Control-oriented Modeling Toolchain for Reactivity Controlled Compression Ignition Marine Engines

Clean Propulsion Technologies

RCCI| low temperature combustion | control-oriented modelling | model-based powertrain development

Abstract

Clean Propulsion Technologies aims to demonstrate for the first time a state-of-the-art, ultra-efficient Reactivity Controlled Compression Ignition (RCCI) engine for marine and stationary applications. The challenge of engine controller development is overcome by conceiving a novel model-based controller design (MBCD) methodology which incorporates a simulation toolchain to arrive at a physics-based real-time capable (5-20 ms) combustion control model. Thus, the approach enables development of robust controller capable of handling 12 – 15 independent control parameters.

The models

The toolchain mainly involves a (1) fully predictive chemical-kinetics based UVATZ (University of Vaasa Advanced Thermo-kinetic Multi-zone) and (2) a linearized physics-based real time model (RTM). Fig. 1 shows the components and development phases of the MBCD simulation toolchain. Phase 1 is measurement campaign of steady-state operating data from target platform. Phase 2 validates the fully predictive UVATZ, based on which the RTM is calibrated in Phase 3. The UVATZ also provides transient operation data for validating the RTM. In Phase 4 model predictive controller (MPC) design and model-in-the-loop (MIL) simulation is conducted. Finally, full controller validation is performed on the target hardware in Phase 5.

Figure 1. Schematic of RCCI control-oriented modeling toolchain and MBCD workflow

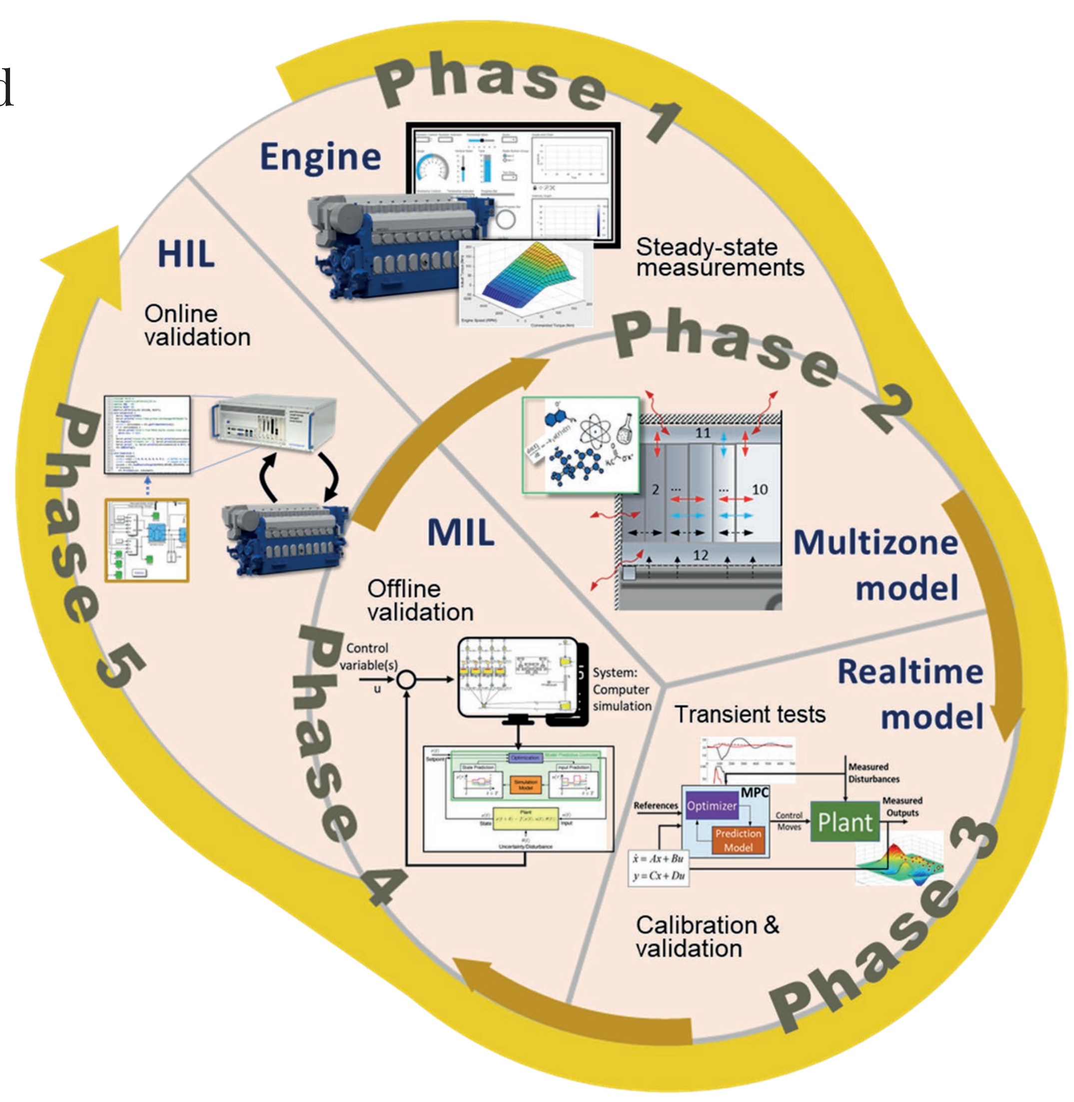


Table 1. UVATZ and RTM modelling assumptions

	RTM	UVATZ
Heat release	Linear observer	Full chemical reaction
Fidelity	SOC estimation, apparent heat release, cylinder pressure estimation	Chemical kinetics, fuel stratification, turbulence-based mixing
Predictivity	Total fuel energy, blend ratio (BR), TIVC,EGR	Full in-cylinder physics
Simulation time	5–20 ms	3–5 min

Results

The UVATZ model and RTM are compared with the experimental measurements at two steady-state operating points (1a and 1b). The indicated mean effective pressure (IMEP), crank angle of 50% mass burned (CA50), and peak cylinder pressure Pmax are compared in Fig.2 and Fig.3

Figure 2. UVATZ and RTM modelling errors concerning experimental measurements, dashed lines indicate the target accuracy (±5%)

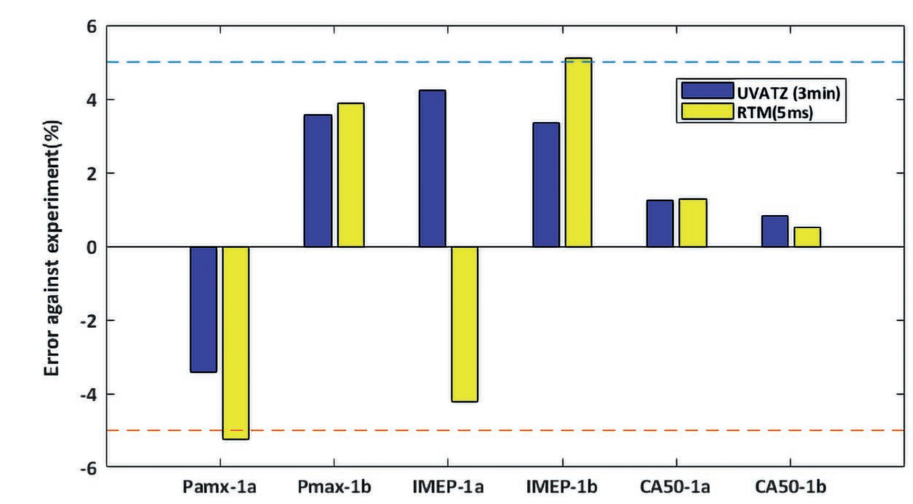
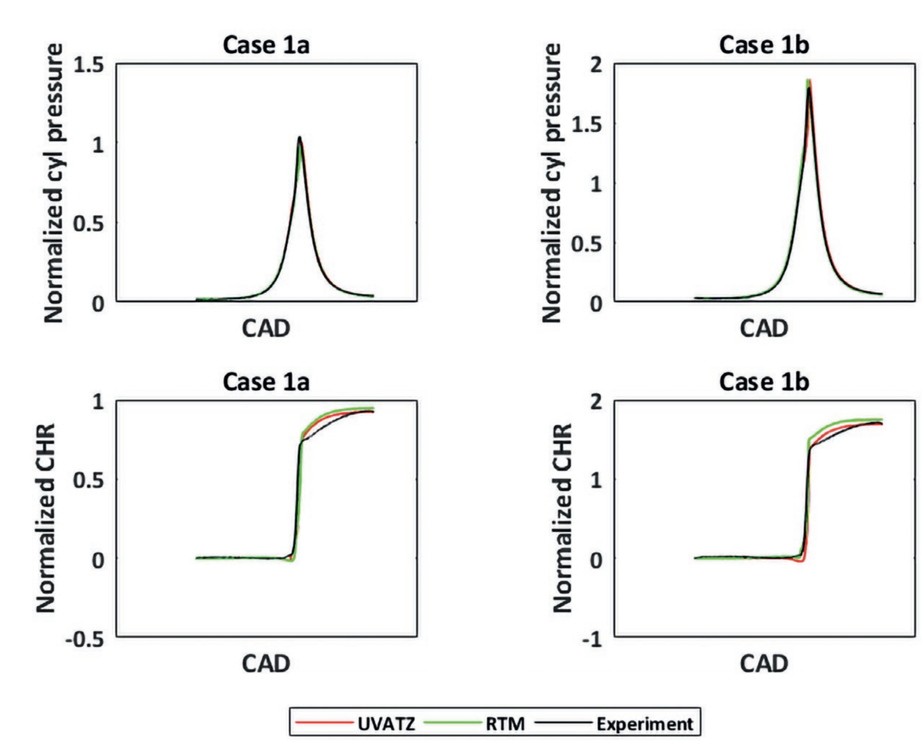


Figure 3. UVATZ and RTM simulation results against experimental measurements of cylinder pressure and cumulative heat release (CHR)



Conclusions

- UVATZ and RTM simulation frameworks have been comprehensively validated against experimental data. RTM can predict both cycle-wise combustion IMEP, CA50 and Pmax , but also crank angle-based cylinder pressure, pressure rise rate, and CHR.
- Overall, RTM achieves both steady-state and transient estimation errors for IMEP, Pmax, and CA50 are below 7% compared to experimental results with a simulation speed of around 5-20 ms.
- MPC is validated through model-in-the-loop simulation.
- Once completed, will be first of its kind fully predictive toolchain for efficient RCCI simulations.

Find out more

SAE International — Vasudev, A., et al. *"Towards next generation control-oriented thermo-kinetic model for reactivity controlled ignition marine engine"*, SAE Powertrains, Fuels & Lubricants Conference, 2022

Progress in Energy and Combustion Science — Vasudev, A., et al. *"Thermo-kinetic multi-zone modelling of low temperature combustion engines"*, Progress in energy and combustion science, 2022

IFAC — Modabberian, A., et al. *"Towards Real-Time Combustion Phase Estimation for linear RCCI Model-Predictive Control Design"*, IFAC World Congress 2023*

Storm, X., et al. *"Real-time Predictive Model for Reactivity Controlled Compression Ignition Marine Engines"*, Control Engineering Practice, 2023*

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