Bayesian inference for data integration and diagnostic optimization in fusion devices

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Abstract

Data integration involves the combination of data from multiple, possibly heterogeneous diagnostics, to enhance accuracy, resolution and robustness of inferred system conditions. When focusing on real-time aspects, the approach is sometimes referred to as "sensor fusion", with common applications in domains like aerospace or autonomous driving. In the context of fusion devices, data integration can benefit physics studies in an off-line mode, or plasma control in a real-time setting. Bayesian inference has been used for many years as a framework for data integration in fusion science, with the additional benefit of incorporating uncertainty propagation into the analysis. In future reactors, data integration will only gain importance, as diagnostic measurements will be limited by spatial constraints and cost. In addition, Bayesian methods enable optimization of diagnostic design, by minimizing the projected uncertainty on quantities of interest. In this contribution, we present recent advances in data integration for various fusion diagnostics at the WEST tokamak, as well as diagnostic optimization, using Bayesian inference. We discuss magnetic diagnostics for solving the inverse problem of plasma equilibrium reconstruction, diagnostics for measuring plasma density and temperature, and spectroscopic diagnostics for studying the transport of (highly charged) impurities [1, 2]. We employ Gaussian processes as computationally efficient tools for modeling spatial correlations in local plasma quantities. We focus in particular on accelerating data integration methods, by exploring different techniques to probe the high-dimensional probability distributions characterizing the plasma state, by leveraging the opportunities for parallelization offered by GPUs, or by modeling the entire inference chain using a neural network surrogate model. We then illustrate the potential of Bayesian experimental design for optimizing diagnostic configurations, presenting an application to a key set of magnetic sensors at WEST [3]. In particular, we show that the number of magnetic sensors can be significantly reduced without compromising the accuracy of key inferred quantities.

References

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