PID Controllers

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Introduction

As electronic devices trend towards further automation, engineers are tasked with finding new ways to control processes without human supervision. In this environment, feedback controllers, which can help systems self-adjust and adapt to new conditions, are becoming increasingly relevant. However, one of the simplest feedback controllers, the PID controller, is still useful to modern systems, due to its high versatility. PID controllers use the proportional, integral, and derivative (PID) components of a system's error to reduce it to zero. These controllers are mathematically simple, but have countless applications in electrical and mechanical engineering (Vilanova and Visioli, 2017). This paper aims to describe the basics of PID controllers: the mathematics behind them and a set of simple methods to tune them.

PID Basics

Motivation

Imagine a robotic arm controlled by a motor. To pick up an object, the gripper must close around it with enough force to hold it securely, but not so much that the object breaks. An intrepid engineer could measure the correct way to do it and hard-code these movements and distances into the robot, but then it wouldn't work for other objects, which have different sizes, weights, and strengths. When a person picks up an object, they don't need to run through a table in their brain of how to pick up various objects. Instead, they can sense how secure their hold on the object is and adjust the tightness of their grip accordingly. Applying a PID controller to the robotic arm's programming is a simple method of allowing the robot to do the same.

Concept

Like all forms of feedback control, PID controllers change the input signal going into a device, or "plant", to produce a desired output from that plant. For example, in the scenario in the previous section, the plant is the robotic arm, the input signal is the commands controlling the arm, and the desired output is picking up an object correctly.

PID controllers compute the input signal to the plant as a function of the error signal, which is the difference between the desired and actual output of the plant (see Figure 1). In our example, a PID controller for the robotic arm computes its error by checking the strength of its grip on the object. If the grip is too strong, it can loosen it by moving its grippers farther apart. If the grip is too weak, it can do the opposite. By doing this continuously, a controller can correct the error over time and hold the object correctly.

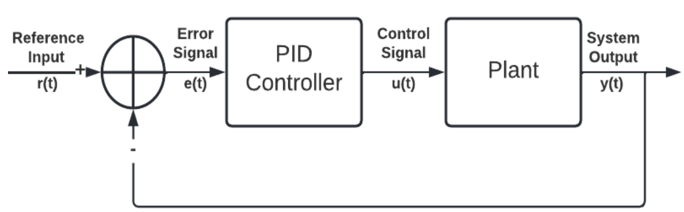

Figure 1. Block diagram for a PID controller. The PID controller computes new inputs for the plant based on its error.

Design

Terms

PID controllers are differentiated from other feedback control methods by their use of proportional, integral, and derivative components of the error signal to compute new inputs for the plant (see Figure 2). PID controllers compute a weighted sum of these three components and use it to decide what new commands to send to the plant to reduce the system's error (O'Dwyer, 2009).

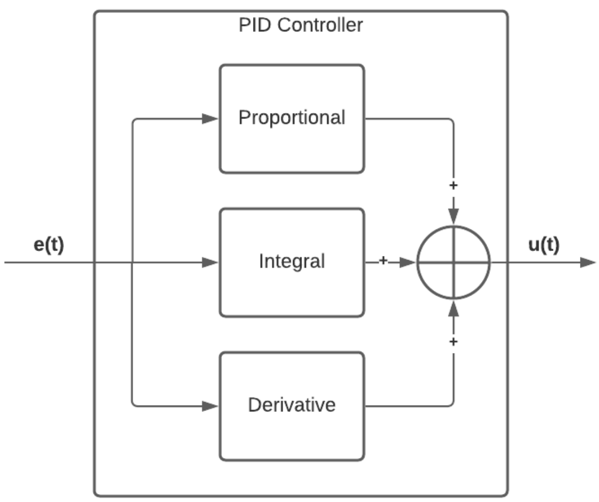

Figure 2. Block diagram inside a PID controller, showing a weighted sum of the proportional, integral, and derivative components of the error signal.

The proportional component of the error is equal to the current error of the system. Similarly, the proportional term in a PID controller is just the error of the system, multiplied by a constant weight (see Design section). This term serves to reduce the error of the system quickly by attempting to cancel out the error currently present.

The integral of the error signal is the sum of all past values of the error. The integral term in the PID controller, which is the integral of the error signal multiplied by a weight, is able to look at past patterns in the error signal and remove error that has remained constant and stayed in the system over time.

The last component of the error, the derivative, is the rate of change of the error signal, or how quickly the error signal is changing. Like the other two terms in the PID controller, the derivative term is the derivative of the error multiplied by a weight. Since the derivative is related to how the error signal is changing, it is able to approximately predict future values of the error. With this information, the derivative term in a PID controller can attempt to remove error proactively (Ang et al., 2005).

Each of the three terms above serves a purpose in reducing the error: the proportional term looks at the current error, the integral term sums past error, and the derivative term predicts future error. Using a sum of this information, a PID controller can choose the best new inputs to the plant. With these three terms, it is possible to bring the error to 0 over time and get the intended behavior from the plant.

Tuning

The main task of designing a PID controller is choosing weights for the PID equation terms to "tune" the controller (Kulakowski et al., 2007). There is no single set of rules for choosing these values, as there are different methods for different applications. One common tuning approach is to use one of the Ziegler-Nichols rules, a set of general rules, for an initial estimate, then continue adjusting the values manually to fit the specifications of the problem. This extra adjustment is often necessary, especially because weights obtained with the Ziegler-Nichols rules tend to cause high overshoot in the plant's response to error (Ogata, 2010).

Conclusion

PID controllers are useful for a number of applications where a plant that is difficult to model needs to produce a particular output. In particular, PID controllers are distinguished from other feedback controllers by their simplicity and versatility, since they only have proportional, integral, and derivative terms. This information serves as an introduction to basic PID controller concepts. There are so many PID controller forms and tuning methods that this report is far from comprehensive, but knowledge of these simple forms will assist in understanding other variants of the PID feedback-controlled system.

References

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