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White Paper



### Principles of PID Controllers

Zurich Instruments

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#### Introduction

Self-regulating systems using feedback loops, i.e. the routing back of the output of a system to its input, have existed since antiquity and have nowadays become an integral part of modern technology. One of the first attempts to rigorously describe control loops using feedback traces back to more than 150 years ago with James Clerk Maxwell's article, "On Governors" [1].

In the context of control strategies, an open-loop control system refers to a controller whose action is determined based on predetermined input values without considering feedback. In contrast, a closed-loop controller incorporates continuous feedback, enabling real-time adjustments to enhance precision, stability, and robustness, making it more suitable for achieving desired control objectives in changing conditions. Today, the most widespread type of closed-loop control systems is the Proportional-Integral-Derivative (PID) controller. These types of controllers continuously measure and adjust the output of a system to match a desired setpoint, that is, a given target condition for the system or process under consideration. Requiring little prior knowledge or model of the system, PID controllers are extremely versatile, relatively cost-effective and straightforward to implement, making their realization possible in a large variety of processes from hydraulics and pneumatics to analog and digital electronics. For this reason, they have become ubiquitously used in a variety of industries and research applications, including manufacturing, photonics, sensors, material science and nanotechnology.

PID control loops are widely employed in various aspects of everyday life and industrial automation, such as the gyroscopes found in smartphones and self-driving cars, means used for cooking food or satellites. Flow controllers in pipes, and even in managing the daily vehicle traffic. At the same time, they also stand out in more advanced research fields as well, for example in the stabilization of laser cavities and interferometers in optics and photonics, in closed-

loop control of MEMS-based inertio-electromechanical systems, gyroscopes, and in the characterization of mechanical resonators in scanning probe microscopy (SPM).

This white paper presents the key functions and principles of PID control loops by analyzing their basic building blocks, by describing their strengths and limitations, and by outlining the tuning and designing strategies and how they can be easily implemented with Zurich Instruments' lock-in amplifiers.

#### PID working principle and building blocks

The goal of a PID controller is to produce a control signal that can dynamically realize the difference between the output and the desired setpoint of a certain system. Let's consider the exemplary scheme depicted in Figure 1. As a first step, the output of the

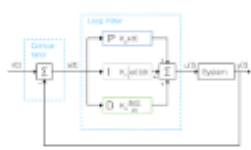


Figure 1. Schematic representation of a general PID control loop in its most general form.

system  $y(t)$  is looped back and measured against the setpoint  $r(t)$  by the comparator, thereby generating the time-dependent error signal  $e(t) = r(t) - y(t)$ . Subse-

## Maximize Control: Unlocking Efficiency with PID Controllers

Our white paper on PID controllers delves into key topics such as control strategies, system performance, and tuning methods. It provides practical insights and guidance to help readers solve control-related problems and gain a deeper understanding of PID controller principles. Whether you're a beginner or an experienced practitioner, this paper equips you with the knowledge to optimize control systems and improve overall performance.

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