Model-assisted optimal control framework for industrial system coupling problems

Wei, X.

Summary

This dissertation investigates coupling phenomena in industrial systems and proposes a model-assisted optimization control framework tailored to three representative scenarios: system–environment coupling, coupling among system components, and system–working medium coupling. Following a progressive path of "classification–modeling–customized optimization", it systematically addresses the core control challenges inherent to each coupling type.

In the system–environment coupling scenario, to resolve the decision inaccuracies caused by partially observable environmental states, a layered partially observable Markov decision process (POMDP) framework is proposed. Taking TBM trajectory navigation as a case study, the belief layer models the temporal sequence of historical observations to implicitly infer unobservable geological states, while the joint decision layer fuses raw observations with inferred beliefs in parallel. This enables optimal thrust prediction and path planning without requiring explicit reconstruction of the environmental state.

In the system–component coupling scenario, to reconcile the conflict between high-dimensional parameter spaces and the prohibitive cost of high-fidelity simulations, a surrogate-assisted one-shot optimization method is developed. Using reflow soldering temperature zone control as a case study, a Transformer – CNN hybrid architecture is constructed to invert the production workflow into an end-to-end inverse mapping. This approach achieves accurate and rapid control parameter prediction from limited data, completely eliminating iterative search procedures.

In the system–working medium coupling scenario, to address the nonlinear hysteresis and overshoot risks introduced by capacitive media, a CMA-ES-based safe and coordinated control strategy is proposed. Taking a centrifugal compressor as a case study, the Greitzer lumped-parameter model is employed to quantify the surge boundary in real time. The control objective is reformulated from “minimizing response time” to “planning feasible trajectories within safety constraints.” An evolutionary algorithm is then applied to optimize multivariable PID parameters online. The proposed strategy effectively suppresses overshoot and enhances robustness across three typical operating conditions.