Advanced Control Design for Automotive Powertrains

The automotive industry currently spends approximately $1 billion each year in the development and calibration of powertrain control. According to one survey, the number of lines of code in a vehicle is increasing by a factor of 10 every eight years, and the development cost for software will exceed that of hardware before 2020.

Modern automotive control problems are outpacing the design techniques that have been traditionally used to solve them. The legislated and consumer demands of reduced fuel consumption and emissions have driven increased complexity into modern powertrains in terms of sensors, actuators, and new subsystems. Engineering, calibration, and test cell time and cost are all increasing. At the same time, the optimal coordination of subsystems remains elusive.

The OnRAMP Design Suite provides a systematic framework for end-to-end model-based powertrain control design. Controllers can be designed and deployed in weeks instead of months, as was previously the case.

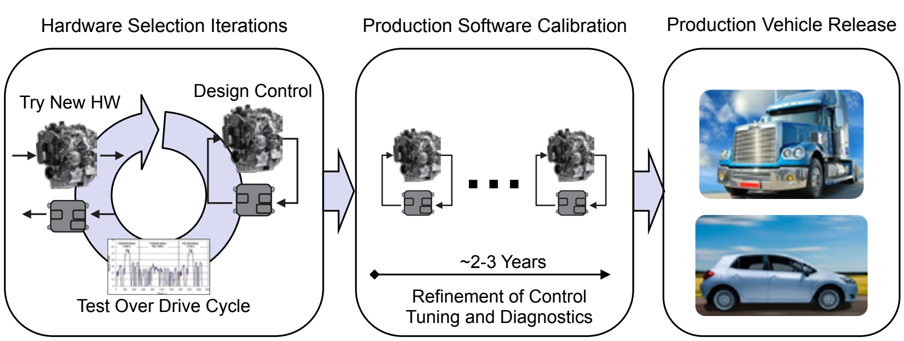
Problem Characteristics

Automotive powertrains comprise many different configurations—single-stage and multistage turbocharging, high- and low-pressure exhaust gas recirculation, variations on existence and arrangement of throttles and valves, and various exhaust aftertreatment options and configurations—depending in part on the intended application and target market for the vehicle.

From a control perspective, any one of these configurations represents a highly nonlinear, multivariable plant with significant model uncertainty due to both manufacturing variability within a production line and in-service aging. At the same time, any designed control must satisfy constraints on both actuator and output (e.g., turbocharger speed or air-fuel ratio) while hosted on an embedded hardware platform with limited memory and processor power (less than 60 MHz and only a few megabytes of flash memory) at fast sample times typically measured in milliseconds.

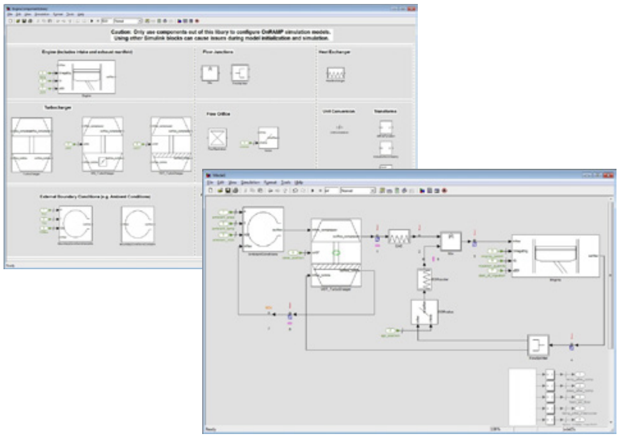
Current State of the Art

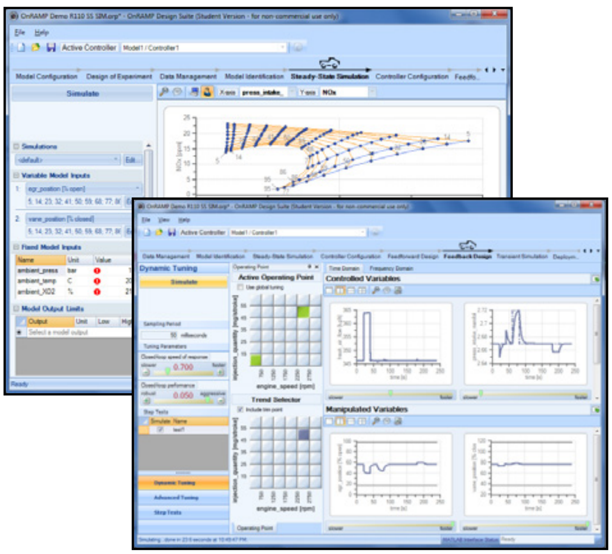
The current process for automotive control design is highly manual and labor intensive. It typically involves many months of experimental work in an engine test cell and vehicle to tune or "calibrate" standard production controllers over all conditions (engine speed, load, ambient temperature, pressure, etc.) they may encounter in practice. The finalization of the control and diagnostics can easily take two to three years as the vehicle passes through more than one season of testing. Systematic model-based control design techniques are still relatively rare in production automotive applications.



Every step of the powertrain development process involves control design. Today's process typically requires a few years from requirements specification to engine certification.

Contributor: Gregory Stewart, Honeywell, Canada





The OnRAMP Design Suite was released as a product in late 2011. Some 35 users have been trained, and the technology has been applied for several applications by engine manufacturers. The clean-sheet development time to achieve transient control is reduced in most cases from several months to a few weeks.

The Innovation: OnRAMP Design Suite for Powertrain Modeling and Control Design

OnRAMP supports end-to-end powertrain control design. The user is guided through three phases—modeling, control design, and controller deployment—each of which is supported by software tools based on a control-theoretical foundation. Multivariable control over a transient drive cycle can typically be achieved in two to three weeks, with the current record being four days for a new engine.

Modeling

A fully identified model of the engine or aftertreatment device may be obtained in less than a week. The modeling uses a physical-component-based library to produce the ordinary differential equations (ODEs) suitable for control design while avoiding the complex wiring challenges in ODE configuration. A second key innovation has been the automatic and robust identification of nonlinear models useful for engine applications. A hierarchical identification strategy first fits individual model components, and then a systemwide nonlinear optimization of all model parameters simultaneously over all of the recorded data—including all inputs, outputs, and operating points—is performed.

Control Design and Tuning

The control approach automatically generates both the feedforward and feedback control required by powertrain applications. As constraints are of key importance, the feedback uses a version of explicit model predictive control (MPC) that fits within the processor and memory limitations of modern ECUs.

Tuning is intuitive with a slider bar for speeding up or slowing down a given output or actuator action. MPC weights are then computed such that the resulting (linearized) closed-loop transfer functions will satisfy a small-gain theorem condition for robust stability. Tuning is thus user friendly without risk of generating unstable control in the face of real-world model uncertainty.

Award

"IEEE Control Systems Technology Award" from the IEEE Control Systems Society "*for the design, implementation and commercialization of the **OnRAMP Design Suite for Powertrain Control***," awarded to Francesco Borrelli, David Germann, Dejan Kihas, Jaroslav Pekar, Daniel Pachner, and Greg Stewart in 2012.

For more information: G.E. Stewart et al., Toward a systematic design for turbocharged engine control, in L. Del Re et al. (eds.), Automotive Model Predictive Control, Lecture Notes in Control and Information Sciences, vol. 402, pp. 211-230, Springer, 2010; R. Beňo, D. Pachner, and V. Havlena, Robust numerical approach to mean-value modeling of internal combustion engines, Proc. 7th IFAC Symposium on Advances in Automotive Control, Tokyo, September 4-7, 2013; www.honeywellonramp.com.