New Strategy for Torque Estimators

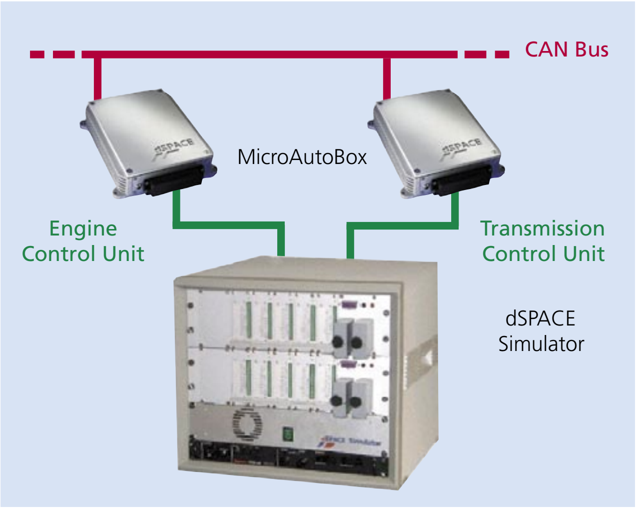
- Università del Sannio uses dSPACE Simulator Mid-Size
- Torque estimator for internal combustion engines
- Testing of integrated control strategies

In automotive powertrain control strategies, engine torque estimators are preferred to expensive sensors for obvious economic reasons. At the "Group for Research on Automatic Control Engineering" (GRACE) laboratory at the Università del Sannio in Benevento, Italy, engineers developed a completely new strategy, called "nicely nonlinear torque estimator". This is an algorithm that can be efficiently used for engine-transmission or engine-vehicle integrated control strategies. The tests confirming the performance of the proposed algorithm were run with dSPACE prototyping and hardware-in-the-loop systems.

Torque-Based Control Strategies

In automotive control strategies, particularly vehicle dynamics applications, an amount of torque generated by the internal combustion engine is required at the crankshaft in order to achieve specific goals. For example, traction control applications require net torque regulation during wheel slip or in response to the driver's request. Similarly, for emissions reduction and fuel consumption strategies, a suitable torque profile is actuated without degrading the performance requested by the driver. In this scenario, a controller able to accurately regulate the engine torque is vital to reach high performance. Since cheap and noninvasive on-line engine torque sensors are not yet available, an observer is necessary to design a closed-loop control scheme. In this project a torque estimator, suitable for different applications, was developed and tested in real time. We set up a control architecture using dSPACE rapid control prototyping (RCP) and hardware-in-the-loop (HIL) hardware. The dSPACE Simulator Mid-Size for HIL tests is equipped with a DS1005 PPC Board and two DS2211 HIL I/O Boards. The engine and transmission control strategies that we are developing are tested by means of two MicroAutoBoxes. The I/O capabilities of MicroAutoBox allow communication between the two electronic control units (ECUs) by means of a CAN bus based communication link. The engine model running on the dSPACE Simulator Mid-Size is an en-DYNA® SI 1.5 from TESIS.

▼ *The RCP and HIL station, at the automatic control laboratory of the Università del Sannio.*

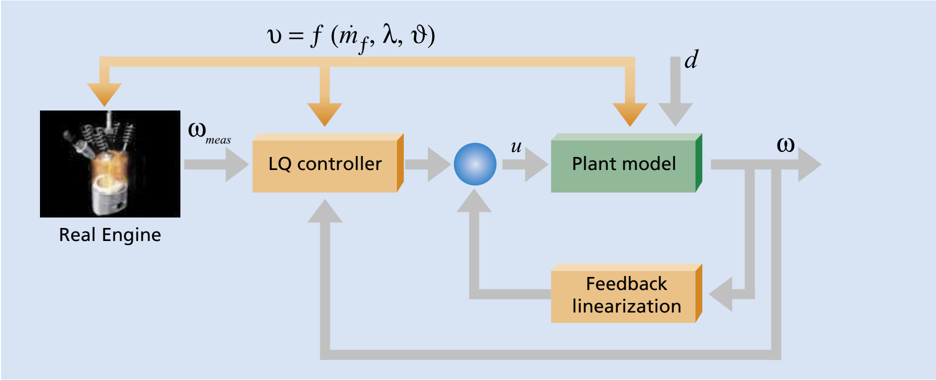


The Nicely Nonlinear Torque Estimator

The problem of estimating the mean value of the total torque acting on the crankshaft was treated as a tracking problem, solved by utilizing the information on injected fuel, air-fuel ratio, spark angle and the measured shaft speed (see tracking control scheme). The system to be controlled is a simplified nonlinear model of the combustion process. It reproduces the engine torque production and the shaft speed dynamics. In order to track the measured shaft speed ω_{meas}, a model-based control strategy is designed. In particular, the control input u represents the amount of extra torque that the system needs to reach the desired shaft speed, compensating both model uncertainties and all unknown external torques. It is computed by solving an optimal control problem to minimize the following function:

$$V=\frac{1}{2}\int_{0}^{\infty}\left[q(\omega-\omega_{meas})^{2}+\rho u^{2}\right]dt$$

The algorithm consists of three steps. First a nicely nonlinear model, i.e., a second-order Taylor approximation of the engine model including the combustion model and crankshaft dynamics, is computed. Then a linear model of the engine is obtained by means of feedback



Tracking control scheme: d is the unknown disturbance, which groups all external load torques, and υ is the known disturbance, a vector formed by fuel mass flow rate, air-fuel ratio, and spark advance.

Variables	Description
ω	Shaft speed
u	Control input representing the amount of extra torque
d	Unknown disturbance
υ	Known disturbance
$\dot m_f$	Fuel mass flow rate
λ	Air-fuel ratio
ϑ	Spark advance

linearization of the nicely nonlinear system. Finally, an LQ tracking control over an infinite horizon is obtained for the linear system.

Testing Phase

The testing phase confirms the excellent performance of the proposed algorithm, with regard to both the precision of the estimation and the robustness of the strategy to uncertainties. These encouraging tests induce us to continue the development of control strategies for engine and transmission.

Moreover, since in a hierarchical control architecture, such as in automotive applications, high-level strategies are executed on dedicated ECUs and demand specific torque profiles for the torque controller running on a different control unit, and since communication between different ECUs usually relies on data busses such as the CAN bus, another research activity we aim to analyze in depth is the integration and the communication of such different strategies. With this aim, we set up a similar control architecture for integrated engine/transmission control strategies using dSPACE prototyping and hardware-in-the-loop hardware.

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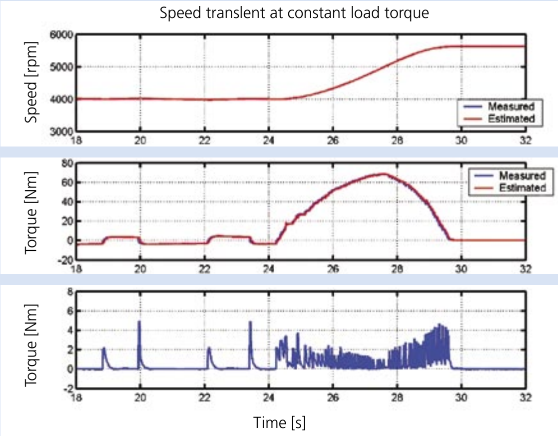
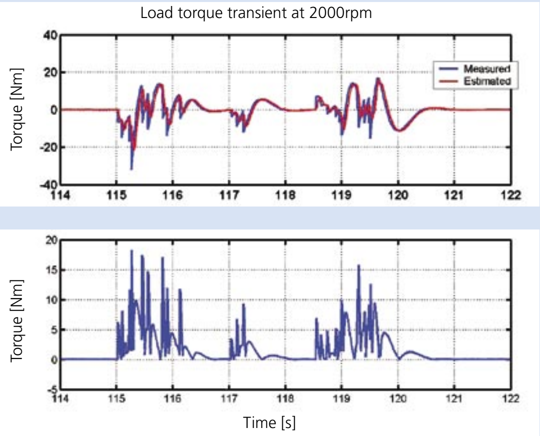
The details of the algorithm can be found in P. Falcone, G. Fiengo and L. Glielmo, "Nicely Nonlinear Engine Torque Estimator", 16th IFAC World Congress, Prague



Speed transient at a constant load torque of 20 Nm.



Load torque transient at a constant speed of 2000 rpm.