Demonstrating and Validating a Next Generation Model-Based Controller for Fuel Efficient, Low Emissions Diesel Engines

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Outline

• The need for advanced engine control

• Proposed alternative to traditional control techniques

• Viability demonstration

• Limitations & next steps
Control Systems Complexity

- Increased number of sensors and actuators
- More degrees of freedom
- New control logic required
- More calibration flexibility
- Calibration optimization more complex
Several Levels of Control

- Individual Component Level:
  - Actuator position control
  - Sensor drift
  - Signal processing
  - Diagnostics

- System Level:
  - Parameter control
  - System Interactions
  - Diagnostics

- Engine Level:
  - Emissions
  - Fuel economy
  - Diagnostics

- Truck Level:
  - Drivability
  - Heat rejection
  - Diagnostics

Constraints:
- Control stability
- Transient response
- Diagnostics

Must integrate systems with:
- Different response times
- Nonlinearities
- Part-to-part variability
Control Components

- Control logic requires extensive mapping of control gains
- Control gains are tuned to ensure stability
- Trade-off is steady-state stability vs. transient response

- Setpoint calibration is increasingly time-consuming
- "Manual" setpoint optimization is less and less practical
Illustration of Engine Control Maps

- Factorial increase in calibration space
- Multiple performance targets

Setpoints:
- Air
- EGR
- Inj. rate
- Inj. timing
- Inj. pressure
- Exh. Temp.
- Urea dosing
- HC dosing

Performance targets:
- Torque
- Drivability
- Durability
- Fuel economy
- NOx / PM / NMHC
- NO/NO2 ratio
- NH3 storage
- Urea consumption
- SCR efficiency
What’s the Alternative?

- A practically-mapless control system
- Based on predictive engine models
  - First principle models
  - Neural networks trained with transient engine data
- A controller with built-in knowledge of system interactions
  - Nonlinearities
  - Individual system response times
- Inputs: Performance targets
- Outputs: Actuator signals
- Includes an optimizer
  - Cost function that minimizes emissions and fuel consumption
  - Optimizes engine operation in real-time
1st Step: Performance Model Evaluation

Performance model accuracy is satisfactory over a wide range of operating conditions.
2nd Step: Optimized Setpoint Evaluation

- Exercised the controller model offline
- Resulting engine setpoints were evaluated at the test cell
- Measurable gains in fuel economy
3rd step: Complete Controller Evaluation

- Full model-based control logic implementation
  - Performance models
  - Controller
  - Optimizer
- Test engine: 2010 Detroit Diesel DD15
- Test cycle: U.S. FTP

Graph showing NOx emissions over time comparing baseline controller and model-based controller.
Results To-date

- Controller evaluation in 3\textsuperscript{rd} quarter of the FTP cycle
- Initial results are encouraging
  - Controller operates in real-time
  - Verified controller’s ability to “steer” engine performance towards high/low NOx and CO\textsubscript{2}
  - Control is stable
  - Torque is maintained
  - CO\textsubscript{2} vs. NOx trade-off benefit
Summary & Next Steps

- Fully model-based, practically-mapless engine control concept is viable

- Main limitations of the approach
  - Large amount of transient engine data required
  - Vehicle-to-vehicle variability
  - Increased ECU computing power required

- Next Steps
  - Expand the use of the control technique to additional systems
  - Evaluate the controller over full transient cycles
  - Quantify the potential fuel economy benefits in a vehicle
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