

Investigation of a Vehicle Aerodynamic Prediction Model Using Latent Representations with Separated Global and Local Geometric Features

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Recent advances in machine learning have promoted the development of three-dimensional vehicle shape generation and surrogate models for aerodynamic prediction. However, conventional shape generation models generally represent global structure and local geometric features in a single latent space. This makes it difficult to independently control shape features at different spatial scales. In our previous study, we developed a latent representation that separately describes the global structure and local features of vehicle geometry. In the present study, this latent representation is applied to aerodynamic vehicle shape editing and three-dimensional flow-field prediction.

Figure 1 shows an overview of the proposed framework. The global structure of a vehicle is represented by a latent variable Z_c obtained using a three-dimensional convolutional autoencoder. Local geometric features are represented by another latent variable Z_s obtained during the training of a shape detailization model based on DECOR-GAN. The two latent variables are integrated to reconstruct detailed vehicle geometry. The integrated latent representation is then used as a common input for aerodynamic performance prediction, vehicle shape editing, and flow-field prediction.

A multilayer perceptron regression model was constructed to predict the drag coefficient C_D , drag area $C_D A$, and 33 representative vehicle dimensions from the latent variables. Vehicle shape editing was performed in the latent space with the aim of reducing the drag coefficient by 10%. The local-feature latent variable Z_s , vehicle height, vehicle width, and wheelbase length were constrained during the editing. The resulting modification mainly appeared in the rear-window inclination angle, which generally has a strong influence on vehicle aerodynamic performance. This result indicates that the vehicle shape can be edited while preserving local geometric features and specified vehicle dimensions.

The integrated latent representation was also used for three-dimensional flow-field prediction with DeepONet. The latent variables describing the vehicle geometry were provided to the Branch Network, while the coordinates of each evaluation point were provided to the Trunk Network. The outputs of the two networks were combined to predict the velocity and pressure at each point around the vehicle. The predicted velocity field reproduced major flow characteristics, including the deceleration region in front of the vehicle and the wake structure behind the vehicle. These results show the potential of the integrated latent representation for aerodynamic vehicle shape editing and three-dimensional flow-field prediction.

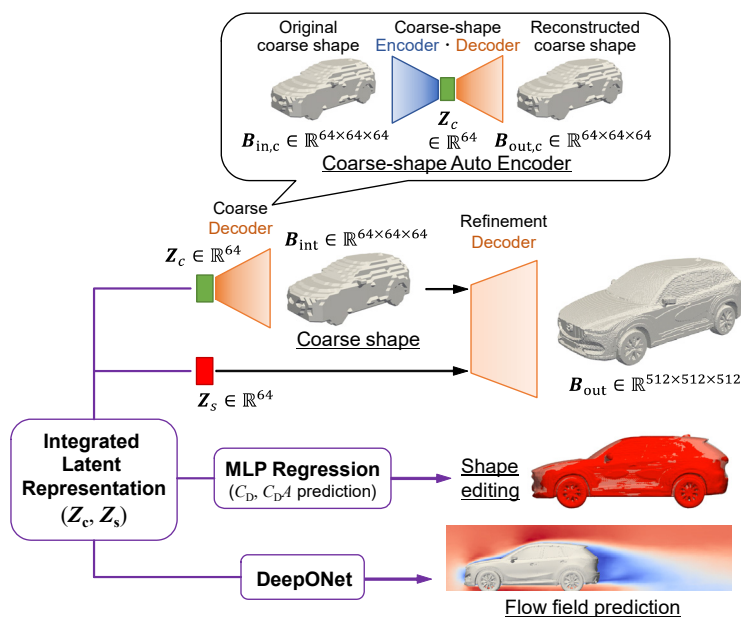


Fig.1 Overview of the proposed framework for vehicle shape editing and flow-field prediction using integrated latent representations.