Smart Transmitters Enable Smart Sensors

Integrating digital technologies made instrument transmitters smart, with instrument sensors following in their wake.

By Steven J. Smith, Endress+Hauser

Process instruments consist of two main components: a sensor and a transmitter. The sensor is sometimes part of the instrument assembly, as with some pressure instruments, but is more often separate, as with analytical instruments, such as those used for pH measurement.

Before sensors could become smart, transmitters had to gain intelligence by adapting digital technologies because it would not have been practical, or sometimes even possible, to connect a smart digital sensor to a simple analog transmitter.

Industrial instrumentation has progressed significantly since the 1970s, when the vast majority of instruments simply had a single 4-20 or 0-20 mA (analog) output proportional to the process variable. Some sensors had the inherent ability to measure multiple process variables, but it would require multiple analog outputs to access this additional information.

Instrument transmitters became smart by integrating digital technologies, paving the way for instrument sensors to acquire a similar level of intelligence.

Benefits

- Instrument transmitters gained intelligence through HART and other digital communications, then sensors became smart by integrating other types of digital technologies.
- Smart instruments provide a wealth of data to host systems including secondary process variables, calibration information and diagnostics.
- Smart sensors are the latest advancements in smart instruments, extending many smart transmitter benefits to the sensor level.

With an analog transmitter with a single analog output, secondary variables remained stranded, as did data regarding the configuration or health of the instrument. The process variable was relegated to a dedicated analog signal transmitted from the instrument over two wires to an indicator or control system, with a multi-drop configuration.

Working with these instruments required direct access to the device and manual adjustment by maintenance personnel. What was missing from this environment was any information about the instrument itself, or about secondary process variables, for example the temperature from a pH sensor.

HART Emerges

In the early 1980s, instrument vendors realized the potential benefits of digital technology in instruments. There was a wealth of useful data contained in an instrument including other measured process variables, device configuration, alarm limits, operating time, operating conditions, diagnostic information and a broad range of device health data.

Obtaining this data from an instrument can help optimize the use of the device, and ultimately improve process performance, and HART communications emerged as one of the first ways to access this stranded data to make an instrument smart.

HART digital technology allowed for communications with an analog instrument using a digital communication signal (Bell 202) transmitted over the same two wires as the analog output. This digital signal provided two-way communications between the instrument and a host without disrupting the output, allowing various pieces of data to be accessed. Using HART, users could talk to the instrument, perform configuration or diagnostics — all while it was making one or more real-time process measurements.

At the same time, various companies were making progress in the development of other digital technologies that would be transmitted over dedicated communication highways, each offering specific benefits. Various Fieldbus technologies emerged — including EtherNet/IP, FOUNDATION Fieldbus, Profibus and Modbus — and today these comprise the majority of new applications for fieldbus communications.

In a similarly fashion with respect to wireless digital communications, many technologies have been reduced to two clear leaders: ISA100 and WirelessHART.

Digital Technology Expands

The realization that instruments contained a vast amount of valuable data that could be bidirectionally communicated between instruments and control systems dramatically changed the way companies operated a process and managed assets — and it drove the rapid expansion of digital technology in the industrial environment. There are very few instruments today that are not smart, at least to some extent. From the 1980s to 2000, digital communication technologies emerged in industrial markets, and today are providing significant benefits.

Around the same time, office computer networks were evolving. In 1989, the first prototype of the internet was developed by Tim Berners-Lee and Robert Cailliau at CERN, eventually leading to the implementation of the World-Wide Web. With networked computers and the internet, there became internet-enabled coordination and integration across the value chain, allowing suppliers to reach customers and business partners regardless of geography.

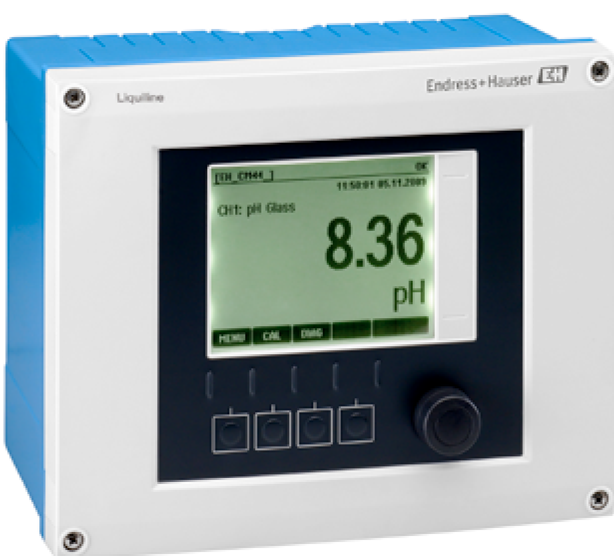


Figure 1: This Endress+Hauser Liquiline transmitter offers EtherNet/IP, Modbus RS485 or TCP, PROFIBUS DP, and HART as well as a web server. This transmitter can communicate with up to eight smart sensors.

This internet-enabled integration has also allowed for enhanced access to process data from the point of measurement all the way to the business system level and beyond. Not only can one see process data critical to the operation of a process, one can also access this key asset information.

As we move well into the second decade of this century, basic information technology has become more deeply embedded in industrial and consumer products, allowing them to become part of the Internet of Things (IoT). In one lifetime, process control migrated from pneumatics to electrical analog, and then to sophisticated digital communications extending out to the internet. And most of today's smart instruments (Figure 1) connect easily to digital communications systems, and in some cases contain web servers and Ethernet ports for direct connection to the internet.

Smart instruments can acquire so much data, they need a high-speed digital interface to send it all. For example, some Coriolis flowmeters can simultaneously detect multiple measured process values including mass flow, volume flow, density, concentration and temperature.

In addition to these measured variables, built-in electronics monitor instrument performance and report status and diagnostic values.

Once smart instruments became widely accepted, mostly by adding the aforementioned features to the transmitter, smart sensors followed.

Smart Sensors Improve Operations

With digital information residing in the sensor and communicated to the transmitter, health diagnostics can be performed, and the state of the sensor and transmitter health can be communicated to the host systems in real time.

Real-time diagnostics and sensor-health data allow for better management of a sensor. The need to clean and calibrate the device can be proactively managed, rather than reactively performed. In fact, some smart sensors can determine if they actually need to be cleaned and calibrated.

For example, calibration cycles for standard temperature sensors in critical service are every six to twelve months. This requires a technician to remove the sensor, take it to a lab for calibration and then re-install it. But one RTD sensor (Figure 2) is able to determine if it needs a calibration when used in sterilize in place (SIP) processes.

In SIP processes, steam at 121°C (250°F) is used to sterilize equipment. The sensor uses a reference material with a Curie Point of 118°C (244°F). When the SIP process reaches 118°C, the reference sensor sends a signal. Simultaneously, the RTD measures the temperature. Comparison between these two values is used to determine if the temperature

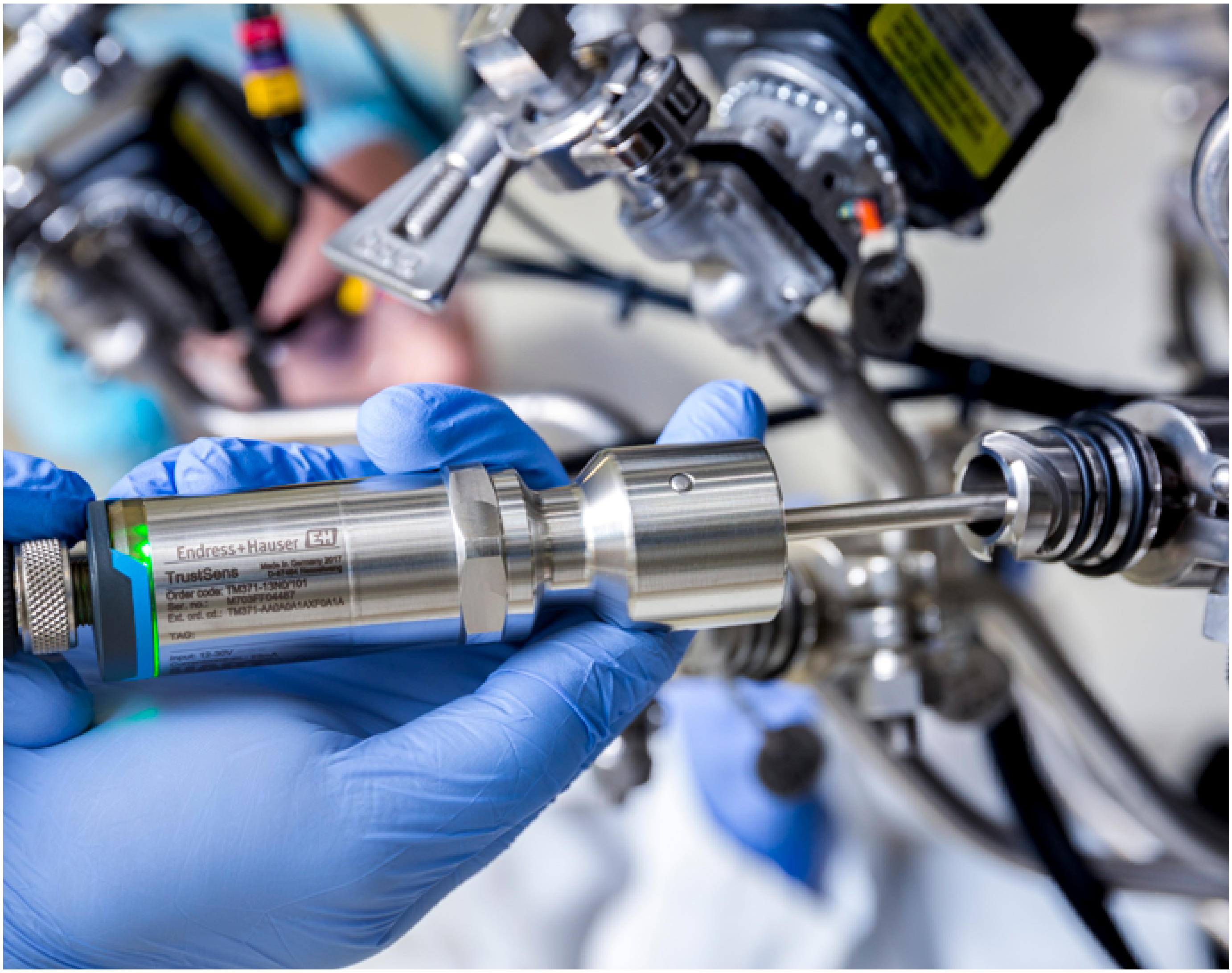


Figure 2: Endress+Hauser's TrustSens RTD checks its calibration every SIP operation.

sensor needs calibration. If both sensors read a value close enough to 118°C, the RTD sensor is still in calibration.

Another example of real-time diagnostics and sensor-health data is a four-pole conductivity sensor (Figure 3). This sensor uses four conductors to measure conductivity, and its four-pole design allows the sensor to operate over a broader range of measurement than two-pole conductive sensors. It uses digital sensor technology in the head of the sensor to digitize the measurement signal, and providing a host of performance and diagnostic information.

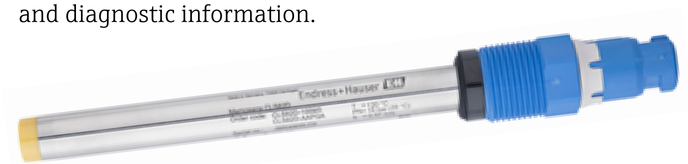


Figure 3: Endress+Hauser's CLS82D four-pole conductivity sensor with Electrode Connection Surveillance smart diagnostics.

One diagnostic function that makes this sensor particularly smart is Electrode Connection Surveillance, which monitors the connection between the electrodes and the electronics. If there is a connection error, an error message is sent to the transmitter to notify the user of a connection problem within the sensor.

Accessing Smart Sensors

Maintenance personnel are stretched thin at many process plants and facilities, resulting in the need to enhance the use of digital technologies, such as remote access to an instrument beyond the control system. With the use of digital communications, especially over an industrial Ethernet network, an instrument can become a "thing" in the industrial internet of things (IIoT).

Some more sophisticated digital transmitters have an embedded web server, permitting properly authorized access

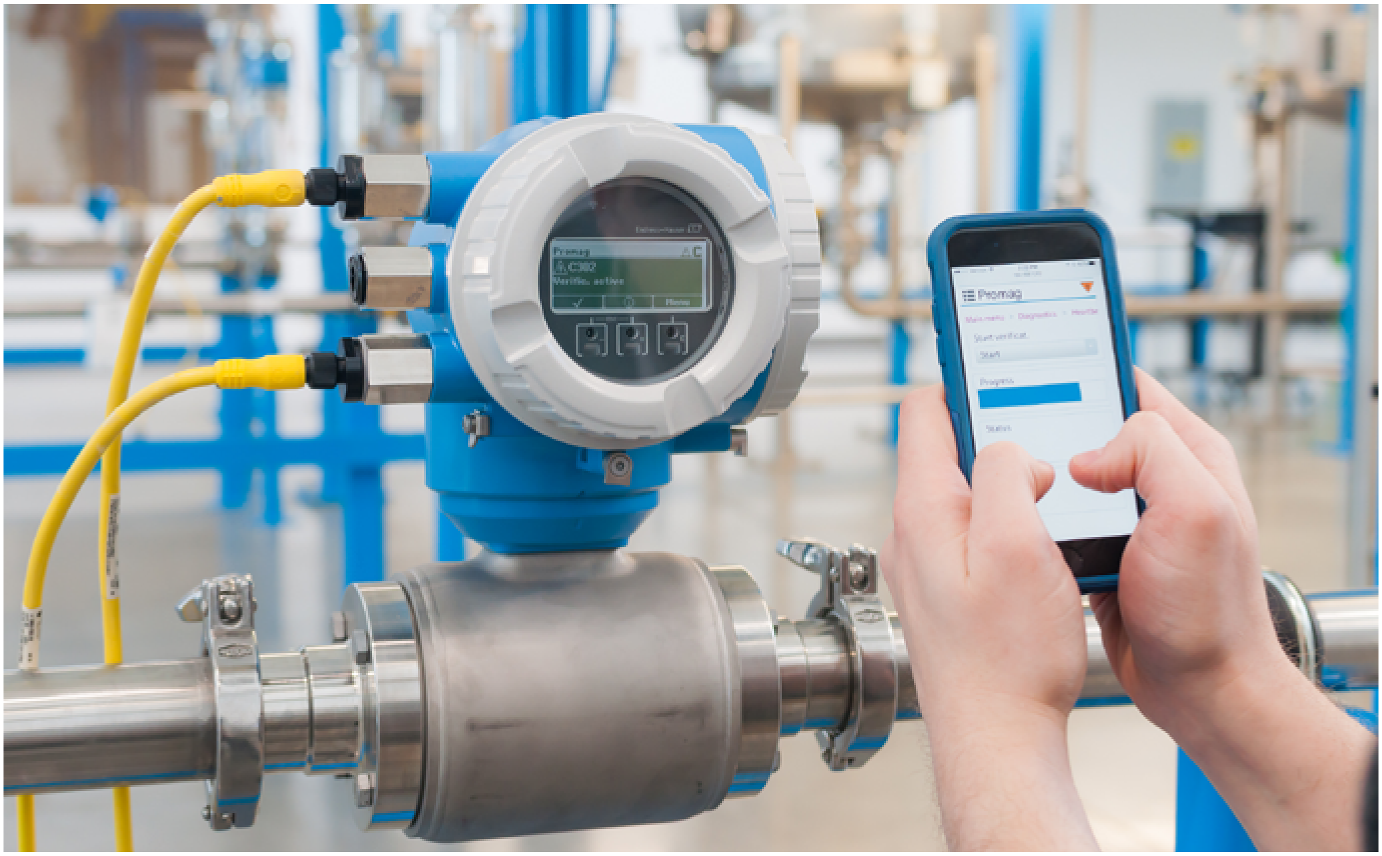


Figure 4: A technician can connect a smartphone to an instrument, such as this Endress+Hauser flowmeter, and access the meter via its integrated web server. The same procedure can also be used for access done from a remote PC or tablet.

from any device connected to the internet and capable of hosting a web browser, such as a smartphone (Figure 4).

Two of the leading networks for local access to smart instruments from host systems are Modbus and EtherNet/IP. Common hosts are control systems and asset management systems.

Modbus is an open protocol, allowing any manufacturer to integrate the protocol into an instrument. Modbus is a serial, master-slave, protocol. The master requests information and the slaves respond, with one master communicating with up to 247 slaves. Each slave in the network is assigned a unique ID. When a Modbus master requests information from a slave, the first data communicated is the slave ID.

Modbus can be difficult because one can use 16-bit or 32-bit signed integers and unsigned integers, ASCII strings, discrete on/off values, and 32-bit floating point numbers. To program a system for a device using Modbus communications, a significant amount of information is required about the slave device and its registers. A programmer has to obtain a Modbus map from an instrument manufacturer and carefully program the master to communicate properly with each slave device.

An improved version called Modbus TCP/IP is now available whereby Modbus data can be framed in a TCP/IP packet, allowing the information to be more easily communicated over an Ethernet network.

EtherNet/IP is becoming one of the most widely used industrial protocols due to its ease of integration and operation. Like Modbus TCP/IP, EtherNet/IP data is transferred in a TCP/IP packet. Each device on an EtherNet/IP network presents its data to the network as a series of data values called attributes.

Because EtherNet/IP uses the Common Industrial Protocol (CIP), consistent device access is possible with one configuration tool. Devices become "objects" on the network that are easy to integrate. Once on the network an object has a profile that allows sensor data to be assigned within the profile, without the need for detailed programming information.

With digital sensors, digital transmitters and control systems communicating, data can be easily and clearly communicated from the process to the host control system, and on up to the enterprise level. Data is no longer just the primary process variable, but also includes secondary process variables, sensor health, sensor performance characteristics, calibration information and real-time diagnostics. All this information can be used to improve the process, optimize the performance of the instrument while extending its life, and maximize productivity of maintenance personnel.

With the advent of the internet, these digital-based devices and systems are being further transformed and becoming part of the Internet of Things (IoT). This transformation will take us to places and capabilities we never imagined. Let's look at the journey of one industrial process measurement over the past 50 years to see how it has been completely transformed by digital technology: pH measurement.

The Digital Journey of One Measurement

pH is a fundamental measurement that has been used across a range of industrial processes for many years. pH is a measurement of the hydrogen ion activity in a sample and represents the acidic or basic nature of a fluid. The pH range is defined from 0 to 14.

Determining a solution's pH began as a lab-based measurement. A sample would be brought to a lab and a benchtop pH system would be used to measure the sample. The measuring system didn't actually measure pH, but calculated pH based on a measured mV potential signal produced by the pH sensor. To do this, a benchtop pH sensor has two electrodes (a measurement electrode and a reference electrode, enclosed in separate glass cells) and, due the effects of temperature on the measurement, a temperature sensor is required.

Historically, with lab-based systems, the measuring electrode, reference electrode and temperature sensor were three separate electrodes that were immersed in the sample while connected to electronics that would measure the low-level mV signal and convert this value to pH. This was

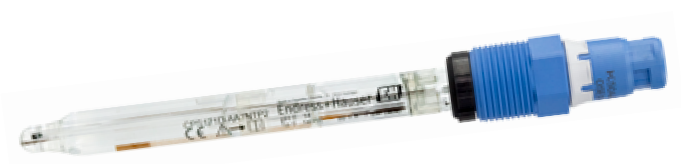


Figure 5: Endress+Hauser's CPS171D pH sensor stores measuring and operating data in the sensor including serial number, calibration date, number of calibrations, offsets, pH application range, number of calibrations, hours of operation under extreme conditions and other information.

truly an analog system and an off-line measurement that involved a significant amount of operator effort, with considerable time lag between the time a sample was collected and results were reported.

One of the first significant changes to occur in the measurement of pH was to integrate the three separate electrodes into one device, which resulted in a combination electrode.

The sensor was still an analog device with hardwired connections to the transmitter, and all the inherent problems associated with a hardwired, low-level analog signal. The next significant improvement in pH measurement was the introduction of digital technology to the sensor, enabled by continuing advancements in miniaturization (Figure 5). And, as with all smart sensors, it allows new pH sensors to provide more data, and to operate more reliably.

At the transmitter end of a pH instrument, the data communicated by a digital smart sensor can be read and sent out to a control and/or an asset management host system, also using digital communications protocols. With the abundance of data residing in the sensor, and the ability to digitally communicate this data to a digital transmitter and beyond, users now have the information needed to better operate the process and manage the asset.

Although this example pertains to pH measurements, much of the discussion also applies to other process variables.

Summary

In half a century, technology advances have allowed for the evolution from the transmission from an instrument of just the primary process variable to a wealth of information that can be accessed up to the enterprise level. As we move into the future, digital technology will continue to provide more information from instruments, with access from anywhere in the world.

A pH measurement is no longer just the pH value, it also includes the temperature, quality of the calibration, number of calibrations, overall operating time, operating time over critical process conditions and much more. Tools are available to turn this data into actionable information, with virtually no limitations when it comes to improving operations and efficiency.

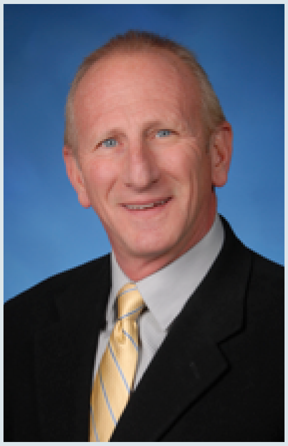
Resources

HART makes troubleshooting easy
https://www.isa.org/standards-and-publications/isa-publications/intech-magazine/2012/april/automation-basics-hart-makes-troubleshooting-easy/

The Smart Evolution
https://www.isa.org/standards-and-publications/isa-publications/intech-magazine/2006/march/supplement-flow-level-smart-flow-the-smart-evolution/

Industry 4.0 for process
https://www.isa.org/intech/20170601/

About the Author



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