Artificial Intelligence Based Calibration and Control for Future Engines

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Outline

• Trend of Development
• Research Methodologies
• Research Facilities
• Achievements
• Conclusions
• Future Outlook
Publications used for this presentation


Trend of Development

Engine Control Road Map

Vision and Target

Source: Ford, 2018
Trend of Development

Engine Calibration

- Start
  - DoE based Tests Planning
  - Current Model-based Engine Calibration Approach
  - Experimental Measurements on Test Bench

- Parallel Engine Measurements and Calibration/Optimization
  - Model-based Engine Calibration/Optimization
  - Statistical Engine Model Development

- Finish

Methods:
- Non-model based
- Model based
- Human based
Efficient Calibration

- More efficient:
- Online
- Iterative processing
- Self-adaptive
- Self-learning

Source: Ford, 2018
Efficient Control based on Calibration

- Online parameters optimization
- Automatic
- Self-adaptive
- Self-tuning

Source: Ford, 2018
Research Methodology

- Strength Pareto Evolutionary Algorithm 2 (SPEA2)
- Chaos-enhanced Accelerated Particle Swarm Optimization (CAPSO)

Application
- Intelligent Engine calibration
- Intelligent Component Sizing
- Top Level Online Intelligent Control

Application
- Model-Free Predictive Control
- Complex System Modelling
- Driver Behavior Prediction
- Advanced Model Predictive Control

Artificial Intelligence
Intellectualizing the Future

Evolutionary Algorithm

Fuzzy Logic
- Fuzzy Logic Controller (FLC)
- Fuzzy clustering

Machine Learning
- Model Predictive Control (MPC)
- Model-free Predictive Control (MFPC)
**Research Methodology**

- **Model Predictive Control (MPC)**

\[
\text{if } N_{\text{eng}} \in [A_i, B_i] \text{ and } Q_{\text{fuel}} \in [C_i, D_i] \\
\text{then } W_y = W_{y_i}; W_u = W_{u_i}; W_{\Delta u} = W_{\Delta u_i} \\
\text{then swi is } N \text{ (i.e. MPC } N \text{ and internal model } N \text{ is active)}
\]
• Self-adaptive PI-like fuzzy knowledge based controller (FKBC)


The rule in column 4 and row:

IF $X_1$ is Zero, AND $X_2$ is Negative Medium, THEN PI output = Positive Small.
Research Methodology

- **Multi-objective Optimization based on Strength Pareto Evolutionary Algorithm 2**

The implementation of the Strength Pareto Evolutionary Algorithm 2 (SPEA2) to find the optimal engine parameter settings for the lowest fuel consumption and PM emissions.

**Working flow of SPEA2**

**Platform combined with SPEA2 and test bench**

Research Methodology

- Multi-objective Optimization based on Chaos-enhanced Accelerated Particle Swarm Optimization Algorithm

Experimental Facility and Methodology

Design of control strategy

Rapid Control Prototyping (RCP)

Engine test bench

ETK-bypass

INTECARIO

INCA-EIP

SIMULINK

Rapid Control Prototyping (RCP)
Experimental Facility and Methodology

Design of control strategy

Offline Test

Online Test

Hardware In the Loop (HIL)

Control-oriented Engine Model

Test Bench Validation

CAN interface
Ethernet
CAN interface

I/O PIN
Controller
Host PC

I/O PIN
RTPC
Short interface
Achievements

- **Computational Intelligence Non-model-based Calibration Approach (CINCA)**

![Diagram of the GDI engine]

Platform combined with SPEA2 and test bench

Optimization problem

\[
\begin{align*}
\min \text{ BSFC} &= f_1 (IVO, EVC, Spk_t, Inj_t, Rail_P) \\
\min \text{ PMn} &= f_2 (IVO, EVC, Spk_t, Inj_t, Rail_P) \\
\min \text{ PMm} &= f_3 (IVO, EVC, Spk_t, Inj_t, Rail_P) \\
-25\text{CAD} &\leq IVO \leq 35\text{CAD}, \text{ after gas exchange TDC} \\
0\text{CAD} &\leq EVC \leq 50\text{CAD}, \text{ after gas exchange TDC} \\
-10\text{CAD} &\leq Spk_t \leq 50\text{CAD}, \text{ before combustion TDC} \\
250\text{CAD} &\leq Inj_t \leq 400\text{CAD}, \text{ before combustion TDC} \\
15\text{MPa} &\leq Rail_P \leq 20\text{MPa}
\end{align*}
\]

Achievements

- Computational Intelligence Non-model-based Calibration Approach (CINCA)

Convergence of particles after 50 loops of iteration
(1500 rpm / 8.3 bar BMEP)


<table>
<thead>
<tr>
<th>BSFC</th>
<th>3.1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMn</td>
<td>6.8%</td>
</tr>
<tr>
<td>PMm</td>
<td>6.9%</td>
</tr>
</tbody>
</table>
Achievements

- Intelligent Air/Fuel Ratio Control Strategy with a PI-like Fuzzy Knowledge Based Controller for GDI Engines

Self-adaptive and self-tuning

Settling time  56.25%
ITAE  58.67%

Experimental Facility and Methodology

- Tuneable model predictive control of a turbocharged diesel engine with dual loop exhaust gas recirculation
Results and discussion

- Tuneable model predictive control of a turbocharged diesel engine with dual loop exhaust gas recirculation

The mechanism of the BSFC reduction via the MPC-based controller is the improved VGT efficiency. Compare with the PI controller, the MPC-based controller achieves better performance on regulating the LPEGR fraction, while keeping the total EGR rate as the target value.

Research Methodology

- Intelligent Transient Calibration of a Dual-loop EGR Diesel Engine using Chaos-enhanced Accelerated Particle Swarm Optimization Algorithm

Results and discussion

- Intelligent Transient Calibration of a Dual-loop EGR Diesel Engine using Chaos-enhanced Accelerated Particle Swarm Optimization Algorithm

Results and discussion

• Intelligent Sizing of for the Hybrid Engine
  - An algorithm for hybrid electric powertrain intelligent sizing is developed
  - The proposed CAPSO algorithm is capable of finding the real optimal result with much higher reputation.
  - The CAPSO gave more reliable results and increased the efficiency by 1.71%.

https://hyperdriveinnovation.com/new-hybrid-aircraft-push-back-tractor-on-show-at-inter-airport-europe-exhibition/

Zhou Q., Zhang Y., Li Z., Li J, Xu H.*, Oluremi O., Cyber-Physical Energy-Saving Control for Hybrid Aircraft-Towing Tractor based on Online Swarm Intelligent Programming, IEEE Transactions on Industrial Informatics, 2018,
Results and discussion

- Energy Management for Hybrid

  - The OSIP can optimize the vehicle performance in real-time with a maximum prediction horizon size of 35s.

  - The vehicle with OSIP outperforms the system without it in energy saving at all initial battery SoC level

  - The proposed energy management method is robust and reliable, and up to 17% fuel and 13% total energy saving

HiL test result (vs. CD/CS)

Modelling of energy-flow

Controller framework

Target vehicle

Zhou Q., Zhang Y., Li Z., Li J., Xu H.*, Oluremi O., Cyber-Physical Energy-Saving Control for Hybrid Aircraft-Towing Tractor based on Online Swarm Intelligent Programming, IEEE Transactions on Industrial Informatics, 2018,
Outlook
Contributions & Future Work

- A TMPC controller for the diesel engine’s air path has been developed;
- A model-based computational intelligence multi-objective calibration approach for internal combustion engines is developed;
- A computational intelligence non-model-based calibration approach for internal combustion engines is developed;
- A PI-like fuzzy knowledge based controller for feedback control loop of internal combustion engines is developed;
- 11 research papers have been published.

☐ An online self-mapping fuzzy logic PI controller is being developed now.

☐ Artificial neural network model (deep learning) for model development.

☐ From model-based control method to model-free control method (deep reinforcement learning).
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Yunfan Zhang – Model Based Diesel Engine Control

Quan Zhou – Artificial Intelligence for Hybrid Electric Vehicles Development and Control

Scott Cash – Hybrid Electric Vehicle Modelling and Control

Ziyang Li – Non-model Based GDI Engine Optimization

Ji Li – Development of Driver-oriented Energy Management Scheme for Hybrid Electric Vehicles

Yinglong He – Energy Management for Connected and Autonomous Vehicular Platoon


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Thank you for your attentions