Research on Actual Road Emission Prediction Model of Heavy-Duty Diesel Vehicles Based on OBD Remote Method and Artificial Neural Network

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Abstract. In order to establish a prediction model of PM and NOx emission factors for heavy-duty diesel vehicles under actual road conditions based on OBD remote monitoring and big data, this paper carried out actual road tests on two China V heavy-duty diesel vehicles to obtain transient OBD and emission data by a Portable Emission Measurement System (PEMS) and self-developed On-board Remote Emission Measurement System (OREMS). According to the degree of influence of different parameters in the engine OBD on PM and NOx emissions, the principal component analysis method is used to extract the principal component parameters used to predict the model input, and the construction of a "Heavy-duty Diesel Vehicle Predictive Model based on Remote Monitoring Data and Neural Network Technology". Finally, the predictive model is trained and verified by PEMS test data. The prediction model provides new means and methods for the future development of large-scale heavy-duty diesel vehicle NOx and PM emission predictions under actual road operation.

1. INTRODUCTION

Heavy-duty diesel vehicles are currently the focus of mobile source pollution prevention and control[1]. Their emission control management methods have changed from laboratory engine and vehicle drum testing to actual road operation supervision[2-3]. However, the on-board emission test system (PEMS, Portable Emission Measurement System) is due to high equipment cost and test cost, the complicated testing and operation, the limitation of bicycles, and the heavy test workload makes it difficult to carry out large-scale actual road emission tests[4-6]. Therefore, how to effectively monitor and control the pollutant emissions and fuel consumption of heavy-duty diesel vehicles under actual road conditions has become the focus of controlling diesel vehicle emissions and fuel consumption and improving urban air quality.

OBD (On-Board Diagnostic System) is an important source of big data for remote monitoring of diesel-duty vehicle emissions (especially PM and NOx), and will become a new type of vehicle emission testing and prediction technology in the future[7]. However, in practical applications, some current heavy-duty diesel vehicles cannot collect fuel consumption and NOx data, as well as the immature and widespread application of automotive particulate sensor product technology. Artificial Neural Network (ANN), as one of the fastest-growing information processing technologies in the field of artificial intelligence, has been widely studied and applied in the field of environmental protection of...
motor vehicle emissions.

Shude Ji et al.\[8\] used a neural network model to carry out diesel engine NOx emission prediction research on the engine bench, based on the engine speed, intake air volume, circulating oil volume, engine water temperature, air intake temperature after intercooling, intake air humidity, and exhaust air. Back pressure, diesel temperature and other parameters are used as input, and nitrogen oxide emission quality is output. By optimizing parameters such as hidden layer nodes and the number of iterations, a nitrogen oxide emission prediction model is constructed. Jiehui Li et al.\[9\] used BP neural network to fit and predict CO, HC, NOx and soot concentrations in dual-fuel engine exhaust. Aida Domínguez-Sáez et al.\[9\] used artificial neural networks to predict the transient CO\(_2\), NOx, accumulation mode (30-560nm) and nucleation mode (5.6-30nm) particulate matter of 2.0L China IV diesel vehicles with different ratios of biofuel.

Based on the large emission data obtained by the portable vehicle emission test system and OBD, this paper extracts the principal component parameters in the multiple data according to the degree of influence of different parameters on the emission of particulate matter and nitrogen oxides, and at the same time, through the hidden layer and output Different activation functions and optimization algorithms are set up at different levels for comparative research, and finally a large-scale heavy-duty diesel vehicle actual road particulate matter and nitrogen oxide emission factor prediction model is established.

2. RESEARCH ON THE TEST PLAN

2.1. Test Vehicles

Two urban heavy-duty diesel buses belong to China V were selected as the research objects to carry out NOx and PM emission prediction models under actual road conditions. The parameters of the test vehicles are shown in Table 1.

| Table 1. Test vehicle parameters |
|--------------------------------|
| **Item** | **Parameters** |
| Vehicle model | DFL1160BX1V |
| Engine model | ISD210 50 |
| Displacement (L) and rated power (kW) | 6.7/155 |
| Driving mileage (km) | 60818/60556 |
| Pollution control device | EGR+SCR |

2.2. Test equipment and plan

Under actual road conditions, the author independently developed On-board Remote Emission Measurement System (OREMS) based on OBD and Portable Emission Measurement System (PEMS) Test the actual road emissions of the test vehicle, and then randomly divide the PEMS test data samples into two groups according to the ratio of 70% and 30%, and train and verify the constructed neural network prediction model respectively.

2.2.1. OREMS system

The OREMS system is mainly composed of the main body of the vehicle terminal, OBD collector, GPRS, GPS, exhaust gas sampling tube, NOx sensor and temperature sensor. The NOx sensor and temperature sensor are installed axially and vertically on the exhaust gas sampling tube, and data is transmitted through the wiring harness. For the main body of the vehicle-mounted terminal, the exhaust gas sampling pipe is connected to the vehicle exhaust pipe through a rubber connecting sleeve. The performance of OREMS system meets the requirements of GB17691-2018 Appendix Q.

The OREMS system automatically obtains the real-time data stream of the engine and pollution control device operating status through the OBD collector and the vehicle OBD diagnostic interface communication, mainly including the engine coolant temperature, the intake air temperature, the intake manifold pressure, the air mass flow, and the engine speed , Engine fuel flow, calculated load value,
vehicle speed, fuel pressure and other data, obtain NOx concentration and exhaust temperature data through the exhaust gas sampling pipe, obtain vehicle geographic location and vehicle speed data through GPS, and finally remotely transmit to the monitoring platform through GPRS for data processing analysis. The data acquisition and transmission frequency are both 1Hz.

**2.2.2. PEMS system**
PEMS equipment mainly includes two parts: One is HORIBA OBS-2200 gaseous pollutant analyzer, which mainly measures CO/CO₂/HC/NOx concentration, exhaust flow, temperature, pressure, environmental humidity, latitude and longitude, altitude, vehicle speed and other information, and the vehicle ECU information is read through the OBD interface module; the second is the Dekati ELPI (Electrical Low Pressure Impactor) particulate matter analyzer, which is mainly used to measure the quality and quantity of particulate matter within the range of 30nm~10um in diameter.

**2.3. Test route**
Tests are carried out in Tianjin in accordance with the actual road conditions of urban vehicles specified in the "On-board measurement methods and technical requirements for exhaust pollutants from heavy diesel vehicles and gas fuel vehicles" (HJ857-2017). Among them: 70% of urban roads, 30% of suburban roads, the specific test route is shown in Figure 1.

![Actual road emission test route](image)

**3. NEURAL NETWORK MODEL STRUCTURE AND VERIFICATION**

**3.1. Neural network model structure**
A neural network is a complex network system formed by a large number of interconnected neurons. Although the structure and function of a single neuron is simple, the combination of multiple neurons makes the entire neural network present non-linear, high-dimensional, parallel, distributed, etc. feature. The structure of a typical single neuron is shown in Figure 1, where: \( i \) is the neuron; \( X_1, X_2...X_n \), etc. are the input parameters of the neuron; \( K_i \) is the weight of the input parameter; \( Z_i \) is the output value after linear weighting of the input signal; \( H_i \) is the correction value to \( Z_i \); \( f(z) \) is the activation function, usually a non-linear function; \( Y_i \) is the non-linear output value of the neuron.
BP neural network (Back Propagation) is currently the most widely used multi-layer feedforward neural network trained according to the error back propagation algorithm, and it has strong nonlinear mapping capabilities. Therefore, this paper will use BP neural network to construct the actual road emission prediction model of heavy diesel vehicles. Usually the BP neural network is composed of a three-layer network including an input layer, a hidden layer and an output layer, as shown in Figure 3. The learning function is one of the most important features of neural networks.

3.2 Evaluation method of model prediction results
In order to evaluate the accuracy of the emission model for predicting NOx and PM emissions, this paper uses the sum of square error and relative error as the evaluation index of the model prediction result. The smaller the sum of square error and relative error, the more accurate the prediction result. The calculation method of relative error R is:

$$R = \frac{|X-Y|}{Y} \times 100\%$$

Where: $X$ is the predicted value obtained from training; $Y$ is the actual road measurement value.
The calculation method of the error sum of squares is as follows:

4. VALIDATION OF NEURAL NETWORK PREDICTION MODEL

4.1. Model input parameters and algorithms
Through principal component analysis, five characteristic parameters, including vehicle speed, exhaust gas temperature, torque, rotation speed, and fuel consumption rate, which most affect the NOx and PM emissions of heavy-duty diesel vehicles, are selected as the input parameters of the prediction model.

From the perspective of the influence of different optimization algorithms and activation functions on the prediction results: two optimization algorithms such as the conjugate gradient method and the gradient descent method have less impact on the prediction results of the model, but the gradient descent method is compared with the conjugate gradient method. The prediction result is slightly better; the activation function used in the hidden layer and the output layer has a greater impact on the prediction result, especially when the output layer uses the identity function as the activation function, the error of the sum of squares between the predicted value and the experimental measurement value is relative. It is much larger than other schemes, which shows that the generalization ability of the neural network that uses the identity function as the activation function in the output layer is weaker, and the error in the prediction ability of the result is larger. The error of the function is smaller.

Through the above comparison and analysis, the gradient descent method is selected as the optimization algorithm in the prediction model of this paper, and the S-type activation function is selected as the hidden layer and output layer activation functions.

4.2. Predictive model verification and application
The established neural network prediction model is used to train and verify the particulate matter and nitrogen oxide emissions of test vehicles, and the correlation between the prediction results based on the OREMS and neural network prediction models and the PEMS test results is compared, as shown in the Fig.4.

Carrying out the PEMS test of heavy-duty diesel vehicles under actual road conditions can reflect the actual emission characteristics of the vehicle to the greatest extent. Therefore, it is of great significance to carry out the comparison test of the remote measurement system and the PEMS equipment under the actual road conditions.

The comparison of the NOx and PM emissions obtained by the remote measurement system and the PEMS equipment is shown in Fig.4. The overall trend correlation $R^2$ between the two reached 0.9633 and 0.8609, respectively.

![Fig.4  Correlation between PEMS and remote monitoring method](image)
5. CONCLUSION

Based on the second-by-second data collected by the PEMS test equipment, the artificial neural network is used to train the actual road emission data of the vehicle, and the NOx, PN emission prediction model is constructed, which solves the problem that the product technology of vehicle particulate matter sensor is not yet mature.

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