Data-Assimilation-Based Tokamak Plasma Prediction System

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Future fusion plasma control will require multivariate control strategies that simultaneously optimize multiple actuators and regulate various physical quantities, while accounting for their mutual interactions. These control strategies must rely on accurate plasma state estimation using limited diagnostics. A promising approach to achieve this is model predictive control using integrated simulation codes. However, the modules within these codes involve uncertainties arising from various approximations and assumptions in the underlying physical models. These uncertainties interact with each other and degrade the accuracy of simulation results. Furthermore, many physical phenomena are not accounted for in the codes. As a result, predictions from integrated simulations often fail to match actual plasma behavior.

To address these issues, a method that incorporates data assimilation (DA) technique into conventional numerical simulations is being actively studied. DA system ASTI has been developed for the accurate prediction and control of fusion plasmas. Its capability to control helical plasmas has been demonstrated through control experiments conducted at LHD [1]. We are currently expanding ASTI for application to the control of tokamak plasmas [2]. In this study, we apply ASTI to the predictive simulations that reproduce JT-60U discharges [3].

Figure 1 shows the structure of ASTI. It mainly consists of two parts: a numerical simulation code and a data assimilation system. We employ the integrated simulation code TASK as the simulation model and use the ensemble Kalman filter as the DA algorithm. The time evolution of the plasma state is calculated by solving 1-D diffusive transport equations of particles, energy, and magnetic field. Experimental observations are assimilated at each time point when they are available, and model parameters such as diffusivities and particle and heat sources are optimized. As observations, we use measurements of electron and ion densities and temperatures, as well as analyses of poloidal flux at the LCFS.

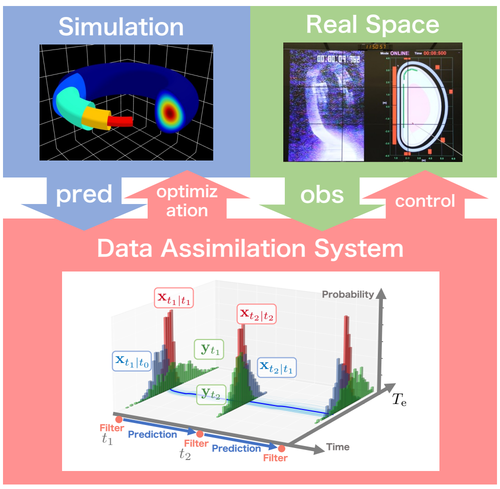

Figure 1. Structure of ASTI.

Figure 2 shows a comparison of predictions obtained from simulations with and without DA. The figure clearly demonstrates that the reproducibility of the observation is improved by applying DA. The presentation will also include results on the optimization of model parameters, as well as analyses of poloidal field and safety factor.

References
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[2] R. E. Ichikawa *et al.* Plasma Fusion Res. **20**, 1403036 (2025)
[3] H. Urano *et al.* Nucl. Fusion **53**, 083003 (2013)

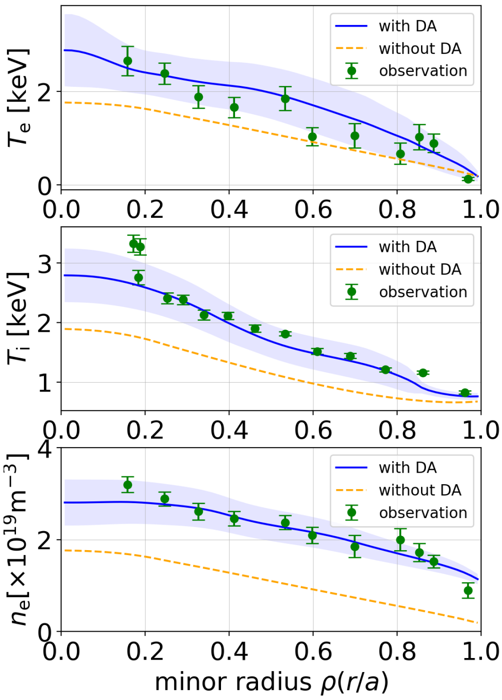

Figure 2. Radial profiles of electron temperature, ion temperature, and electron density. The blue lines show the prediction with DA, and the orange lines show the prediction only by TASK. The green dots represent the observations.