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Closed-Loop PID Re-Tuning in a Digital Twin By Re-Playing Past Setpoint and Load Disturbance Data

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Abstract Text:

Objectives

The PID controller is the most widely used basic regulatory control algorithm. PID control is important in chemical engineering processes as it plays a critical role to form the basis of advanced process control and optimization systems such as model predictive control (MPC) and real-time optimization (RTO). However, its performance can vary greatly on the tuning of its three (3) parameters. There are several different types of the PID tuning rules or heuristics reviewed in [1]. However, it can be demanding for the regular operators, instrument technicians and process engineers or inexperienced process control engineers to choose the most suitable rule and use the rule properly in the actual operating physical system or environment.

Optimization-based PID tuning is the other option and thanks to the advances of computational power can be a viable approach provided the objective function and setpoint and load disturbance scenarios are properly chosen. Numerical optimization techniques are divided into two different categories. One is a model gradient-based optimization and the other is non-gradient based optimization. However, because of the non-convexity nature of the PID tuning model, a majority of the PID tuning research has been done using non-gradient optimization algorithms such as particle swarm [2, 3], and extremum seeking [4] algorithms. The other group of research study has been done using random search methods or meta-heuristics including genetic algorithm [5] for example.

The main objective of this study is to propose a practical technique using past or historical setpoint and load disturbance data to re-tune the PID controller's installed tuning parameters in a more effective and way. The brute-force or exhaustive search method guarantees to find the optimal value of the objective function without the risk of stalling at a local minimum value at the expense of traversing a pre-defined PID parameter search space. Additionally, the reliability of the tuning result is further increased by setting the simulation conditions to be as close as possible to the real or actual operation to create a digital twin or cyber-physical view of the installed characteristics of the PID controller.

Methods

This study proposes two main ideas to improve the PID re-tuning practice in real operating environments. First, it uses an exhaustive search method, alternatively called a brute- force method. This method has several benefits. First, it is very simple to implement. It does not employ any of numerical methods other than a simulation of the expected installed performance using past setpoint and load disturbance data. It simply evaluates all the possible combinations of PID parameters resulting in the list of the objective function values and finds the smallest or minimum value out of the list. The logic can be written in any computer programming language just three (3) DO or FOR loops. Despite the simplicity of the method, its performance can be greater than the other advanced optimization methods, especially for the PID tuning because it never converges to a local minimum stalling at a local stationary point in the search region. Second, it employs several elements to pose simulation or surrogate conditions that better replicates the real operating environment of the PID controller by: (a) re-playing back the past or historical setpoint and load disturbances [6]; (b) allowing multiple, simultaneous and weighted process models to be included in the digital twin simulations (i.e., multiple scenarios or situations with probabilities); (c) including multiple and simultaneous PID controller configuration formulation (Equation A or B); (d) specifying any type of performance objective function criteria i.e., minimize the output-error and input-move variances, etc. and (e) adding stability rules to the search to cut-off unstable sections of the closed-loop operating space.

To test the value of the exhaustive search method, an Arduino temperature control kit is studied. This is a physical device that has a heater and temperature sensor which can be controlled and measured. First, the temperature control kit is run to create the closed-loop operation data with de-tuned PID parameters and selected setpoint change sequences. A process model is then identified using a second-order plus dead time (SOPDT) structured model using the GEKKO dynamic optimization suite [7] estimating its coefficients using a least-squares objective function. Then, the exhaustive search method evaluates the range or domain of the different P, I, and D parameters. The best search objective function found provides the P, I, and D settings which are updated to the corresponding PID parameters through the following equations. The PID controller is then run again with the temperature control lab now using the re-tuned PID parameters and the data recorded.

Results, Observations, Conclusions

The PID tuning result using the exhaustive searching method is investigated and tested using the Arduino temperature control device. This method shows the reliable performance for the global minimum searching as opposed to the gradient-based optimization that can easily stall at local minima depending on the location of the initial value of iteration. The higher accuracy of the PID tuning is achieved by using the exact same sequences of setpoint change and reflecting the load disturbance during the process model evaluation.

Novel/Additive Information

- The exhaustive search method is applied to PID tuning suggesting the straightforward method that can be easily applied in real operation using a digital twin simulation.
- Re-tuning the PID controller in the digital twin and re-playing setpoint and load disturbances where the residuals of estimation are considered as the unmeasured load disturbances.

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