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Development of Digital Twin for Taiwan's First Spherical Tokamak (FIRST): Simulation, Diagnostics, and Integration Framework

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The Formosa Integrated Research Spherical Tokamak (FIRST) is currently under conceptual and engineering design and will be the first tokamak experiment constructed in Taiwan. At the National Center for High-performance Computing (NCHC), we are developing a digital twin platform for FIRST that integrates plasma simulations, diagnostic modeling, and control-system emulation. This effort is carried out in collaboration with the theory team, which provides fine-tuned magnetic equilibria, and the hardware teams responsible for designing the experimental chamber and associated subsystems.

After first plasma, diagnostic signals—such as magnetic probe measurements, plasma emission spectra, and electrical diagnostics—will be streamed into the digital twin framework. These signals can be processed using physics-based models or AI-inferred microservices to estimate plasma parameters and system behavior. The inferred results can then be compared with experimental measurements to support model validation, diagnostic interpretation, and performance analysis. While strict real-time response is limited by computational and physical constraints, the digital twin will maintain synchronized interaction with the control system: it can receive command signals and generate predictive or inferential feedback to guide experiment planning and analysis.

The system is deployed on the NVIDIA Omniverse platform, where both simulation and experimental data are visualized through the Omniverse Kit interface. Plasma quantities can be rendered using NVIDIA IndeX for enhanced spatial visualization, supporting diagnostic development, scenario evaluation, and public outreach. A preliminary digital laboratory has been built, incorporating realistic 3D models of the tokamak and laboratory environment, along with simplified signal emulation and reduced physical models.

This digital twin infrastructure facilitates experimental design, synchronized monitoring, model validation, and data-driven diagnostics. It also serves as a bridge between simulation and experiment, offering an integrated environment for scientific exploration, operational coordination, and STEM education. Figure 1 presents the development roadmap of the digital twin system for the FIRST project in Taiwan.

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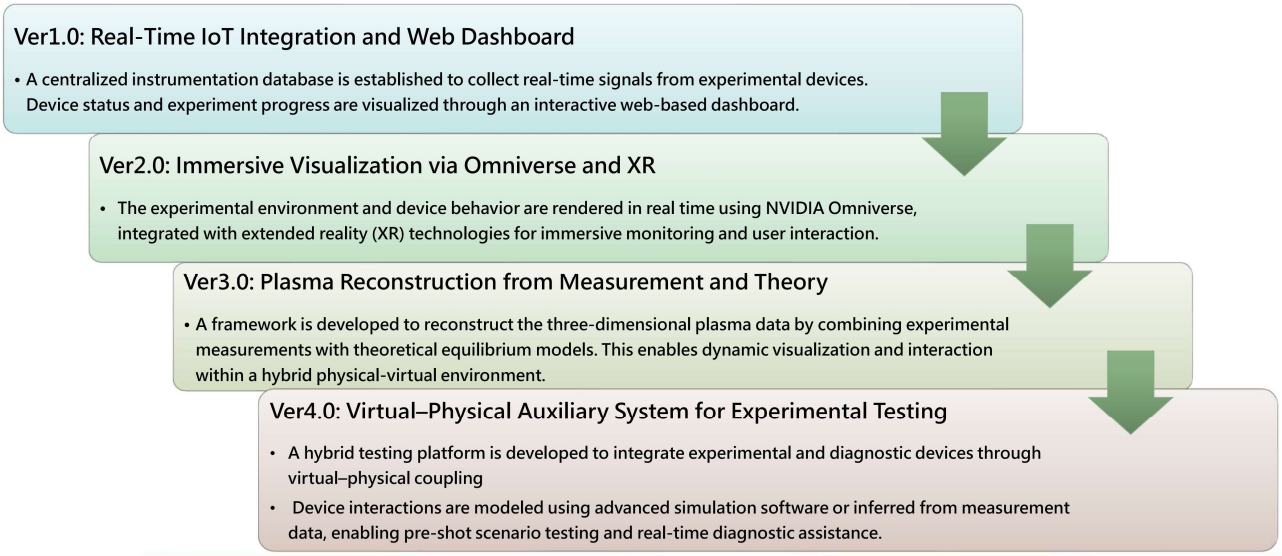

Figure 1. Development roadmap of the digital twin for FIRST in Taiwan, highlighting key stages including real-time IoT integration, immersive visualization, plasma data reconstruction, and a virtual–physical auxiliary system for experimental testing.