Unfortunately, a proportional controller tends to quit working once it has succeeded in driving the process variable close enough to the setpoint. As it happens, this automatic reset operation is mathematically identical to integrating the error and adding that total to the output of the controller’s proportional term. The result is a proportional-integral (PI) controller.

The traditional PID formula calculates the derivative term by differentiating the error signal $e(t) = SP(t) - PV(t)$, where $PV(t)$ is the process variable at time $t$ and $SP(t)$ is the setpoint. $CO(t)$ is the controller’s overall output.

Integral action

Control engineers in the 1930s discovered that the error could be eliminated altogether by automatically resetting the setpoint to an artificially high value. The idea was to let the proportional controller pursue the artificial setpoint so that the actual error would become large enough to start driving the process variable in the opposite direction. This, in turn, would cause the controller to shift back to the setpoint.
and $P$, $T_I$, and $T_D$ are "tuning constants" that define the relative strengths of the proportional, integral, and derivative terms.

On the other hand, dramatic swings in the control effort can be troublesome in applications (such as room temperature control) that require slow and steady changes in the controller's output. A blast of hot air following every adjustment to the thermostat would not only be uncomfortable for the occupants of the room but hard on the furnace as well.

If the setpoint changes only in a stepwise manner as in this example, its derivative is almost always zero anyway, so the derivative action can be computed more-or-less correctly by differentiating just the negative of the process variable.

For such applications it is advantageous to forego derivative action altogether or calculate the derivative from the negative of the process variable rather than directly from the error. If the setpoint is constant, the two calculations will be identical. If the setpoint only changes in a stepwise manner, the two will still remain identical except at the instant when each step change is initiated.

The negative derivative of the process variable will lack the spike present in the derivative of the error. See the "Smoother derivative action" graphics. Most modern controllers offer this option for applications that cannot withstand "kicking."

Using the modified derivative term eliminates the spikes that would otherwise appear in the derivative action when the setpoint changes. However, if the setpoint fluctuates at all between step changes, the modified derivative term will produce erroneous results.

Derivative action is also a problem for applications that involve noisy measurements. The derivative term will contribute to the controller's output every time the process variable appears to change. The controller could end up taking corrective actions even if the actual process variable has already reached the setpoint. Virtually all modern controllers offer a filtering option to present a much smoother input to the derivative term.

In all, derivative action is considered by many control engineers to be more trouble than it's worth. Nonetheless, the complete proportional-integral-derivative (PID) controller had become the state-of-the-art by the mid-1950s and remains predominant to this day. It works well enough for most process control applications (with or without derivative action), it is relatively easy to implement, and its basic operating principles are easily understood.

PID in action
Consider the room temperature control example again. If the room is large and the furnace is small, the process will tend to respond slowly to the controller's efforts. If the process variable should suddenly begin to differ from the setpoint because someone opened a door or turned up the setpoint on a cold day, a PID controller's immediate reaction would be determined primarily by the actions of the derivative term. This will cause the controller to initiate a burst of corrective efforts the instant the error changes from zero. The error between the setpoint and the process variable would also initiate the thermostat's proportional action.

After a while, the integral term will also begin to contribute to the controller's output as the error accumulates over time. In fact, the integral action will eventually come to dominate the output signal since the error decreases so slowly in a sluggish process. Even after the error has been eliminated, the controller will continue to generate an output based on the history of errors that have been accumulating in the controller's integrator. The process variable may then overshoot the setpoint, causing an error in the opposite direction.

If the integral action is not too aggressive, this subsequent error will be smaller than the original, and the integral action will begin to diminish as negative errors are added to the history of positive ones. This whole operation may then repeat several times until both the error and the accumulated error are eliminated. Meanwhile, the derivative term will continue to add its share to the controller output based on the derivative of the oscillating error signal. The proportional action, too, will come and go as the error waxes and wanes.

Now suppose the process is a small room heated by a large furnace. This process would tend to respond quickly to the controller's efforts. The integral action will not play as dominant a role in the controller's output since errors will be so short lived.
On the other hand, the derivative action will tend to be larger since the error changes rapidly when the process is highly responsive.

Clearly the possible effects of a PID controller are as varied as the processes to which they are applied. A PID controller can fulfill its mission to eliminate errors, but only if properly configured for each application.

**Timeline of PID Controllers**

- **1788**: James Watt equips his steam engine with a flyball governor, the first mechanical feedback device with proportional control capabilities.
- **1933**: The Taylor Instrument Company (now part of ABB at www.abb.com) introduces the Model 56R Fulscope, the first pneumatic controller with fully tunable proportional control capabilities.
- **1934-1935**: Foxboro (www.foxboro.com) introduces the pneumatic Model 40 controller, the first proportional-integral controller.
- **1940**: Taylor introduces the Fulscope 100, the first pneumatic controller with full PID control capabilities incorporated into a single unit.
- **1942**: Taylor’s John G. Ziegler and Nathaniel B. Nichols publish their famous Ziegler-Nichols tuning rules. World War II - Pneumatic PID controllers stabilize gun fire control servos as well as the production of synthetic rubber, high-octane aviation fuel, and U-235 for the first atomic bomb.
- **1951**: The Swartwout Company (now part of Prime Measurement Products at www.prime-measurement.com) introduces their Autronic line, the first electronic controllers based on vacuum tube technology.
- **1954**: Taylor Instruments demonstrates its first single-loop digital controller but does not market it widely.
- **1969**: Honeywell introduces their Vutronik process controller line with the derivative action calculated from the negative of the process variable rather than directly from the error.
- **1975**: Process Systems (now MICON Systems at www.miconsystems.com) introduces the P-200 controller, the first microprocessor-based PID controller.
- **1976**: Rochester Instrument Systems (now part of AMETEK Power Instruments at www.rochester.com) introduces Media, the first packaged digital implementation of PI and PID control.
- **1980s to present**: A variety of alternative control techniques begin to migrate from academia to industry for use with more difficult control loops. These include artificial intelligence, adaptive control, and model-predictive control. See "Techniques for Adaptive Control" by the author, available through the Control Engineering bookstore at www.controleng.com.

**A PID alternative**

Although PID controllers are by far the most widely applied feedback devices in today’s industrial automation applications, they aren’t always well suited for every process control problem. Academics have been working on countless alternatives, a few of which have been offered as commercial products.

The latest is “SuperPID” from Honeywell Automation & Control Solutions, which will be available next year as part of Honeywell’s Experion Process Knowledge System (PKS). Known by the product name Profit Loop, SuperPID is a model-predictive control algorithm intended to operate at the lowest level in the control hierarchy where PID is normally hosted. See “Model-predictive Control Looks to the Future,” Control Engineering, August 2003.

SuperPID provides full-order model-predictive control with only one knob required to specify a faster or slower closed-loop response, compared to the usual three tuning constants for adjusting the strength of the proportional, integral, and derivative terms in a traditional PID controller. Honeywell believes that SuperPID will also outperform traditional PID controllers by reducing the jittering caused by noisy process variable measurements.

Experion PKS will contain both PID and SuperPID capabilities to enable on-line migration to this new technology. Honeywell has designed it so that users inexperienced with model-predictive control will find it easy to use, since its setup, interface, and operation will be very much like PID.

Honeywell Automation & Control Solutions. www.acs.honeywell.com

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