Control with Wireless Technology

INTRODUCTION

Wireless measurement devices are becoming common features of modern process control systems. They allow plants to quickly and relatively inexpensively add new measurement and control capabilities—especially where it has been too difficult or expensive to use wired instruments. Wireless measurement devices also allow plants to quickly and economically test new control schemes.

Despite the proven reliability of wireless technologies, manufacturing plants have mostly limited their use to providing measurement in an open-loop capacity, rather than using these devices as part of a closed-loop control scheme. This may be a result of concerns that wireless devices will transmit measurement updates at slow or variable rates—or suffer signal interruptions—that are incompatible with traditional proportional-integral-derivative (PID) control. Alternatively, manufacturing plants may be concerned that limited device battery life will require maintenance personnel to make frequent, potentially hazardous trips to the field to replace the batteries of wireless devices.

It is possible to resolve these concerns by using a modified measurement-device transmission scheme in combination with a specialized PID algorithm, such as "PIDPlus," which is available with Emerson's DeltaV digital automation system. Configuring wireless devices to transmit updates less frequently can greatly increase battery life—sometimes by years. And unlike traditional PID, PIDPlus includes modified integral and derivative portions that can accommodate signal interruptions and update-rate variations, including the variations that battery-saving transmission schemes can introduce.

Together, these innovations can greatly improve the attractiveness of wireless measurement devices for a wide variety of closed-loop applications—while increasing device energy efficiency.

EXTENDING BATTERY LIFE

In typical wireless measurement devices, signal transmission accounts for a significant share of power consumption. As a result, reducing the overall number of signal transmissions can significantly extend battery life.

This approach need not reduce the effectiveness of measurement devices. Indeed, wired devices often "oversample" a process variable, sending measurements to the controller four to ten times more often than the controller performs algorithm executions. Additionally, many measurement updates that traditional wired devices transmit are essentially identical—or at least very similar—to previous measurement updates, and as a result, these messages often serve no practical purpose.

Some signal transmission schemes, such as the "report-by-exception" scheme available with some Hart 7-compliant devices, have been able to reduce communications-related power usage by more than 90 percent in certain situations. Rather than making measurements at regular intervals and transmitting these values at the same unchanging pace, as periodic reporting does, these alternative approaches apply more flexibility. For example, energy-efficient wireless devices can continue to make measurements at regular intervals, but then only transmit an update to the controller under two conditions: when a measurement deviates from the previously transmitted value by a certain amount, or when a predefined period of time has elapsed since the last transmission.

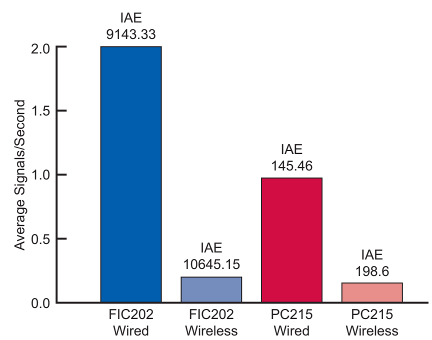

Figure 1. *The average number of signals transmitted per second by measuring devices in two closed-loop scenarios, alongside integrated absolute error (IAE) values. Wireless devices measuring a flow-control variable using the report-by-exception communications scheme transmit about one-tenth as many signals as wired devices using the standard scheme. While measuring a pressure-control variable, report-by-exception transmits about one-sixth as many signals. IAE is comparable in both scenarios.*

Report-by-exception is also known as "window trigger mode," while periodic reporting is often called "continuous trigger mode."

Appropriate settings for the update period, maximum update period, and trigger value depend upon each situation's process dynamics and the urgency of responding to unmeasured disturbances. For many applications, an update period longer than 30 seconds is appropriate.

PIDPLUS AND ACCOMODATING UPDATE VARIATIONS

The traditional PID algorithm often does not generate appropriate output values when its algorithm execution rate is faster than the rate at which it receives measurement updates. When traditional PID receives measurement updates at a variable rate, its output can "wind up" or "spike," and since report-by-exception introduces additional variation in that rate, traditional PID is not suited for pairing with this reporting scheme.

The traditional PID algorithm's poor response results from its design: it executes at a regular, periodic rate, and it requires a new measurement value when it performs each execution. These factors affect how the algorithm's integral and derivative portions respond to variations in the rate at which it receives measurement updates.

But modified terms in the integral and derivative portions of the PIDPlus algorithm allow it to accommodate measurement-update variations. The integral portion of PIDPlus updates only when the controller receives new measurements, and the derivative portion includes a term that incorporates the time elapsed since the most recent measurement.

PID's Presumption of Periodic Execution

The design of traditional PID presumes that measuring devices will provide the algorithm with a new measurement value for each execution. Traditional PID executes at a constant periodic rate, and since standard wired devices transmit new values more quickly than PID executes, this arrangement works well.

But when measurement updates do not arrive in time for each traditional PID execution, the algorithm can respond with inappropriate output values—the controller can "wind up," for example. Specifically, this occurs because the integral and derivative terms of traditional PID incorporate its periodic execution rate in their calculations. That is, the integral and derivative terms cannot correct for differences in the time elapsed between new measurements. Instead, they continue to use each most recent measurement value as if it were new, even if it remains un-updated for several executions.

The Integral Portion of Traditional PID versus PIDPlus

Typically, the integral term of traditional PID calculates its contribution to controller output by integrating past error over a defined period of elapsed time. (Error = set point – process value, where the process value is deduced from a measurement update.) However, because the integral term relies upon the PID execution period to define elapsed time, it produces inappropriate outputs when updates lag behind executions.

For example, consider a situation in which the process value is rising toward the set point, and the integral term in a traditional PID controller is calculating the cumulative error associated with the past five executions. If the controller does not receive a measurement update for the fifth execution, it will incorporate the fourth measurement update twice, overestimate the integrated error, and likely cause the process value to overshoot the set point.

Alternatively, some configurations of traditional PID use an innovative filter function to generate an integral contribution. Generally speaking, these filters often use the most recent controller output value—rather than a direct measurement update—to calculate a contribution to the current output. This calculation also relies upon the algorithm execution rate, and as a result, these filters can respond similarly to ordinary PID integral terms when they do not receive a measurement update for each execution.

By contrast, the modified filter of PIDPlus compensates for variable, slow, and missing measurement updates. As long as PIDPlus is receiving new measurement updates, its integral portion behaves like the filter described above, incorporating the previous controller output to calculate its contribution to the current output. But when PIDPlus does not receive a measurement update to use in an execution, its integral portion does not change its contribution. Instead, it contributes the value associated with the most recent measurement update.

For example, if PIDPlus receives a new update prior to one execution, but does not receive an update for the next three, the modified filter will contribute the same value to all four algorithm executions.

The Derivative Portion of PIDPlus

As with traditional PID's integral portion, its derivative portion is also designed with the assumption that a new measurement update will be available for each execution. When variable update rates deprive controller executions of new measurements, the derivative

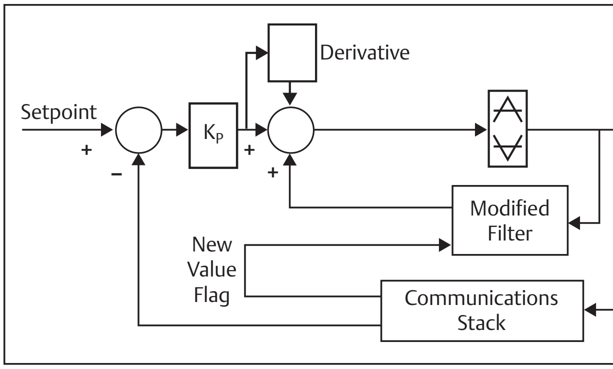

Figure 2. *PIDPlus*

portion often produces a larger output contribution than appropriate. And when updates eventually arrive, output often spikes in an attempt to correct for the apparently large rate of change in the difference between the set point and the measurement.

This results from the derivative calculation's time term, T, which is always equal to the algorithm's execution rate in traditional PID. In place of this term, the derivative calculation of PIDPlus uses time elapsed since the most recent measurement update, ΔT.

$$O_D \propto K_D\left(\frac{e_N - e_{N-1}}{\Delta T}\right)$$

e_N = *Current error*
e_{N-1} = *Error that accompanied most recent measurement update*
O_D = *Controller derivative contribution*
ΔT = *Elapsed time since receipt of a new measurement*

When the time elapsed exceeds PIDPlus's periodic execution rate, this modified algorithm calculates a smaller, more appropriate derivative action than standard PID. Also, when PIDPlus finally receives a measurement update after a period of communications silence, it does not produce an excessively large output spike to correct for the difference between the set point and the measurement.

CONTROL PERFORMANCE

PIDPlus performs well in laboratory demonstrations and field applications involving variable measurement update rates, including situations in which wireless communications are completely interrupted at critical moments.

Measurement Interruption After Process Disturbance

In a closed-loop scenario with wireless measurements, PIDPlus responds more appropriately than traditional PID to a process disturbance followed by an interruption of communications. In Figure 3, a process disturbance occurs just after 11:20:30, causing output changes from PIDPlus (middle, red line) and traditional PID (middle, magenta line). The set point remains constant at 50 units (top, yellow line).

The two control algorithms behave similarly until communication (bottom, aqua line) with a wireless measurement device is interrupted near 11:20:45. Thereafter, the output of PIDPlus stays essentially level, while traditional PID winds up – it continues to decline in a straight line, far below the value required to maintain the set point. When communication resumes just before 11:21:45, PIDPlus quickly reaches an appropriate output to reach the set point. But traditional PID produces a sudden output spike, followed by a gradual increase that brings the process variable to the set point.

The decline in traditional PID output after 11:20:45 results from its inability to correct for elapsed time, coupled with repeated integration using an unchanging error value from the moment communication was lost. By using a reset value resulting from the most recent measurement update, and by compensating for the time elapsed since then, PIDPlus produces a more appropriate output.

Traditional PID produces a spike at about 11:21:45 – overshooting its ideal output – because its derivative component's divisor does not allow for changes in the elapsed time period. Again, by using the time elapsed since the last measurement

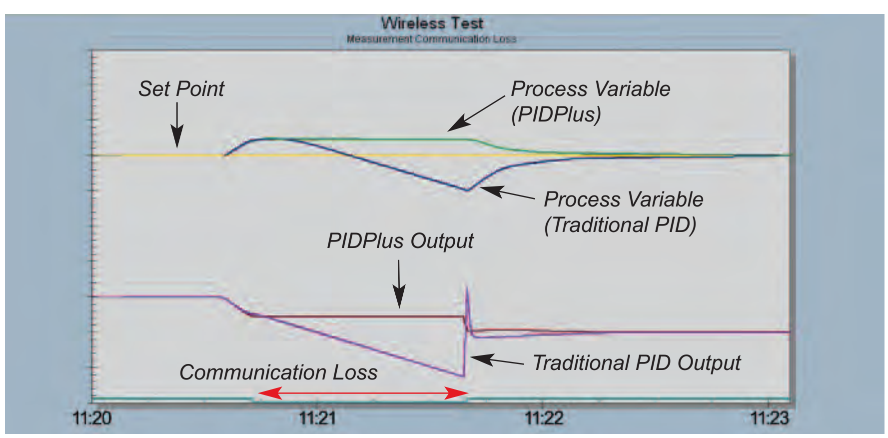

Figure 3: *Simulation of a process disturbance, with controller input interrupted by a loss of communications. Note that in a real-life situation, process variable data would not be available for the entire period.*

as a divisor, PIDPlus makes a more gradual correction.

Measurement Interruption After Set-Point Change
PIDPlus also responds more appropriately than traditional PID when a communications interruption follows a set-point change. In Figure 4, PIDPlus and PID algorithms respond similarly to the set-point change that occurs at about 10:38:40. When new measurements suddenly cease at 10:40:15, traditional PID's output declines in a straight line, while PIDPlus maintains a consistent, more appropriate output. When communications resume at about 10:40:45, traditional PID spikes upward, while PIDPlus output gradually approaches the required value.

As in the process-disturbance example above, the responses of PID result from calculations using inappropriate values. Without measurements, it lacks the ability to estimate a proper response to changing error, so it winds up and spikes at the beginning and end of the communication interruption, respectively. In contrast, PIDPlus calculates a much better response in the absence of measurement updates.

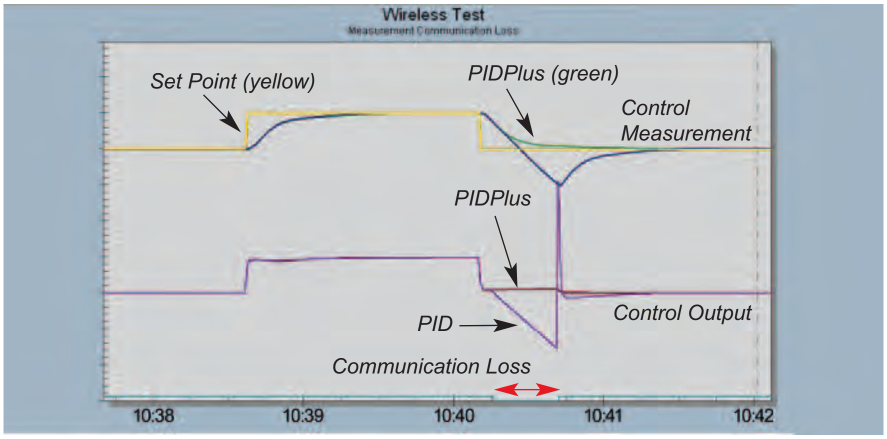

Figure 4. *PIDPlus and traditional PID respond to a set-point change followed by interrupted wireless measurement updates. Note that in a real-life situation, process-value data would not be available during communication interruptions.*

CONCLUSIONS

Wireless measurement technology is being rapidly adopted to provide a quick, economical means of monitoring process measurements.

However, until recent innovations, process control with wireless technology was mostly confined to open-loop applications. This is partly due to a requirement for more frequent communications, and partly due to standard PID's dependence on new measurement values for each periodic algorithm execution.

With the PIDPlus algorithm available in DeltaV, wireless technology becomes more compatible with closed-loop control applications, including situations in which wireless devices—such as HART 7-compliant devices using the report-by-exception capability—send measurement updates less often in order to extend battery life. This arrangement sacrifices very little control performance when a fast measurement rate is coupled with a signal-transmission rate that increases when the process changes significantly. PIDPlus's enhancements complement this scheme, using modified integral and derivative terms that account for the actual wireless measurement update rate.

By combining modified communication features and the corresponding PIDPlus features, users can exploit wireless technology's quick and easy installation for process control applications. These can remain wireless permanently, or they can simply serve as a way to quickly make use of a different measurement value—accessed wirelessly—to test a proposed control scheme.

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