here the "pipe forest" of ITER's "Test Blanket Module") with an operator wearing a ventilated suit to check the accessibility of a connection (symbolized by the red/green arrows in the image on the right) and parallel recording of the operator's posture (image in the center).

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Innovation and advantages of the offer

Real-Time Interaction: Unlike typical passive simulators, XDE is a dynamic physical simulation engine that allows real-time manipulation, essential for environments with complex spatial constraints and high safety requirements.
Enhanced Operator Support with XR Integration: The incorporation of Extended Reality (XR) features provides operators with augmented visualisations, data overlays, and virtual guidance, reducing the cognitive load associated with remote handling tasks.
Adaptive Control with AI Integration: Future developments foresee AI-driven strategies to enhance decision-making, offering predictive insights and supporting high-stakes, time-sensitive operations.

Non-fusion Applications

Beyond nuclear applications, XDE's real-time simulation capabilities can improve safety and efficiency across several other industries, such as **Chemical and Hazardous Material Handling, Space Exploration,** or **Manufacturing and Assembly Lines,** nuclear decommissioning where operational safety and efficiency are non-negotiable.

EUROfusion Heritage

XDE was developed within the framework of EUROfusion's WP Remote Maintenance program, focusing on the DEMO reactor. This work, under the EUROfusion grant agreement No. 101052520, reflects CEA's ongoing commitment to advancing teleoperation capabilities for challenging fusion environments.
XDE's development aligns with fusion-specific needs for remote handling and maintenance in high-radiation conditions. The technology's effectiveness has been demonstrated in simulated tasks for the WEST tokamak and ITER project components.

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