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Estimation of parameter profiles and their derivatives from arbitrary linear observations by using Gaussian processes

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Gaussian process regression (GPR) has been used at major magnetic confinement fusion experiments including LHD[1], ASDEX-Upgrade[2], JET[3], and Alcator C-mod[4] to determine the spatial gradients of plasma parameters, which play crucial roles in the transport processes. Although largely successful in practical use, finite spatial resolution of diagnostics is neglected in the standard GPR. In this contribution, we introduce an alternative GPR, in which any linear observation can be analyzed. This approach not only considers the sampling volumes of local measurements such as TS and CXS but also allows for the inversion of interferometer data within an identical framework.

We applied the alternative GPR to the electron density profile measurements at LHD. Figure 1 shows the electron density profiles and their derivates estimated from TS and FIR data. The shaded regions represent the standard deviations calculated from the diagonal elements of the covariance matrices. Reasonable agreements between the two diagnostics are seen for both the original electron density profile and its derivative. While Fig. 1 looks encouraging, these results are based on a single realization. If the analysis is repeated for another set of data with different random errors, the similarity between the probability distributions is expected to differ. Therefore, we next investigate the robustness of the profile measurements based on FIR by using synthetic data sets. As an input profile, we employ $\mu_{\theta_{TS}}$ shown in Fig. 2(a). Then, we generate synthetic FIR data by adding random noise with the relative amplitude of 3% to the noise free observation given. We repeat this procedure and calculate the electron density profiles and their derivatives 10,000 times for different realizations. The 16th, 50th, and 85th percentiles of the profile distributions and the input profiles are shown in Fig. 2. Over all spatial positions, the input profiles fall within the 16th and 84th percentiles.

Since GPR estimates profiles through linear operations, computation can be sufficiently fast for real-time applications. The findings in this work indicate that real-time monitoring of the density profile and its derivative by using an interferometer may be possible. Since the conventional TS system will probably not be available in a commercial fusion reactor due to the harsh radiation environment, an interferometer-based density monitoring may become a powerful tool to stably sustain a burning plasma by feedback controls. In addition, the proposed GPR is expected to find use in other scientific disciplines where the derivatives of spatial or temporal profiles carry important information.

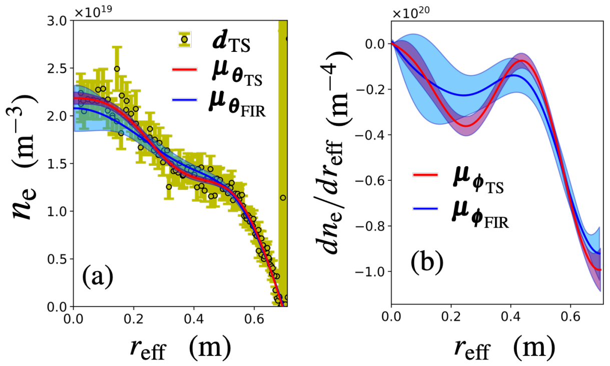

Figure 1. (a) shows the TS data points and the probability distributions of the electron density profile estimated from TS and FIR. In (b), the probability distributions of the derivative of the electron density profiles are shown for both diagnostics.

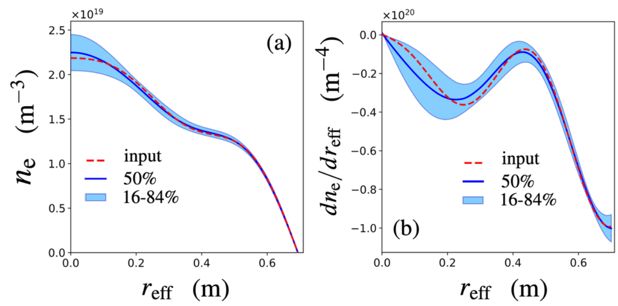

Figure 2. Percentiles of the density profile (a) and its derivative (b) estimated from 10,000 sets of FIR synthetic data. The red dashed lines represent the input profiles.

References

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