Prediction of Plasma Confinement Indexes by Gaussian Process Regression

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To realize a helical fusion reactor with a wide variety of magnetic field configurations, it is necessary to design a device that simultaneously satisfies various requirements. The requirements include conditions on plasma confinement performance of a reactor and engineering constraints. The former include MHD stability and suppression of neoclassical and turbulent transport, and the latter include the distance between coils and plasma to ensure blanket space, the distance between helical coils, and the maximum curvature and torsion of superconducting coils. We seek possible optimized configurations by changing the winding shapes of the helical coils in various ways.

In this study, the object is to solve such a multi-objective optimization problem by using Gaussian process regression with machine learning. For proof of principle, we limit the number of objective functions to two and show prediction results. Gaussian process regression allows one to naturally obtain confidence of predictions and to represent complex models with a combination of kernel functions. The two objective functions are the minimum value of Mercier criterion in the small radius direction (D_{Merc} (min)), and plasma volume (V). The kernel function used for the covariance matrix is the RBF kernel.

The results shows that the expected values of the predictions in both cases were clustered close to the true values, and the dependence of the objective function on the coil shape parameters is well evaluated. On the other hand, the variance of the predictions is large and increased with increasing β value. These results indicate that Gaussian process regression has sufficient performance to be used for optimized configuration survey, but the prediction accuracy needs to be improved. In the future, we will apply different kernels with additional training data and implement applied method of Gaussian process such as NNGP for improvement of accuracy. Furthermore, neoclassical transport computed by using KNOSOS code added to the objective function.

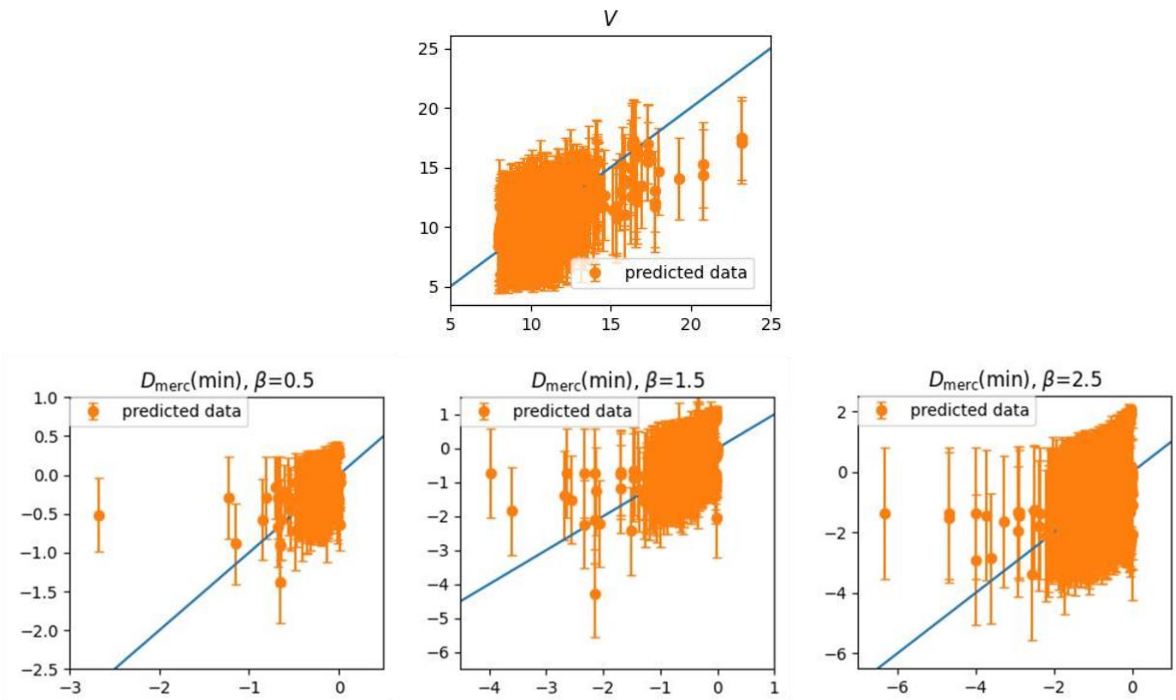

Figure 1. Results of the prediction of plasma volume and Mercier criterion at each β value. The horizontal axis is the actual value, and the vertical axis is the predicted value; the blue line is $y = x$. In regions with sufficient data, the expected values are close to the true values, but the variance of the predictions is large in all regions.