PID Control

By CARL KNOSPE, GUEST EDITOR

INTRODUCTION TO THE SPECIAL SECTION

Proportional-integral-derivative (PID) control is certainly the most widely used control strategy today. It is estimated that over 90% of control loops employ PID control, quite often with the derivative gain set to zero (PI control). Over the last half-century, a great deal of academic and industrial effort has focused on improving PID control, primarily in the areas of tuning rules, identification schemes, and adaptation techniques. It is appropriate at this time to consider the state of the art in PID control as well as new developments in this control approach.

The three terms of a PID controller fulfill three common requirements of most control problems. The integral term yields zero steady-state error in tracking a constant setpoint, a result commonly explained in terms of the internal model principle and demonstrated using the final value theorem. Integral control also enables the complete rejection of constant disturbances. While integral control filters higher frequency sensor noise, it is slow in response to the current error. On the other hand, the proportional term responds immediately to the current error, yet typically cannot achieve the desired setpoint accuracy without an unacceptably large gain.

For plants with significant dead time, the effects of previous control actions are poorly represented in the current error. This situation may lead to large transient errors when PI control is used. Derivative action combats this problem by basing a portion of the control on a prediction of future error. Unfortunately, the derivative term amplifies higher frequency sensor noise; thus, a filtering of the differentiated signal is typically employed, introducing an additional tuning parameter. A PID controller with a derivative filter is often referred to as a PIDF controller. While the three PID terms are sufficient to parameterize a structure that permits successful control of many plants, the number of terms is small enough to allow manual tuning by an operator. Furthermore, the small number of terms lends itself to both direct adaptive control and self tuning through heuristics.

The impulse response of each of the PIDF control actions can be viewed as a basis vector for the overall control action. The impulse response of the controller is constructed by a linear combination of these basis vectors. In design or tuning, the challenge is to achieve acceptable performance from a controller in the subspace spanned by this basis. In this light, alternative basis functions can be employed (and implemented digitally with ease) to achieve the same basic functionality as PID, such as immediate response, internal model, and error prediction.

Given that this functionality can be achieved in multiple ways, what accounts for the overwhelming popularity of PID? First, the three terms are reasonably intuitive, allowing a nonspecialist to grasp the essentials of the controller's action. A working knowledge of PID does not require the operator to be familiar with advanced mathematical developments. As such, PID is found in essentially all undergraduate control courses. Second, PID has a long history, dating back to a predigital, even pre-electronic, period. As such, many engineers are familiar with PID, and its use has become standard practice. Third, the introduction of digital control has enhanced PID's capabilities. Adaptation, self-tuning, and gain scheduling can be easily introduced into PID control. Since engineers prefer to enhance the performance of a well-known solution through additional capabilities rather than switch to an untested solution, alternative digital control methods have not supplanted PID's primacy in industrial control. One possible exception is

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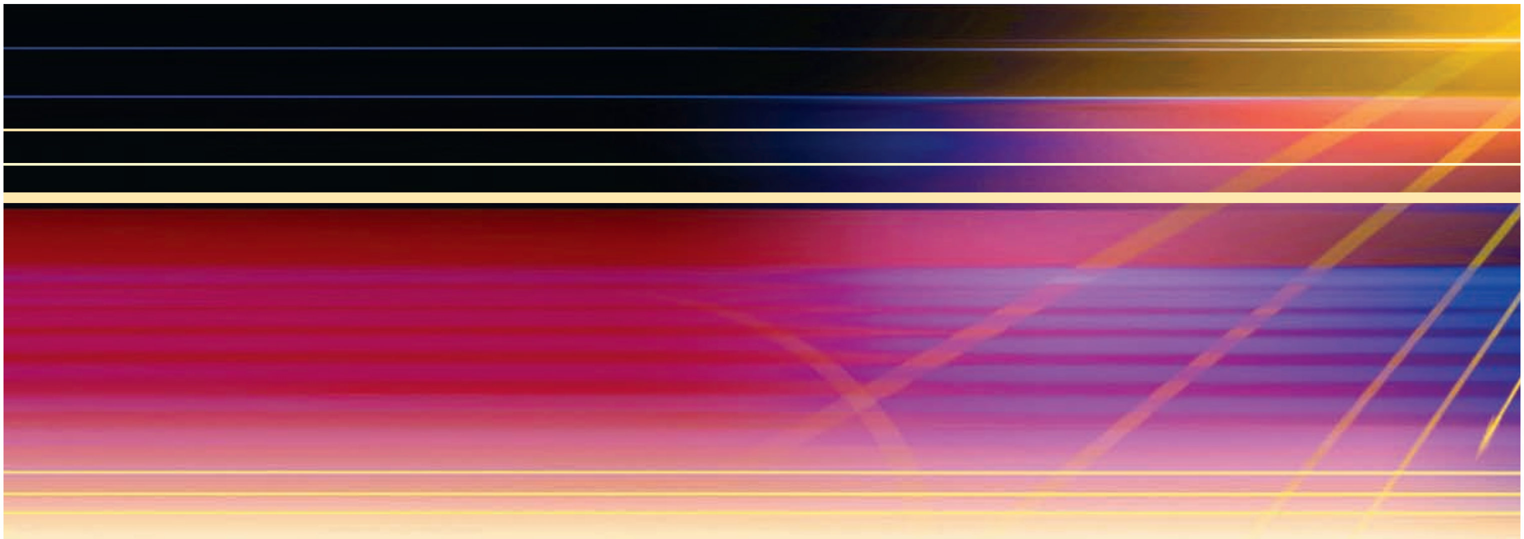

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model predictive control, where the real-time computational capability of today's processors is harnessed to calculate the control law on the fly. Of course, PID still has a role in this case, handling lower level loops.

This special section includes five feature articles that examine PID control as it is practiced today and explore recent innovations that point toward the future. The first article by Li, Ang, and Chong provides an overview of PID control. The PID terms and their effect on stability and performance are examined in detail, and some common misconceptions are dispelled. Design methods are then discussed, with the authors employing the software package PIDEasy as an illustrative example. The second article, also by Li, Ang, and Chong, reviews the state of industrial PID control with a careful examination of patents, hardware, and tuning software. This review makes it clear that PID vendors have fully embraced the capabilities offered by digital control. However, the article also shows that the flexibility offered by digital hardware can result in ad hoc control approaches that detract from the simplicity and ease of use of PID.

In the third article, Kristiansson and Lennartson present new PIDF tuning rules developed through optimization so as to achieve good midfrequency robustness with a favorable tradeoff between output performance and control effort. These rules are formulated for the one-degree-of-freedom control problem and, of particular significance, include tuning of the derivative filter pole as well as the standard terms.

In the article by Killingsworth and Krstić, online adaptation of the PID parameters is achieved by a discrete version of extremum seeking (ES). Several cost functions are considered. Although ES requires selection of the parameters associated with its adaptation algorithm, the article demonstrates that the PID solution achieved by the adaptation is not strongly affected by the choice of these tuning parameters.

In the final article by Hara, Iwasaki, and Shiokata, a convex optimization approach to synthesizing PID controllers is presented from the perspective of the loop-shaping paradigm. Here, the goal is to find a PID controller (if one exists) that allows the loop transfer function to achieve gain and phase specifications over finite frequency intervals. The results are based on a generalization of the Kalman-Yakubovich-Popov lemma, which is necessary and sufficient. As such, if a solution to the convex optimization is not found for a given set of specifications, there is no PID controller that satisfies these specifications.

The PID framework solves many control problems and is sufficiently flexible to incorporate additional capabilities. We can thus expect that this technique will continue to play an important role in control practice. In spite of PID's long history and widespread usage, surveys of industrial applications report that many PID feedback loops are poorly tuned. Advances in automated tuning and diagnostics can improve the performance of existing loops, thereby increasing efficiency and productivity.

I wish to thank the authors who have contributed to this special section. Their work represents a key step in realizing the potential of PID control.

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