Abstract

In this work two different kinds of model-based controllers have been developed, assessed and tested with the aim to reduce the engine calibration effort and exploit the potential of the new vehicle-to-x systems.

The idea is to investigate the potential of model-based controllers in substitution of the traditional map-based approach.

The base of all the activities is a previously developed mean-value 0D combustion model that, given the main combustion parameters as input (such as: injection timings, injection quantities, boost pressure, intake temperature and humidity, EGR level, rail pressure), is able to simulate heat release rate, pressure trace and emission formation inside the combustion chamber. Starting from the simulation of the combustion process performed by the model, also several combustion metrics, such as MFB50 or inner torque, can be extracted.

This model has been used in different ways to develop two different controllers.

The first controller has been developed in the framework of the HERCULES project, that is a collaborative project between General Motors-Global Propulsion systems and Politecnico di Torino, with the objective to control the torque of a 1.6 litres diesel engine, by acting on the main injection fuel quantity, regardless of the combustion mode or injection pattern which are featured by the engine, including complex injection patterns such as multi-after ones.

The objective of the project is to reduce the experimental effort needed for the calibration of the injected quantity for the different combustion modes, including multi-after ones. The effort derives from the fact that, despite the late burning, the after-injection pulses can produce a torque that has to be taken into account (adjusting the main injection quantity) in order to realize the engine torque required by the driver.

Since the objective of the activity is to replace the conventional map-based approach, the main requirements for the controller are a good accuracy and a running time which is compatible with a real-time application in a commercial engine control unit.

Due to the constraints in terms of running time, it has been verified that the mean-value 0D combustion model cannot be directly used as base for the controller, because it requires a too high computational time. In order to solve the problem, a meta-modelling approach has been followed, exploiting the capabilities of artificial neural networks.

The approach consisted in the use, as a controller, of a feed-forward neural network that has been trained using a large virtual dataset (more than 200000 virtual engine points) generated by the mean-value combustion model. The resulting neural network was then able to replicate the performance of the mean-value 0D combustion model in terms of accuracy, but with the advantage of requiring a

much shorter computational time, that is compatible with the implementation in a modern commercial engine control unit.

Basically, the approach allowed to take the advantages of both modelling approaches, since the mean-value 0D combustion model, due to its structure, requires a low number of experimental points for its calibration and is quite robust with respect to extrapolation outside the calibration range. However, the neural network is faster to run but generally requires a higher number of experimental points to be calibrated and is less accurate in terms of extrapolation. The use of a 0D combustion model, which is low computationally demanding, allowed to generate a very large training dataset for the neural network in a short amount of time. As a matter of fact, more than 200000 virtual points were generated, which explore a wide range of input variations at several engine working conditions. This allowed to obtain a very robust neural network.

The second controller has been developed for a 11 litres diesel engine in the framework of the European IMPERIUM H2020 collaborative research Project, to which Politecnico di Torino participated as a partner. The project had the aim to achieve fuel consumption and urea reduction of up to 20% in diesel-fuelled heavy-duty vehicles , whilst keeping the vehicle within the pollutant emission limits.

One of the objectives of the project was the development of an energy manager supervisor, which was performed by AVL. This supervisor, on the basis of the knowledge of the road characteristic and the of the traffic conditions in advance (by means of an eHorizon system), requests specific instantaneous targets of torque and engine-out nitrogen oxide (NOx) emissions, in order to globally optimize the performance of the vehicle in the future time frame. The task of Politecnico di Torino was to develop a model-based controller, which is able to achieve the desired torque and NOx emission targets in real-time, cycle-by-cycle, by acting on the main injection parameters (i.e., start of injection of the main pulse, injected quantity, injection pressure).

The developed controller exploits the 0D mean-value combustion model as a virtual sensor for the torque and NOx emission control, which is used within a control loop in order to reach the desired targets. In this project, the controller was implemented on a rapid-prototyping device (ETAS ES910) that is more computationally powerful with respect to a commercial engine control unit. It was verified that the 0D combustion model featured a computational time that is compatible with a cycle-by-cycle control when implemented on the rapid prototyping device. Therefore, the use of faster modelling approaches, such as neural networks, was not necessary.

First, the 0D model has been calibrated and widely validated along steady state tests and integrated in the newly developed control algorithm. The controller has then been tested at both steady-state and transient operations and its capabilities to achieve the required torque and NOx targets has been verified on-line. Finally, the complete IMPERIUM system (including the combustion controller) has been successfully tested on a real vehicle prototype in public roads.