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Machine Learning Modeling of Soot Emissions in a Medium Duty Diesel Engine

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ABSTRACT

Heavy-duty and medium-duty diesel engines play a significant role in the transportation industry. A major disadvantage of these engines is their high levels of soot emission, which is very harmful for human health. To reduce engine soot emission, it is imperative first to model it accurately. Due to the complex processes of oxidation and formation, modeling soot emission is much more challenging than modeling other emissions. Especially for real driving cycles, where we need model predictive soot control, fast and computationally effective soot models are necessary. Detailed combustion mechanisms can be used to model soot emissions accurately; however, it is an extremely time-consuming process and requires high computational power that is beyond the capabilities of the engine electronic unit (ECU).

To address this problem, an innovative modeling approach, which is a combination of a physics-based model and a machine learning model which is fast and accurate, is presented in this study to predict soot emissions of a 4.5-litre diesel engine for its entire working condition. Three classes of models are developed; the physical model which is based on an experimentally validated 1D engine model in GT-power software, the black-box model which is based on trained machine learning methods with experimental data and the grey box model which is a combination of the first two class of models. For black-box and grey-box soot emission modelling, different machine learning approaches are used, including a Regression Tree (RT), an Ensemble of Regression Trees (ERT), Support Vector Machines (SVM), Gaussian Process Regression (GPR), Artificial Neural Network (ANN), and Bayesian Neural Network (BNN). Experimental data from the engine running under 219 conditions of load and speed are measured and used to train and test soot models. 41 models including one physical model, 16 black-box models, and 24 grey box models are developed in this study. As a pre-processing tool, the least absolute shrinkage and selection operator (LASSO) and physical insight about soot formation and oxidation processes are used to select input features for models. The k-means clustering algorithm is used to select the best models for various applications as a post-processing tool. This approach allows for systematic categorization of feature sets and machine learning methods and can facilitate optimal model selection. Among the sixteen developed black-box models, LASSO-based GPR performed the best with R^2 of 0.96. Among 24 grey-box models, LASSO/physical insight-based SVM demonstrated the best performance with an R^2 of 0.97.

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