Advanced Control in Industrial Diesel Engines

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Diesel engine control

Outline of presentation:
- Drivers for increasing complexity
- The industrial control development process
- Control problem
- Computing environment
- An innovation
Powertrain Control in the Transportation Industry

- Increasingly Tighter Requirements
  - Emissions Legislation
  - Fuel Efficiency
  - Performance
  - Reliability
  - Cost

- Increasing Engine Complexity
  - More components, actuators, & sensors

- Lines of automotive code have been increasing by a factor of 10 every 8 years

- Development cost for software will exceed that of hardware before 2020

Industry currently spending $1B/yr in control design
Industrial Powertrain Control Development
Overview of Standard Control Development Process

- Development and testing of prototype controller structures

Engine and steady-state calibration

Control development

Design for many different, highly nonlinear subsystems
Overview of Standard Control Development Process

- Engine and steady-state calibration
- Control development
- Software development
- (Potentially lengthy) coding of prototype control into embedded platform (ECU)
Overview of Standard Control Development Process

- Engine and steady-state calibration
- Control development
- Software development
- Calibration (tuning) of controllers

• On-engine tuning of free controller parameters to achieve desired performance

Calibration process must be fast, robust and require no advanced control expertise
Overview of Standard Control Development Process

- Preparation and testing with certification authorities

Engine and steady-state calibration

Control development

Software development

Calibration (tuning) of controllers

Certification

- Euro 6
- US2010
- Tier 4
- ULEV
- ...

Cold start phase 0-505s
Transient phase 505-1369s
Hot start phase 1369-1874s

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Overview of Standard Control Development Process

- Potential revisions to control due to post-release issues

Engine and steady-state calibration

- Control development

- Software development

- Calibration (tuning) of controllers

- Certification

- Release

- Post-release support
The control problem (plant)
Nonlinear and Multivariable Interactions in Turbodiesel Air System

• Even at fixed engine speed and fuel rate there are significant nonlinearities.
• Transient driving conditions are even more challenging…

Compare similar illustration in “Control of Variable Geometry Turbocharged Diesel Engines for Reduced Emissions” by Stefanopoulou, Kolmanovsky, and Freudenberg. IEEE TCST, July 2000.
Nonlinearity is also a function of engine speed and injected fuel quantity.

- Contours of Constant VNT and EGR @ NE = 1200 [rpm], Fuel Rate = 3.55 [kg/hr]
- Contours of Constant VNT and EGR @ NE = 1500 [rpm], Fuel Rate = 5.45 [kg/hr]
- Contours of Constant VNT and EGR @ NE = 2000 [rpm], Fuel Rate = 7.51 [kg/hr]
- Contours of Constant VNT and EGR @ NE = 2500 [rpm], Fuel Rate = 12.43 [kg/hr]
- Contours of Constant VNT and EGR @ NE = 3000 [rpm], Fuel Rate = 3.72 [kg/hr]
- Contours of Constant VNT and EGR @ NE = 3500 [rpm], Fuel Rate = 12.12 [kg/hr]
- Contours of Constant VNT and EGR @ NE = 4000 [rpm], Fuel Rate = 4.74 [kg/hr]
• The preceding nonlinearities occur in this simple configuration…
Multiple Stage Turbocharging

Serial dual-stage

Parallel dual-stage*

* EGR not illustrated
Overview of Standard Control Development Process

Resulting controller must perform well for all engines and over lifetime of fleet.

Engine and requirements

Control development

Software development

Calibration (tuning) of controllers

Certification

Release

Post-release support

fleet

time [years]

0

20

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The control problem
(control)
Challenging control problem

• Many different control configurations exist in practice:

**Setpoints**
- Intake pressure (MAP)
- Compressor flow (MAF)
- EGR flow
- Exhaust temp
- Exhaust NOx
- Etc.

**Actuators**
- Turbocharger vanes (VGT)
- Wastegate
- EGR valve
- Intake throttle
- Exhaust throttle
- Fuel injection timing
- Rail pressure
- Etc.

**Constraints**
- Actuators (always)
- Air fuel ratio
- Turbospeed
- Intake pressure
- Static or varying
- Etc.

• Even a single engine maker may need to support various control configurations.
The computing platform
Control Implementation Platform

Automotive* versus Process industry

*Image from “Cat Electronics Product Directory”
Processor Speed

*Image from “Cat Electronics Product Directory”

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Control Implementation Platform

Memory

2-4 MB

32 GB

automotive  process industry

*Image from “Cat Electronics Product Directory”
An innovation
Honeywell OnRAMP

Model Structure

Control Design

RP System or ECU

Optimal Multivariable Control

• Explicit MPC control
• Robust to engine variability and aging
• Automatic generation of models and code for embedded systems
• Human-machine interface tailored to skill set of users

Commercial software released in Fall 2011
Summary

• Industrial powertrain control requires balance of many requirements

• We overviewed:
  - Drivers for new complexity
  - The industrial control development process
  - Challenges from the plant
  - Challenges from control needs
  - Computing environment

• Honeywell powertrain control – systematic tool:
  - Modeling
  - Control Design
  - Controller Deployment
Honeywell is recruiting!

- Open positions in Honeywell Automotive Software in research and development for advanced powertrain control.

- See [www.honeywellonramp.com](http://www.honeywellonramp.com) for details.
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Our Selected Publications


• "A Pragmatic Approach to Robust Gain Scheduling" Greg Stewart, in proceeding of IFAC Symposium on Robust Control Design, June 2012.