講演番号	285

文献番号	20226285

Reduced order modeling of CFD model using machine learning and an application for heat damage evaluation

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KEY WORDS: **heat-fluid, Computational Fluid Dynamics, Surrogate model,** Tucker decomposition, Machine Learning, Heat damage [D1]

Due to rapid change in the market, vehicle maker is required to shorten the development period effectively by following agile development process. To meet this demand, it is important to make clear feasible design space by using simulation in early stage of vehicle development. However, it is still not straightforward to use Computational Fluid Dynamics (CFD) in early stage of vehicle development due to its computational cost. The purpose of this paper is to propose a method to construct a surrogate model which can predict three-dimensional flow filed of velocity magnitude and temperature.

In the proposed method, training data are corrected from CFD simulation based on a Design of Experiments (DOE). Then the Tucker decomposition is applied to the training data in order to extract features from the tensor type training data. For regression model, Gaussian process is introduced and applied to each feature values which can be obtained by projection of training data to the parameter modes.

Figure 1 shows a demonstration of feature extraction method by tucker decomposition. Training dataset $\boldsymbol{\mathcal{Y}}$ corrected from CFD simulation is decoupled by using tucker decomposition into four tensors $\mathbf{G}, \mathbf{A}, \mathbf{B},$ and $\mathbf{C}$. Then, prediction $\hat{\boldsymbol{\mathcal{Y}}}$ can be obtained by using GP model and the extracted tensors $\mathbf{G}, \mathbf{B},$ and $\mathbf{C}$ as shown in figure 2. In the numerical example, we assumed that CFD model as shown in figure 3. In this model, vehicle runs in stationary state in 35[km/h]. Heat source temperatures of an engine and an exhaust pipe are set at 373.15[K] and 573.15[K], respectively. Purpose of this numerical examples is to surrogate CFD result regarding the distribution of flow velocity with respect to change of location of engine. Figure 4 shows a comparison between CFD result and prediction by proposed method. It can be seen from this result that the proposed method can mimic CFD result, precisely. The computational cost of CFD was 13 hours while our proposed method was 20 seconds. The proposed method can be used in early satage of vehicle development to accelerate enginner's studies to find feasible region where multiple performances are satisfied.

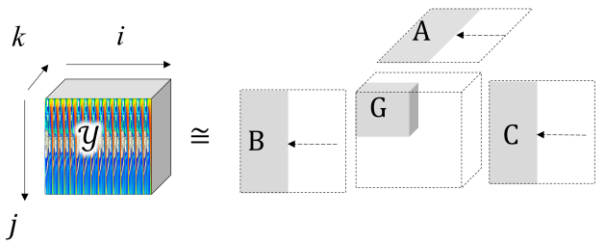

Fig. 1 Feature extraction method by tucker decomposition

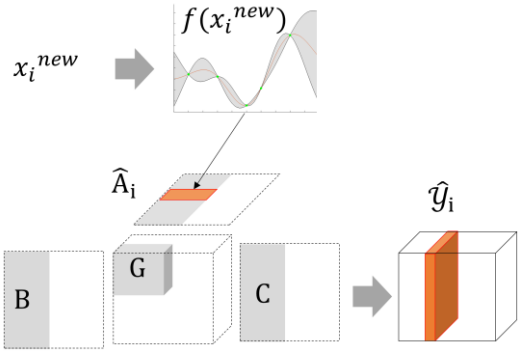

Fig. 2 Prediction of tensor data by using both gaussian process and tensors obtained by tucker decomposition.

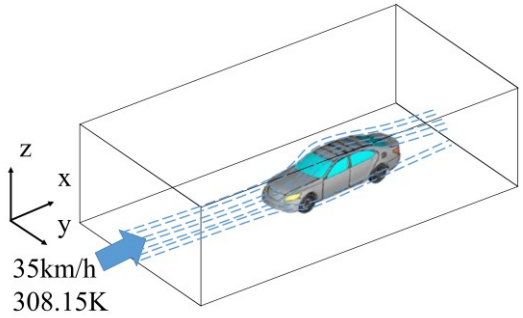

Fig. 3 Condition of CFD model

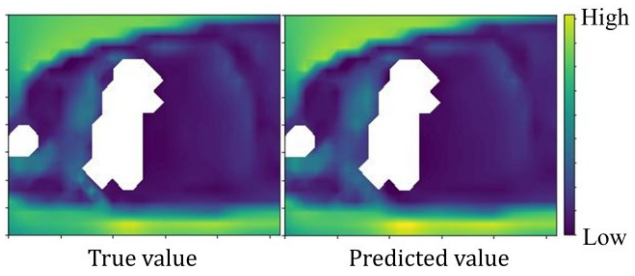

Fig. 4 Velocity cross-section contour