Automatic PID Tuning Using Extremum Seeking

Nicholas J. Killingsworth
(925) 422-8489
killingsworth2@llnl.gov

About ninety percent of all control loops use proportional integral derivative (PID) controllers. These controllers are typically tuned manually, often with poor results. A large increase in system performance can be achieved using a more systematic approach to controller tuning, leading to a more efficient and robust system. However, available tuning methods are overly complex, are valid only for linear systems, or require a model of the system. There is considerable need for straightforward non-model-based methods that are easy to implement and applicable to nonlinear systems.

We have created a non-model-based method of tuning PID controllers that can be applied to nonlinear systems on-line. This method uses extremum seeking (ES), which is a non-model-based real-time optimization algorithm (Fig. 1). The ES PID controller tuning tool has the potential to optimize system performance while minimizing engineers' time dedicated to controller tuning.

Project Goals

The main goal of this project is to create a set of rules to automate the selection of the parameters of the extremum seeking algorithm. A block diagram of the ES algorithm is presented in Fig. 2. To effectively use the ES algorithm, the adaptation gain, γ_i, and the perturbation amplitude, α_i, must be selected for each input to the system because they depend on the system's being optimized. Automating this selection procedure will allow non-experts to use the ES algorithm for optimization

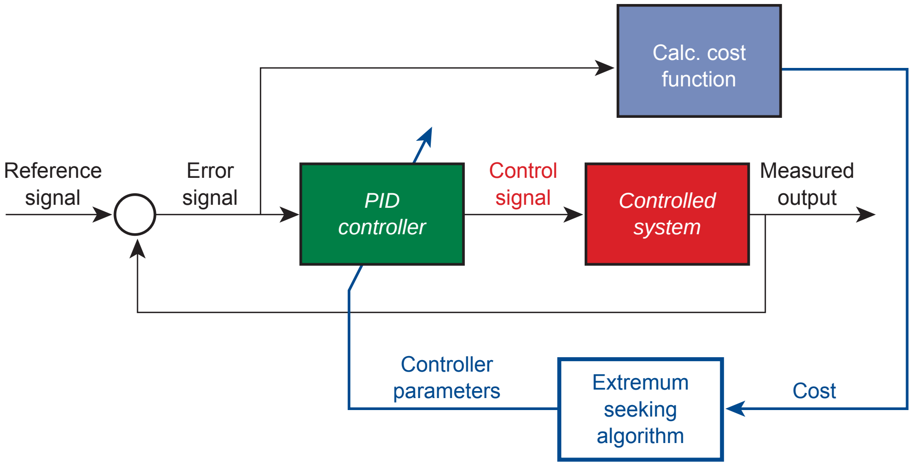

Figure 1. The overall ES PID tuning scheme. The ES algorithm updates the PID controller parameters to minimize a cost function that quantifies the performance of the PID controller on the controlled system.

of their system. This automated tuning procedure will be implemented in a user-friendly software package, permitting inexperienced users to optimally tune a PID controller for any application.

After testing the automated procedure on simulated systems we are planning to demonstrate the capabilities of the methodology by applying it to the control system for advanced internal combustion engines. Additionally, we plan on applying the method to the sulfur hexafluoride (SF_6) gas pressure control system of the flash x-ray (FXR) radiographic facility at LLNL. FXR constitutes the ideal test bed for this application due to its great complexity (currently with 27 PID controllers, expandable up to 66), which makes it extremely time-consuming to tune with other available procedures.

Relevance to LLNL Mission

Our automated tuning procedure has great potential for improving operational control due to the widespread use of PID controllers. The market potential within and outside LLNL is enormous, leading to improved operation and external funding. This project has application to many LLNL programs using feedback control. We will be applying this tuning method to the FXR experiment. We also anticipate applicability of this technology to energy security topics of interest to LLNL, such as control of hybrid vehicles and internal combustion engines.

FY2008 Accomplishments and Results

We have produced a methodology to automate the selection of ES parameters. This methodology has been successfully implemented in software and applied to find the extrema of various nonlinear maps. This automated software package was then adapted to optimally tune PID controllers. The tuning method has been demonstrated on a variety of *simulated* systems, including systems that are

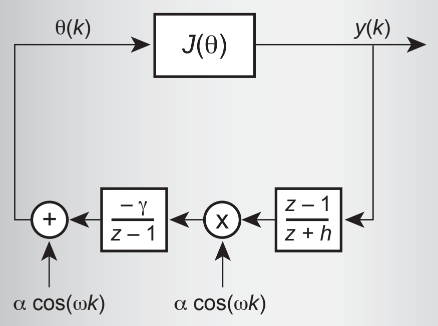

Figure 2. Block diagram of ES algorithm. The input parameters θ (k) are perturbed by the signal $\alpha_i, cos, (\omega_i, k)$. The output of the cost function J (θ (k)) is then high-pass filtered, demodulated, and finally low-pass filtered to yield new output parameters.

difficult to control, such as those presenting non-minimum phase behavior and nonlinearities. Fig. 3 shows an initial PID controller tuned using the industry standard Ziegler-Nichols tuning rules (ultimate sensitivity method) and acting on a system with non-minimum phase behavior. A controller tuned using the automated ES algorithm greatly improves the performance, reducing the system's overshoot and settling time.

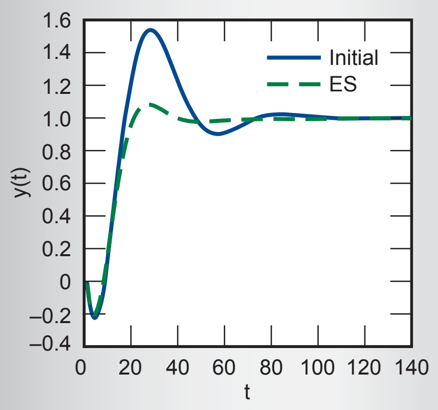

Figure 3. Step response of initial PID controller tuned using the Ziegler-Nichols tuning rules and the PID controller tuned using the automated ES methodology both applied to a non-minimum phase system. The automated ES tuning method decreases the system's overshoot and settling time versus the initial controller when a step function is applied at time zero.

Related References

1. Killingsworth, N. J., and M. Krstic, "PID Tuning Using Extremum Seeking," *Control Systems Magazine*, **26**, pp. 70–79, 2006.
2. Killingsworth, N. J., S. M. Aceves, D. L. Flowers, F. Espinosa-Loza, and M. Krstic, "HCCI Engine Combustion Timing Control: Optimizing Gains and Fuel Consumption Via Extremum Seeking," *IEEE Transactions On Control Systems Technology*, 2008.
3. Ariyur, K. B., and M. Krstic, Real-Time Optimization by Extremum Seeking Feedback, Wiley-Interscience, Hoboken, New Jersey, 2003.
4. Astrom, K. J., and T. Hagglund, PID Controllers: Theory, Design and Tuning, Instrument Society of America, Research Triangle Park, North Carolina, 2nd Ed., 1995.

FY2009 Proposed Work

After successful testing of the tool in simulations, the tuning method will be demonstrated on experimental systems, including a high-pressure gas system for an internal combustion engine at UC Berkeley and the FXR SF_6 gas pressure control system. We will work with experienced engineers on both systems to create an implementation plan and desired outcomes. We will apply the PID tuning tool to each system and compare the performance to the PID controllers currently in use.