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Neural network for modeling and optimization of internal combustion engines

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Summary

In this work, the possibility of modeling the engine emissions has been analyzed in terms of NO_x, CO, unburned hydrocarbons and brake specific fuel consumption as a function of injection parameters and EGR levels. The results showed that the neural network technique was capable of analyzing the influence of any single input parameter on any output variable and allowed the formulation of an efficient simple mathematical model of the engine that was able to predict the output of interest.

Keywords

Diesel engines, neural networks, pollutant, multiple injections

Background

In the last few years, the performance and quality of combustion in Diesel engines for automotive applications have been noticeably improved, especially thanks to the use of diagnostic techniques applied to the fuel combustion, with high spatial and temporal resolution. These techniques, based on the light-matter interaction, allow the analysis of both the thermofluidodynamic processes inside the cylinder and the early phase of pollutant formation. Such experimental techniques have allowed fine-tuning of the mathematical model describing

the complex yet fundamental physical phenomena of ignition and the following combustion development. Such models, included in software for multidimensional simulation of thermofluidodynamic processes inside the combustion chamber, have recently underlined, in particular, that the combustion and the related formation of pollutants are strongly influenced by the fuel injection modulation and by the air motion inside the combustion chamber. This led to a new strategy of the fuel injection inside the engine, where the fuel flow rate was modulated by dividing the total fuel mass injected each cycle into five different smaller parts. Further improvements can be obtained performing exhaust gas recirculation (EGR), increasing the injection pressure, varying the timing of intake and exhaust valves, and properly shaping the induction system and the combustion chamber [1]. Several studies in this area have shown, however, that if the aforementioned parameters are not correctly tuned for the different engine operating conditions, their utilization can result in a degradation of combustion instead of an improvement [2]. On the other hand, the large number of parameters and the wide range in which they may be varied makes difficult to carry out the global optimization using a complete experimental and numerical campaign. Therefore, some mathematical methods, like neural networks, can be useful because they are able to model the physical system on the basis of experimental results previously obtained.

In this work, the possibility of modeling the engine emissions has been analyzed in terms of NO_x, particulates, unburned hydrocarbons and brake specific fuel consumption as a function of injection parameters and EGR levels.

Neural network application

Input and output choice

A neural network approach has been applied in order to predict the pollutant emissions in a Diesel engine where the fuel is injected in up to three different injections. As input for the neural network, the Exhaust Gas Recirculation (EGR) rate, the timing and the duration of the first two injections (referred as early and pilot), have been used. All the data were referred to the same engine operating condition, characterized by an engine speed of 1400 rpm and an engine torque of 32 Nm. The output chosen to be predicted by the neural network were the NO_x, total hydrocarbons and carbon monoxide emission levels and the specific fuel consumption.

Neural network architecture optimization

When a neural network is supposed to be applied to every kind of problem, the right choice of its architecture and of the constraints to be imposed during its training are fundamental. During the network training, in fact, the error is calculated for each iteration supplying the network with the same data used during the training. An architecture of the network excessively complex or with restrictive constraints might lead, during the training phase, to an *overfitting* problem. This problem consists in creating a network model able to predict with high precision the data used during the network training, but predicting not existing peaks between a point and the other. The software modeFrontier allows to set, for a neural network with an hidden layer, the number of neurons in the hidden layer itself, the average percentage error allowed during the training and the maximum percentage error allowed for each point during the training.

For the problem under discussion 108 data record were available, 89 of which have been used to train the network (training set) and 19 have been used, a posteriori, to validate the network (validation set).

Figure 1 shows the average percentage error made on validation data as a function of the number of neurons in the hidden layer, when setting, for the training phase, a maximum error equal to 15% and an average maximum error equal to 10%. As shown in the graph, the best performance was obtained with 15 hidden neurons for the NO_x levels prediction and with 12 hidden neurons for the THC. The prediction of the specific fuel consumption seems to be independent from the number of the neurons if higher than 9; this is probably due to a small variation of this output, since the engine speed and torque were kept constant for all the experiments. The scattering of results for NO_x and THC are reported in Figure 2, in both cases for the best neural network architecture.

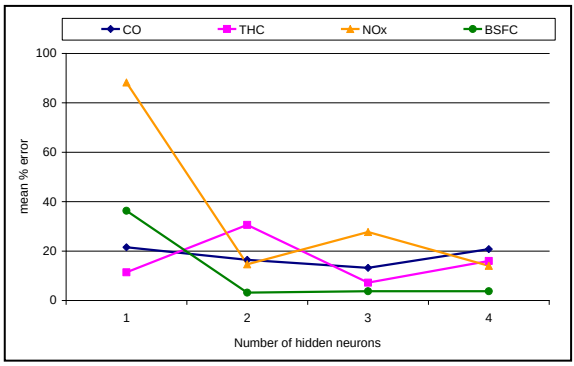

Figure 1: effect of the number of hidden neurons on the mean % error for CO, THC, NO_x and BSFC prediction

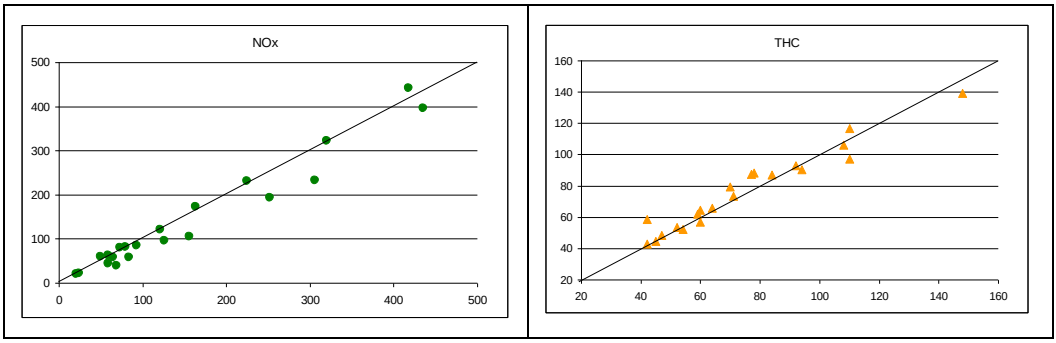

Figure 2: comparison between measured and predicted NOx and THC emission levels

After the effect of the number of neurons in the hidden layer was verified, the effect of the average error allowed during the training phases was assessed. The related results are reported in Figure 3. As it can be seen, the training algorithm stops soon if a high error (15%) is allowed; as a consequence, the network is not able to correctly predict the engine behaviour; on the other hand, if a low error (3%) is required, the overfitting, as previously underlined, is observed. In order to overcome this problem, a validation set is required, in order to verify the effective network performance. The scattering for data related to hydrocarbon levels, referring to two different values of the mean error are reported in Figure 4.

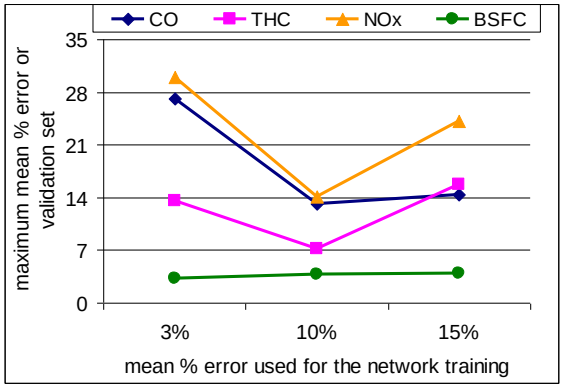

Figure 3: effect of the mean % error on the prediction error

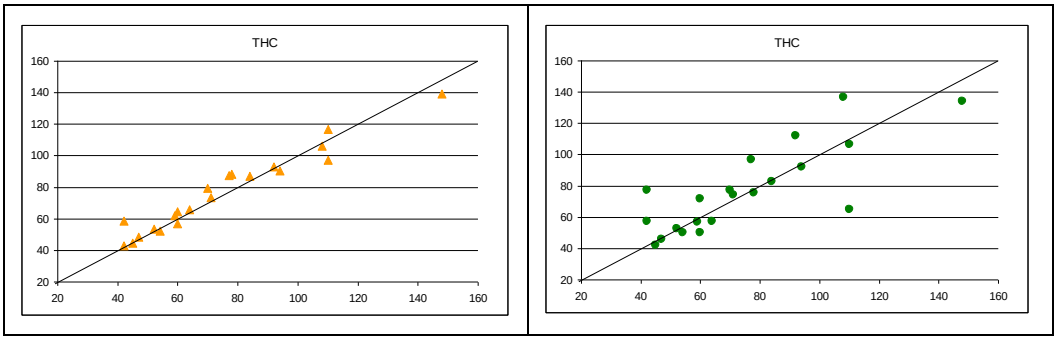

Figure 4: scattering for data related to hydrocarbon levels, referring to two different values of the mean error

Conclusions

The application of the neural network to predict the behaviour of a diesel engine showed to be a very promising approach, because it allows of obtaining predictions with relatively high reliability and with minimal computational resource, in particular taking into account that it is time consuming and sometimes impossible to obtain experimental results or fluidodynamic simulations for all the engine operating conditions.

References

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