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Closed-Loop Control Fundamentals

InTech
DIGITAL MAGAZINE

OCTOBER 2024

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Wireless communications and remote asset management are the themes of this issue of *InTech* digital magazine, the official publication of the International Society of Automation (ISA). Written for engineers, managers, and other automation decision-makers, *InTech* serves ISA members and the wider automation community with practical, in-depth coverage of automation technologies, applications, and strategies that help automation professionals succeed.

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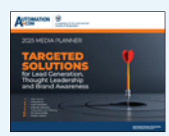

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You Have Questions? ISA Has Answers

By Renee Bassett, *InTech* Chief Editor

Serving up member-generated technical content related to standards, certifications, training, control, safety, cybersecurity, systems integration and other key topics is something the International Society of Automation has been doing since the society began. Whether you need technical explanations or professional development advice, ISA has answers.

ISA's *InTech* magazine has a long, proud history of providing in-depth technical information to instrumentation, automation and control professionals. ISA's I*nstrumentation Technology* magazine—launched as the *ISA Journal* in 1954 and renamed *InTech* in 1978—was expanded when ISA bought *Programmable Controls* magazine in 1989. In subsequent years, ISA expanded its content offerings further by launching its web presence at www.isa.org (1994) and purchasing Automation.com (2015) for industry news and new products, newsletters, ebooks and other resources.

The ISA Interchange blog has been around for more than 15 years. Upgraded in 2019, it has hosted a wide range of subject matter experts over the years. One of its longest-running components is the "Ask the Automation Pros" series. Monthly, ISA Fellow and 2010 ISA Life Achievement Award recipient Greg McMillan collects submitted questions and solicits responses from automation professionals. Using over 50 years of process automation experience and calling on the professionals he's met within ISA, McMillan answers questions like, "How can we compute startup tuning for new control valves?" or "How to best migrate from obsolete to modern instrumentation and control systems?"

The newest way to access ISA expertise is Mimo℠, an AI-powered large-language model educated on ISA content including back issues of *InTech*, standards, training materials, technical reports and more. Mimo has learned about industrial automation and operational technology cybersecurity from studying years of ISA content available on Pub Hub. the ISA member-only content portal. This means Mimo can access files and information not normally available widely or publicly.

Mimo also provides sources for its answers, so users can go straight to the article, standard or report from which Mimo has drawn its answer. This makes Mimo a richer and more relevant resource for automation professionals than ChatGPT or similar services. If you are not an ISA member, or if you aren't logged in, you'll get a short and to-the-point answer. For more details and source files, log in to your member account or join ISA.

As an automation professional, you have questions. ISA has the people, the publications and the resources to get your questions answered.

How Remote Monitoring and IoT Devices Optimize Supply Chains

By Guy Yehiav

Several asset monitoring and inventory management challenges impact an enterprise's supply chain efficiency. Collecting real-time data on asset location and condition on a consistent basis is difficult without the proper technology infrastructure in place. Without timely guidance and accurate intelligence, informed decision-making for successful supply chain operations is almost impossible. Optimizing asset and inventory management is crucial for reducing errors in inventory levels and avoiding out-of-stock and overstock situations.

Scalability issues pose another common challenge. As inventories spanning multiple locations, countries and continents become larger and more globalized, the technology platforms used to manage the value chain must scale accordingly. Unsurprisingly, research from SAP found that 52% of business leaders believe their supply chain needs improvement. To overcome asset and inventory challenges and bolster supply chains, companies must leverage advanced technologies and best security practices including the internet of things (IoT), integrated workflows and real-time prescriptive analytics powered by artificial intelligence (AI) and machine learning (ML).

Producing real-time intelligence

Enterprises optimize their asset and inventory management by strategically deploying IoT-powered devices, sensors and cameras throughout their supply chain which enables remote and automated monitoring of various asset conditions in real time. In previous generations of IoT, supply chain managers would then analyze the data collected from their IoT deployments to laboriously uncover actionable insights. However, now with the use of AI-driven analysis and leveraging of ML models, organizations are unlocking trends and patterns in inventory usage that automagically enhance demand forecasting accuracy, reduce excess stock and minimize out-of-stocks.

IoT sensing capabilities collect critical data on the location and condition of an asset during transportation and storage while reporting other variables such as light, impact, temperature, humidity, vibration, etc. If an asset isn't where it's supposed to be or if any of these defined parameters exceed or dip below established thresholds, the IoT system will automatically notify the pre-determined employee at the precise time, empowering them to respond quickly with corrective action before an issue results in inventory loss.

For example, an edge-to-cloud IoT solution using fever tags for cattle monitoring tracks the health of thousands of individual cattle which helps ranchers to identify, isolate and treat sick cows before they infect the herd.

Another example is having condition-sensitive food or medication products being shipped across the country. IoT tags equipped with multiple sensing capabilities are now able to empower retailers to combat theft and intervene if refrigeration equipment fails along the route.

The growing popularity of IoT adoption demonstrates that businesses recognize its critical role in optimizing asset and inventory management. In fact, the global market worth of IoT in Supply Chain Management (SCM) will reach $41.8 billion by 2033. The real challenge is therefore not deciding to use IoT but figuring out how to effectively integrate these IoT devices, sensors and cameras with existing asset and inventory management systems at scale.

For an enterprise to build a sophisticated IoT solution on its own would require robust network infrastructure and advanced console servers that follow evolving standard communication protocols. Integration with existing IT infrastructure, enterprise resource planning and inventory management systems is also a heady task without the proper expertise and commitment to ongoing support. Thankfully, there are flexible IoT solutions that remove the burden from the enterprise as they deploy at scale.

Best IoT security practices

To take advantage of the incredible value of IoT technologies, protection against cyber-attacks is paramount as companies minimize vulnerabilities and safeguard overall network infrastructure and data. IoT security best practices include:

- Implementing secure access controls, such as role-based access control and multi-factor authentication.
- Using proper encryption to protect data during transit and at rest.
- Disabling unused services and changing default settings, i.e., updating default passwords, usernames and configurations.
- Segmenting networks to separate edge IoT devices from critical internal networks; in the event of a breach, network segmentation will limit the blast radius.
- Leveraging cellular technology instead of Wi-Fi for connectivity whenever possible.
- Educating employees on best practices and suspicious links/phishing emails to promote security across the supply chain.
- Performing regular firmware patches and security updates that allow IoT devices to remain secure over their lifecycle.

Regular security practices like these are only possible with integrated solutions that support remote access and management to all deployed IoT hardware.

ABOUT THE AUTHOR

Guy Yehiav is president of SmartSense by Digi. SmartSense was created to use the power of the Internet of Things to help protect the assets most critical to their customers. Over his 25-year career, Yehiav has built world-class technology companies and prior to SmartSense by Digi, he served as general manager and vice president of Zebra Technologies' Zebra Analytics business unit.

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Total Automation: The Next Frontier Is Sensor to Cloud

Users need guidance to deploy sensors appropriately. A new standard may be the answer.

By Jack Smith

The dictionary defines automation as "the technique of making an apparatus, a process, or a system operate automatically." ISA, the International Society of Automation, defines automation as "the creation and application of technology to monitor and control the production and delivery of products and services."

Using ISA's definition, the automation profession includes "everyone involved in the creation and application of technology to monitor and control the production and delivery of products and services." An automation professional is "any individual involved in the creation and application of technology to monitor and control the production and delivery of products and services."

During an ISA meeting where automation concepts were being discussed, Dennis Brandl, chief consultant at BR&L Consulting recommended that the term "total automation" be used to differentiate it from Hyperautomation. Brandl formally presented total automation at COPERMAN 2023. The Conference on Performance and Management (COPERMAN) aims to bring together researchers and practitioners to present and discuss innovative contributions concerning the measurement and management of organizational performance in a modern business environment.

Total automation is an important aspect of digital transformation because it serves to use information technology/operational technology (IT/OT) to improve performance for dangerous, dirty, demanding, delicate, and dull tasks (the five Ds of manufacturing).

The importance of total automation

According to Brandl, total automation is "a disciplined and all-inclusive approach to the entire process automation strategy of a manufacturing enterprise." He said total automation is the next step beyond Hyperautomation, which he explained as an IT initiative to increase the automation of business processes (production chains, workflows, marketing processes, etc.) by introducing artificial intelligence (AI), machine learning (ML), and robotic process automation (RPA). "Total automation applies the concepts of automation to all elements of a company including OT and IT. The goal is to reduce the human errors that crop up in manual processes, and to use computing resources to verify and validate business operations," he said.

Brandl said that total automation allows for performance management of all activities in a manufacturing enterprise. It is the combination of IT Hyperautomation, process automation, sensor automation, and OT task automation. Another way to look at it is by using new technologies in a real-time environment.

"The objective of total automation is to completely automate the processes in an operational facility to increase efficiency and productivity and reduce errors," said Steve Mustard, president and CEO at National Automation Inc. and former (2021) ISA president. "Even with advances in technology over the past few decades, many organizations continue to operate manual or semi-manual processes. Examples include the manual collection of sensor readings, manual data entry, and manual analysis of data.

"The concept is important now as organizations seek to squeeze out every last drop of efficiency from their operations so they can be competitive in the global marketplace, responsive to changing customer demands, and be resilient to inevitable supply chain disruptions."

Mustard described the automation/manufacturing timeline. The first industrial revolution of the 1800s transitioned processes in labor-intensive industries such as mining and textiles. The second industrial revolution in the 1900s introduced the internal combustion engine and electrification, enabling mass production. The third industrial revolution saw the rise of computers and telecommunications enabling greater automation and digitalization. "The fourth industrial revolution, or Industry 4.0," explained Mustard, "builds on these advances and seeks to reshape how industries operate through the use of disruptive technologies such as AI, big data, and IIoT [Industrial Internet of Things]. Total automation leverages the disruptive technologies of Industry 4.0 to transform how organizations operate."

Mustard shared some examples of the use of these technologies to move toward total automation:

- Using ML to automatically analyze images to detect corrosion or other defects to reduce the time and effort involved in manual analysis and improve accuracy and reliability by the removal of human bias.
- Using IIoT to automatically collect sensor data to remove the need for manual data collection.
- Using AI to analyze sensor data to look for patterns that are not obvious to humans to reduce unplanned downtime.

The need for a total automation standard

The industry already has ISA95. But how would a total automation standard fit the various levels of the ISA95 model?

According to Mustard, total automation applies to all ISA95 levels:

- Level 1: Use of IIoT to collect remote sensor data; use of AI or ML to maintain calibration and report on sensor discrepancies.
- Level 2: Use of AI in expert systems supporting operator decision making.
- Level 3: Use of AI to optimize production schedules and analyze machinery health.
- Level 4: Use of big data analytics, AI, and cloud to automate business decision making.

"Through all layers, the objective of total automation is to use disruptive technology to streamline and automate all processes," Mustard said.

Brandl agrees that a total automation standard would apply to all layers of the ISA 95 model (Figure 1). "Layer 2 is covered by existing ISA and automation standards. Layer 1 is partially covered by the standards on maintenance and security (automated calibration, automated cleaning, automated alignment, automated error detection, etc.).

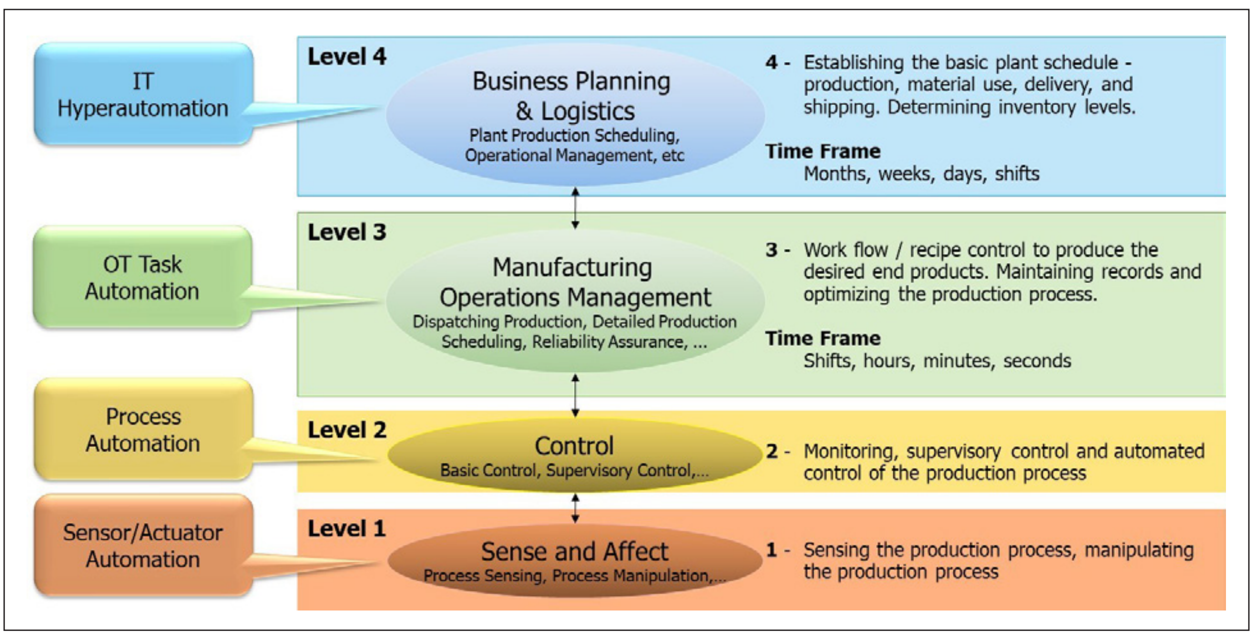


Figure 1. Automation in a manufacturing enterprise—ISA95 levels. Courtesy: Dennis Brandl

Layer 3 is mostly covered by ISA 99, 95, and 88. The concept of interoperable distributed workflows helps fill in some of the missing pieces, in my opinion," he said.

Brandl and Mustard support the proposal of a new standard, or at least a revision to, or expansion of an existing standard. A justification was submitted for the evaluation of such a standard that lays out some considerations.

According to the justification document, users need guidance in deploying sensors appropriately throughout their plants. "However, there are many equipment categories to cover and if we try add sensors to everything, we will never finish. A good start would be common asset types like pumps and heat exchangers found in all plants. More equipment types and other positions could be included in subsequent revisions or other sections. We could start with common asset types like pumps and heat exchangers found in all plants. More equipment types and other positions can [be included In] subsequent revisions or other sections."

Whether total automation, digital transformation, Industry 4.0, or IIoT, getting real-time data begins with the sensors. "Users don't always know what to sense, what sensors are required on each equipment type, what mechanical gauges should be replaced by sensors, where submetering is required, or what update period to set," according to the justification document. "A standard could help plants—especially process plants. It would also make ISA more relevant in the digital transformation/Industry 4.0 megatrend."

There seems to be a gap in the standards with little to guide people in identifying, selecting, and validating sensing opportunities. Some examples may repurpose the data from existing sensors, while others require new sensors. For the former, it is critical that the additional dependencies be documented.

There are not any existing standards that are relevant to the use of this technology, or that must be followed in its application, according to the justification document. "It could be somewhat related to ASME PTC, which defines equations using data because the proposed standard will help users get the right data. API670 is limited to vibration. The proposed standard would be far broader in scope because it would automate all manual measurements (automate corrosion, acoustic noise [leaks], mechanical gauges, and clipboards). API682 is limited to pump seals. The [proposed] standard would be far broader in scope."

"Total automation leverages the disruptive technologies of Industry 4.0 to transform how organizations operate."

—Steve Mustard, president and CEO, National Automation Inc., and a former (2021) ISA president

"There are not really any models or other architecture-related information that helps to understand the technology and its application." "The standard would recommend sensors—not how these sensors are architecturally connected. These are sensors 'beyond the P&ID'—not for process monitoring or control. This would be related to the NAMUR NE175 standard; it is for equipment performance and condition monitoring. In addition, it would also be related to sustainability like energy management, WAGES [water, air, gas, electric, and steam] submetering for EMIS, and emissions monitoring like relief valves, flaring, and methane. It would also support equipment performance monitoring. It would also fit nicely in the various layers in the ISA95 model. There are not really any other technologies related to a proposed total automation standard. The standard should recommend what sensors to deploy on each type of equipment and in other places. It would not define sensor or signal transmission. However, most sensors will be wireless using IEC62591 or other methods."

The technology behind a proposed total automation standard drives functionality, which enables how it would be applied. Application areas include (but are not limited to):

- Reliability/maintenance of rotating equipment, valves, etc.
- Integrity (corrosion/erosion) of piping and vessels.
- Safety (including health and environment): safety showers, manual valves, etc.
- Production/quality would require sensors in place of mechanical gauges.

The technology that supports a proposed standard does not define an architecture per se. It does, however, imply a definite increased sensor count—more sensors in existing architectures. Sensors are selected, installed, configured, and supported by instrument and control personnel, many of whom are members of ISA.

In addition, this standard will make plants more sustainable. By using the appropriate sensors, collected data would detect and pinpoint energy overconsumption, emissions, and equipment inefficiency. It could monitor cleaning optimization and help reduce flaring. Downtime would be reduced due to more predictive maintenance, failure prediction, and reduced loss of containment. Plants will be safer because of reduced human error, and fewer manual valves and leaks. Finally, automating existing manual data collection will enable plants to be more productive.

Looking ahead

Brandl said the concept of a "digital companion" has started in the medical field. A digital companion provides personalized assistance. "We need a digital assistant for everyone performing manufacturing operations management tasks, either on the shop floor or in the production back office. A digital assistant that looks over your shoulder would manage your tasks, make reminders, bring up relevant information, record completions, walk you through manual steps in processes, and collect information from equipment; it is truly mobile. We already have a name for it: Manufacturing operations management [MOM]. But it's your personal MOM, loaded with your tasks and schedules," he said.

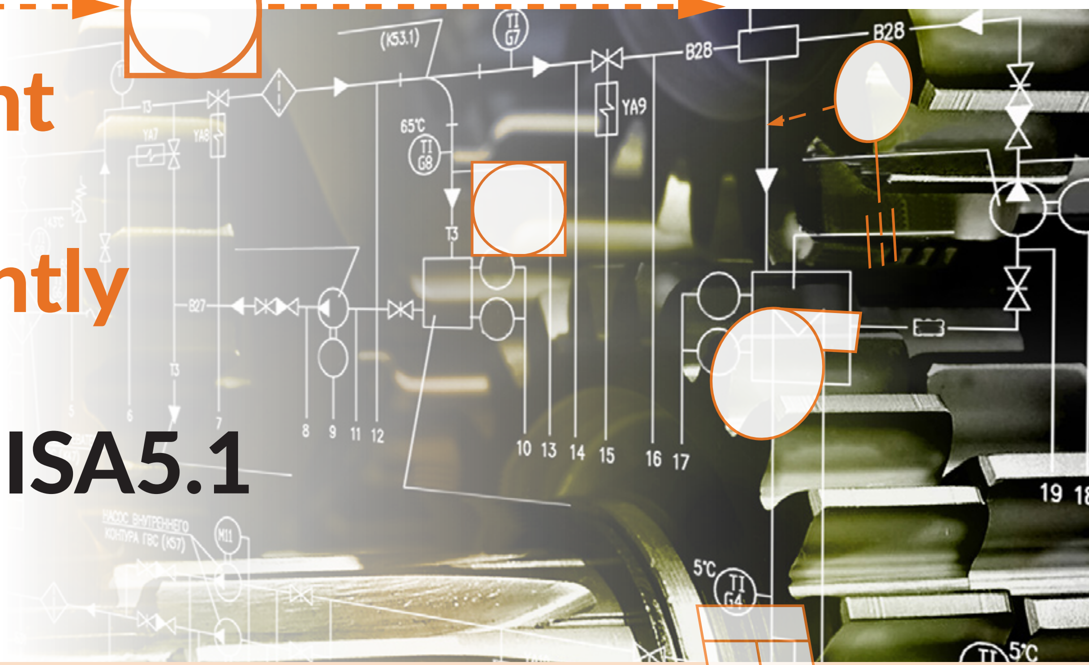
Brandl advocates performance management—measuring and improving individual processes—for all activities. "Personal productivity effectiveness (PPE) is the human equivalent of overall equipment effectiveness (OEE)," he said.

Standards require consensus. With so many things to gain, and nothing to lose, total automation stands to take automated manufacturing to the next level.

ABOUT THE AUTHOR

Jack Smith is senior contributing editor for Automation.com and *InTech* digital magazine, publications of ISA, the International Society of Automation. Jack is a senior member of ISA, as well as a member of IEEE. He has an AAS in Electrical/Electronic Engineering and experience in instrumentation, closed loop control, PLCs, complex automated test systems, and test system design. Jack also has more than 20 years of experience as a journalist covering process, discrete, and hybrid technologies.

Document Projects Consistently with the Updated ISA5.1 Standard



A new release of this widely used ISA standard adds content and improves readability.

By Jim Federlein, PE

In project documents used to specify, purchase, track, install and maintain instrumentation and control system components, consistency is important. The International Society of Automation (ISA) has long known that and promoted such consistency through its standards. Seventy-five years after it was first introduced, ISA has published an update of its most widely used and internationally recognized standard: ANSI/ISA-5.1: Instrumentation and Control -Symbols and Identification.

The symbols and identification methods set forth in the standard are intended as conceptualizing aids, design tools and teaching devices. They are concise and function as a specific means of communication for all types and kinds of technical, engineering, procurement, construction and maintenance documents. This includes identification schemes and graphic symbols for drawings and documentation systems used in the construction and maintenance of industrial plants, including instrumentation and control diagrams, loop diagrams, electrical schematics and functional and binary logic diagrams.

A common misconception is that this standard is a piping and instrument diagram (P&ID) standard. Although it does cover the instrumentation and control portion of P&IDs

and process flow diagrams (PFDs), it does not cover the piping, mechanical and other aspects of these drawings.

A long and proud history

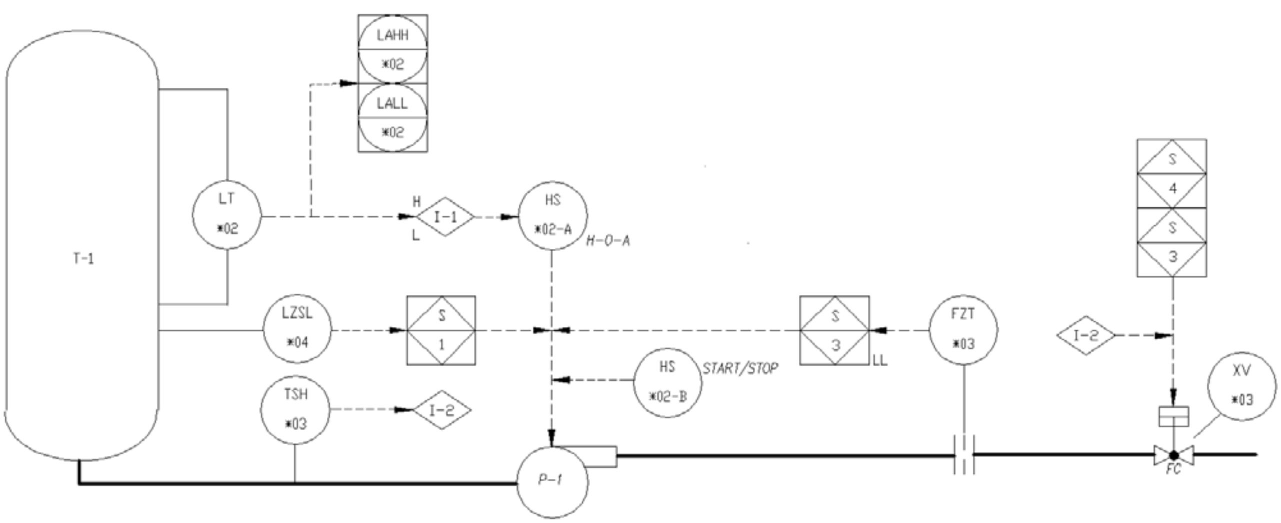
The symbols and identification systems described in this standard accommodate advances in technology and reflect the collective industrial experience gained since the original 1949 ISA recommended practice, RP-5.1, was revised, affirmed and subsequently published as ANSI/ISA5.1-1984. The 1949 recommended practice and the 1984 standard were published as nonmandatory rather than as mandatory consensus documents.

The 1992 revision was published with mandatory and nonmandatory requirements. It incorporated key elements of ISA5.3-1983: "Graphic Symbols for Distributed Control/ Shared Display Instrumentation, Logic, and Computer Systems."

The 2009 revision was published with significant changes as technological advances resulted in the evolution from a hardware (instruments)-centric standard to a hardware/ software (automation)-centric standard. Key elements of ISA5.2-1976: "Binary Logic Diagrams for Process Operations" were incorporated. Binary logic symbols of Scientific Apparatus Makers Association (SAMA) PMC 22.1-1981: "Functional Diagramming of Instrument and Control Systems" were also incorporated. Graphic symbol dimension tables were incorporated to establish minimum mandatory dimensions for the symbols.

Nonmandatory examples were moved to a new Annex B: "Graphic symbol guidelines" (Informative) to provide some limited assistance in the application or were removed for inclusion into future technical reports to provide special practices and requirements of particular interest groups and/or specific industries.

A significant change was to clarify the meaning of the symbols circle-in-square and diamond-in-square. Previously, these



This example of the application of the standard is representative of the ISA standard and the two companion technical reports, ISA TR5.1.02 and ISA TR5.1.03. Source: Figure 6 from ISA TR5.1.03.

represented a distributed control system (DCS) and a programmable logic control (PLC) system, respectively. Given the evolution of control systems, a distinction was no longer necessary, as both systems had evolved to have similar capabilities.

Thus, circle-in-square was redefined to represent the basic process control system (BPCS), regardless of the type of hardware used. In addition, safety systems (ISA84) were becoming prominent, and there were requests for a symbol to distinguish them. The diamond-in-square symbol was redefined to allow the user to choose it to represent either a safety instrumented system (SIS) or an alternate (other than BPCS) control system.

ISATR5.1.01/ISA-TR77.40.01, "Functional Diagram Usage," issued in 2012 and reaffirmed in 2016, was published as the first joint technical report under ISA5.1 and ISA77. The purpose of this technical report was to provide guidance on documenting application software through functional diagrams by illustrating usage of function block symbols and functions and to provide examples of complex function blocks.

The 2022 revision of ISA5.1 was published as an interim revision to correct technical and typographical errors and clarify known usage questions. This provided a corrected standard for users and also served as a starting point for the ISA5.1 Working Group to begin a new revision of this widely used international standard. The corrections made in the 2022 revision are listed in Annex A of that document.

The 2024 revision

The 2024 revision of this standard changed the title from "Instrumentation Symbols and Identification" to "Instrumentation and Control Symbols and Identification" to emphasize that symbols for control are also included. This revision was published with significant changes to improve the readability of the document by organizing notes with corresponding tables; simplifying table numbering; providing definition consistency and clarification; eliminating redundant text; adding new symbols; recognizing alternate symbols, notation and identification for new automation technology; adding new sections for normative reference, abbreviation and bibliography; and adding the loop instrument diagrams symbol table. The changes made in the 2024 revision are listed in Annex A of that document.

This revision moved nonmandatory Annex A and Annex B from the 2022 revision into separate technical reports for easier maintenance and to reduce the size of the standard. The new technical reports are ISATR5.1.02, "Instrumentation and Control Identification System Guidelines," and ISA-TR5.1.03, "Instrumentation and Control Graphic Symbols Guidelines." These TRs provide examples and information on the application of requirements in the standard. Examples in these TRs were updated with additions, revisions, and deletions. The changes made in these TRs are listed in Annex A of the respective document. Users are encouraged to read and use these TRs together with the standard.

Looking ahead

The plan for the ISA5.1 Working Group of the ISA5 committee is to now develop a technical report on instrumentation and control content of PFDs and P&IDs. While ISA5.1 deals with instrumentation and control content on various engineering drawings—including PFDs and P&IDs—this new TR will provide guidance and examples specific to PFDs and P&IDs. This will include guidance to help users decide on the level of detail of instrumentation and control they want to show on their PFDs and P&IDs and what information should be provided at a minimum.

The updated ISA5.1 standard and its accompanying ISA technical reports are available for purchase online. Anyone interested in participating in the ISA5.1 Working Group is asked to contact ISA Standards (standards@isa.org). For information on obtaining any of ISA standards documents and reports, visit www.isa.org/findstandards.

ABOUT THE AUTHOR

Jim Federlein, PE, is Chair of ISA5.1 and a long-time leader in the ISA5 Standards Committee for which he led the 2024 revision of ISA5.1. He is the winner of the 2024 ISA Enduring Society Service Award, one of ISA's highest society-level awards, in recognition of his decades of leadership and service in the ISA Pittsburgh section, in ISA divisions, in several key ISA standards committees, and as a member of ISA's Standards and Practices Board.

A Roadmap for Improved Simulation Success

The most effective simulation solutions for process manufacturing are designed using integrated software to deliver value across the entire lifecycle.

By Dustin Beebe

Today's process manufacturers face a wide array of new complexities. An expanding global marketplace has made it more important than ever to increase efficiency and competitiveness, while global events and trends continually shift, making it harder to achieve those goals. Many organizations around the globe are facing a critical shortage of experienced workers. Plant engineers and operators are retiring at an unmatched pace, taking years or even decades of institutional knowledge with them. New personnel are in short supply, and even when they are available, they take years to upskill to a level where they can meet the performance of their predecessors.

Further complicating the worker shortage are new trends in the workforce, with modern plants seeing a trend of more transient workers. Gone are the days when an operator would sign on and stay for 30 years. Today's talent is typically ready to move to a new role, or even a new location, in fewer than five years. This is often less time than it takes to fully train them. Furthermore, today's organizations are finding it hard to attract anyone at all unless they offer modern working environments. The new generation of workers was raised on digital technologies, and they expect to see those same capabilities in their workplace to help them learn more quickly, make better decisions and collaborate more effectively.

Global pressure to drive increased sustainability while increasing performance is adding additional complexity. Most teams must not only focus on increasing production but also on doing so while reducing emissions and curbing excessive energy use. Meeting those goals often means innovating on traditional operations—a big ask with fewer experienced people and significantly reduced resources.

To meet these challenges, simulation software can be a game changer, but only if a project team approaches it thoughtfully. While it is possible to build one-off simulations for each project and operational need, the result will be costly and difficult to maintain. A better solution is to evaluate simulation at every stage of a project, building a cohesive simulation roadmap that will meet the organization's needs at every stage and continue to deliver value well after operations commence.

The case for simulation

One of the primary benefits of simulation software is that it provides proven results over the lifecycle of a facility. In the earliest stages of project design, simulation helps reduce capital expenditures by helping project teams evaluate and validate process and automation designs, as well as enabling safer testing with improved results to help teams more easily meet or even shorten project schedules.

Yet even after project completion, simulation software continues to deliver value across its lifecycle. Dynamic simulation tools provide the best possible training platform for new operators, providing them the opportunity to work with systems that look, feel and respond exactly like the controls they will use every day. These training simulations can be built, deployed and used well before equipment ever arrives onsite, ensuring operators are ready to perform at their best on the very first day of operation. These simulations can then continue to be used to train new hires throughout operations.

Dynamic simulation tools also provide a test bed where operations teams can test new equipment, strategies, and configurations to help them increase performance and drive more sustainable operations, without interrupting or risking operation of the plant. With the right simulation software in place, the dynamic simulation can be continually synchronized with the changing plant to ensure it is always available to empower operators and enhance the way they work to meet their ever-changing goals.

Different stages have different needs

One of the most important things to remember when developing a simulation software roadmap is while there are different stages of a project and operation, there are also different types of simulation software, and they all must be paired strategically. The earliest stages of project engineering will typically require steady-state models. In the pre-front-end engineering and design (PreFEED) stage, project teams will typically build a simplified steady-state simulation they can use for the conceptualization of the plant.

These models have limited details, only providing the general parameters of the design of the plant the team wants to build. Such a simulation might work in tandem with a capital cost estimator—effectively its own style of simulation—to gather estimates and calculations for what each element of construction might cost, allowing the team to scale certain elements up or down to stay within budget. Teams at this stage might even work with Monte Carlo simulation tools to see how different economic factors will impact their design.

Later, in the FEED stage, the project team will further refine its steady-state model using high-fidelity simulation software. Leveraging these high-fidelity models, the team will develop their final visions for plant operations, define their operating philosophy, set the project strategy and then use those elements to continue to develop and validate their core process designs.

As the team moves into project execution, their simulation needs will change. The team will begin working with dynamic simulation software to execute detailed design, where they develop the automation system and begin testing procedures and controls, tune control loops and eventually enter the commissioning and training stage. Each of these elements can be performed on the simulation software to reduce risk and shorten time to full production.

After project execution, the organization will continue to use and update its dynamic simulation, both to extend training new and experienced operators as roles change, and as a test bed to define and test new operating strategies to unlock constant innovation (Figure 1).

Figure 1. Dynamic simulation can be used to train operators and test control strategies in the control room or even in the field.

The right software at every stage

The most impactful choice a project team can make is to select steady-state and dynamic simulation tools that are designed for flexibility and seamless integration. Unfortunately, many times these choices are made for the immediate next steps without consideration for needs later in the lifecycle of the facility, or even later in the project.

One of the most important factors is re-use because users need simulation to serve as many purposes as possible to maximize its value. For steady-state simulation, teams need ties to many tools, allowing them to perform capital cost estimation—as well as risk, economic and sustainability analysis. Later in the lifecycle, a simulation that can be compared to live plant conditions to look for optimization opportunities can create value for many companies.

In dynamic simulation, one example of re-use is between steady-state simulation and dynamic simulation. When teams select integrated steady-state and dynamic simulation solutions, they can easily transfer their existing flow sheets, base configuration, equipment and instrumentation to their dynamic simulation software.

Just as with the steady-state simulation, teams want dynamic simulation to serve as many purposes as possible to maximize its value. The best dynamic modeling tools also empower project teams to work in multiple fidelities. These solutions offer simulation objects that allow teams to perform high-fidelity dynamic simulation at the core of the process but also provide objects that make it easy to build out lower-fidelity objects as users approach the edges of processes and units. The advantage of such a solution is a final product that is easier and more cost-efficient to manage.

Simulation software can be a game changer, but only if a project team approaches it thoughtfully.

It is important to consider the required fidelity to support individual use cases. For example, contemplate a dynamic operator training simulation where the operator learns to monitor cooling water on an exchanger. The cooling water process could be modeled in high fidelity, but doing so would be complex, and would require many variable changes in the simulation any time the process changed. Those variables, however, offer little value in the training simulation. The operator does not need to know if the cooling water is 81 or 85 degrees. The user simply needs to know if there is cooling water flow—a dynamic that can be modeled and far more easily managed long term in low fidelity.

By contrast, if the simulation is training an operator to know that a bioreactor needs to run at 100 degrees versus 101, that distinction might be critical, in which case

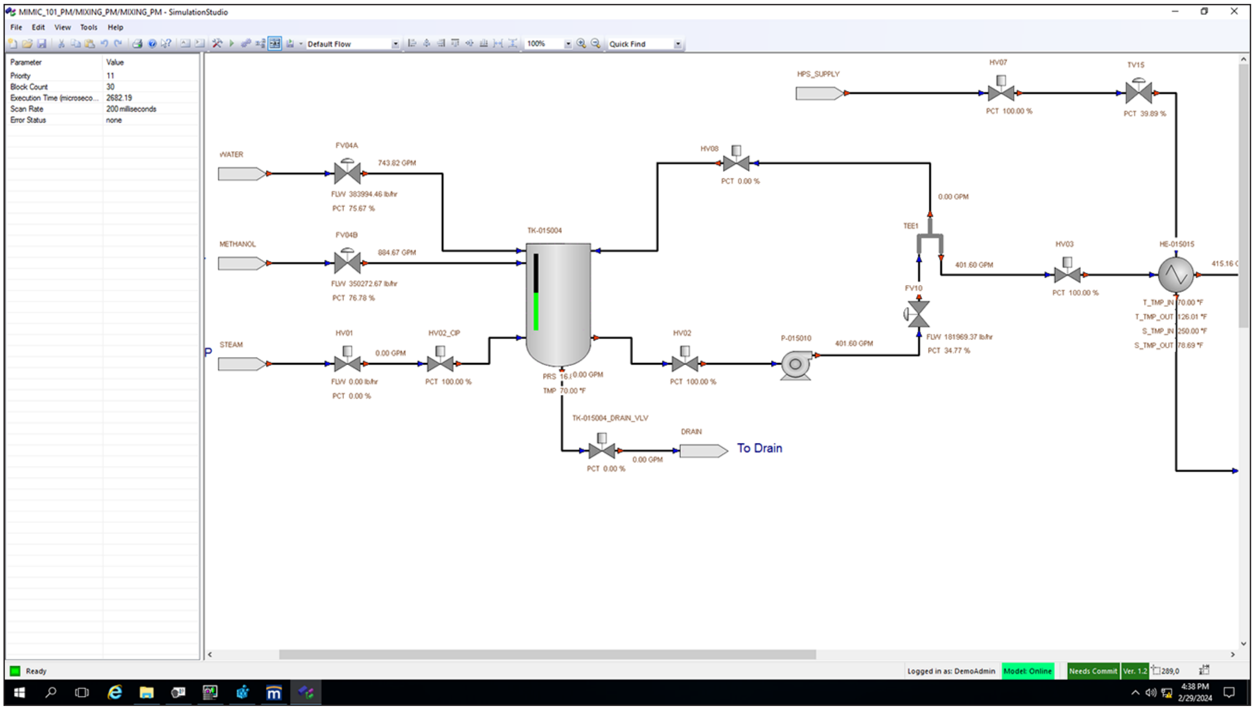


Figure 2. Simulation software allows users to quickly develop high-fidelity simulations using configurable dynamic models of process unit operations.

the simulation might need to be high fidelity. However, that same high-fidelity bioreactor model might be in a training simulation with many other low- and medium-fidelity elements as well. Every model that can be created in lower fidelity reduces the number of complex interconnections in the simulation (Figure 2).

Dynamic simulation software with the capability to easily incorporate high, medium and low fidelity empowers teams to customize their solution to the unique specifications of their process. By eliminating unnecessary interconnections, teams reduce the likelihood that the simulation will be too hard to maintain as variables change due to equipment swap-outs, degradation, fouling, or other changes.

Solutions built for success

Whether an organization still has a deep bench of experienced operators or is trying to onboard a new generation of workers with limited experience, finding a safe way to test, train and tune new processes is critical. New workers will need to gain experience as quickly as possible if the plant hopes to meet the necessary performance benchmarks dictated by competition in a global economy.

Conversely, even experienced workers will have to learn many new operating procedures (on very different, and often more complex equipment than they are used to) if they hope to help their plant meet new sustainability benchmarks and comply with regulations. In either case, operators need a risk-free

Figure 3. As operations become more complex, plant personnel will need increasing access to safe ways to learn and test innovative operations strategies. Simulation will be central to this capability.

environment to learn, test and innovate. Such an environment cannot be provided on live equipment (Figure 3).

Fortunately, today's multipurpose steady-state and multi-fidelity dynamic simulation tools are up to the task. Modern, best-in-class simulation tools offer the flexibility to meet the dynamic environment of today's plants. They also include the features necessary to drive fast return on investment and continuous value over the lifecycle of the facility, from the earliest stages of design, through automation development and startup, and even throughout operations as they change over the years. The key is selecting an integrated solution upfront that is designed for the unique needs of every stage.

All figures courtesy of Emerson

ABOUT THE AUTHOR

Dustin Beebe serves as vice president of Performance Software for Emerson. He is responsible for the alignment of the Control Performance, Operator Performance and Simulation businesses globally and the strategy synergy between Emerson and AspenTech. Prior to joining Emerson, Beebe served as the President of ProSys until it was acquired by Emerson in 2018. He has been in the industrial automation business since 1996. Beebe has a bachelor's degree in chemical engineering from the University of Arkansas in Fayetteville, Ark.

How to Harness Applied AI in Industrial Manufacturing

By Michael J. Anthony, Jon A. Mills, and David C. Mazur, Ph.D.

Properly understand key concepts and use necessary contextual data to train AI models.

Industry 4.0 has continued to evolve and grow its presence within the industrial automation community. As a result, the community faces considerable challenges due to the growth of Industrial Internet of Things (IIoT) devices and technologies. One of these technologies is artificial intelligence (AI). Applied AI has been around as a concept for many years in various fields, but industrial automation has been cautious to adopt the technology. This article will explore a brief history of applied AI and its usage within industrial automation.

History of applied AI

The industrial automation and manufacturing sectors are facing unprecedented levels of pressure. These pressures include increasing demand for products, large backlogs due to supply shortages from the COVID-19 pandemic and significant labor shortages due to lack of skillset ready to enter these markets.

Due to the difficulty of hiring and retaining talent and the skills gap shortage, businesses need to turn to alternatives to help ease the pressures they are facing. Many manufacturers turned to robotics to help solve the labor challenges with various levels of success.

There is much opportunity to use applied AI in manufacturing, but along with that opportunity come many challenges.

A second problem that manufacturers are attempting to solve is the data problem. With computing and processing costs at the lowest levels ever, data from devices and equipment is more prevalent. Manufacturers are struggling on their digital journeys with how to consume the growing volumes of data they're producing. Extracting insights to drive useful outcomes is not easy.

The solution for many manufacturers is applied AI. The impact of applied AI is promising in industrial automation and manufacturing. A major consulting firm has estimated that more than 30 hours of a typical work week would become automated by AI by the year 2030. However, properly using AI in automation and manufacturing environments requires first understanding some key concepts.

How NLP solves the data problem

Natural language processing (NLP), a field at the intersection of computer science and linguistics, has evolved significantly from its preliminary concepts in 17th-century philosophy to its formal establishment with the dawn of computing in the 1940s. These early ideas laid the groundwork for machine translation and the first computational models of language.

The field has seen steady progression, with early rule-based (symbolic) methods being supplemented by statistical models and eventually overtaken by today's advanced neural network approaches. Among the most transformative neural network architectures for NLP is the "transformer," introduced in the seminal paper "Attention is All You Need" under the umbrella of Google's research initiatives in 2017.

Transformers have laid the foundation for the diverse array of NLP-powered AI now being developed across the technology sector. From compact models designed for budget devices to enormous architectures operating on cutting-edge cloud computing resources, the scope and application of NLP models have never been broader. Rather than only being present in research fields, this is offered in forms that are relevant to industry adoption or hyper-specific domain-bound tasks.

Nondeterminism neural networks

Understanding the nondeterministic nature of transformer-based neural networks is fundamental to appreciating the challenges highlighted in this article. These models, which underpin contemporary advances in natural language AI, exhibit inherent stochastic behavior often seen within manufacturing. Not only does nondeterminism enable the generation of diverse and fluent responses across various domains, it also presents unique challenges in standardization and quality assurance when deploying these models into production environments.

Contrary to traditional software, where deterministic input-output relationships allow for standardized testing methods such as unit, integration, and system testing, transformer-based models defy these conventional practices due to their probabilistic outputs. The variability in responses means that results from traditional testing can no longer guarantee consistent model performance.

This inherent nondeterminism necessitates the development of novel testing and validation frameworks attuned to the probabilistic nature of these AI models. Organizations must adapt by implementing strategies like A/B testing, continuous monitoring and dynamic error analysis, which accommodate the variability of responses.

Moreover, product teams must be educated in stochastic model behavior, establishing realistic expectations and a deeper understanding of the tradeoffs associated with leveraging these powerful but unpredictable models in commercial applications.

An analytics module uses AI to detect production anomalies and alert workers so they can investigate or intervene, as necessary.

Applied AI example in industrial automation

Building on the discussion of prompt injection techniques, such as retrieval-augmented generation (RAG), an experiment was conducted to evaluate their efficacy in improving model accuracy and reducing instances of generated hallucinations. The authors used the GPT-3.5-turbo model developed by OpenAI for this investigation, structuring our prompts to solicit specific information. The initial prompt was constructed as follows:

"What is the name of alarm 10041 on the PowerFlex 755T Variable Frequency Drive? Provide only the alarm name, no other text."

To guide the model's responses, we incorporated an exemplar user/assistant exchange:

User: "What is the name of alarm 10012 on the PowerFlex 755T Variable Frequency Drive? Provide only the alarm name, no other text."

Assistant: "Brake Slipped - Drive Stopped"

Upon presenting this structured prompt to the model 10,000 times, we observed 6,934 unique responses, none of which were the correct answer "Precharge Open Alarm." This result suggests an absence of the necessary data within the model's training corpus. The most frequent responses are listed in Table 1.

DC Bus Overvoltage	173	Encoder Fault	61
Drive Overtemperature	124	Motor Overtemperature - Drive Stopped	51
Motor Overtemperature	86	Analog Input Loss	48
Overvoltage Fault	79	Drive Overvoltage	45
Undervoltage Fault	68	Motor Phase Loss	44

Table 1. The initial GPT-3.5-turbo prompt yielded these responses.

To address this variation in response, the authors performed a second trial, introducing a JSON object into the system context, derived directly from the relevant source material:

```
{
    "Condition Type": "Alarm 2",
    "Condition Code": "10041\n11041",
    "Display Text":
    "PrechargeOpenAlm",
    "Full Text": "Precharge Open Alarm",
    "Fault": "The internal precharge-
    circuity-bypass relay (for drives)
    or main contactor (for CBIs) was
    commanded to open while the drive
    was stopped (PWM was not active)
    due to low DC bus voltage.",
    "Action": "Investigate low DC bus
    voltage or the reason the drive
    entered precharge.",
    "Fault Action": "—",
    "Configuration Parameter": "0:37
    [Prchrg Control]\n0:190 [DI
    Precharge]\n0:191 [DI Prchrg
    Seal]\n",
    "Configurable Action": "—"
}
```

With this additional context, a subsequent set of 10,000 queries yielded only 19 unique responses. The majority appropriately identified the alarm as shown in Table 2.

Precharge Open Alarm	7,808
Precharge Open Alm	1,742
Precharge Open	344
PrechargeOpenAlm	44
Precharge Open Alrm	29
Precharge Open Alar	12
Precharge Open Alarm.	11
Precharge Open - Alarm	3
The name of alarm 10041 on the PowerFlex 755T is “Precharge Open Alarm”.	2
Precharge Open-Drive Stopped	2

Table 2. Responses from the contextual prompt.

The introduction of contextual data significantly increased the frequency of the correct response. However, despite the narrowed range of responses, the nondeterminism of the model continued to produce slight variations in the output.

Final thoughts

Harnessing applied AI in industrial manufacturing requires properly understanding key concepts and using necessary contextual data in AI model training. There is much opportunity to use applied AI in manufacturing, but along with that opportunity come many challenges. We are in an exciting time to see how this evolves.

ABOUT THE AUTHORS

Michael J. Anthony graduated from Marquette University in Milwaukee with a Bachelor of Science degree in computer and electrical engineering and started with Rockwell Automation as a software development engineer in 2005. He worked on a variety of information and human-machine interface (HMI)-focused products in the FactoryTalk portfolio and has held roles as a product manager for a variety of HMI, communication, and security software products in the Rockwell Automation portfolio. Currently, Anthony is focused on applications communication technology in the Rockwell Automation Strategic Development organization in the office of the CTO. He earned a Master's degree in 2019 and is pursuing a PhD in manufacturing systems focused on communication technologies from Capitol Technology University in Laurel, Md.

David C. Mazur, PhD works as a senior manager for Rockwell Automation in Milwaukee with a current focus on digital experiences for industrial automation products. His experience includes application development in heavy industry automation and infrastructure. Mazur received his BSEE from Virginia Polytechnic Institute and State University, Blacksburg, VA in 2011. He graduated with his MSEE degree in 2012 from Virginia Polytechnic Institute and State University. He graduated with a PhD in mining engineering in September 2013 for his work with automation and control of the IEC61850 standard. Mazur is an active member of the IEEE IAS and serves as working group chair for the Communication-Based Protection of Industrial Applications Working Group. He also serves as a member of the Mining Industry Committee (MIC) as well as the Industrial and Commercial Power Systems Committee (I&CPS). Mazur is also an active voting member of the IEEE Standards Association (SA).

Jon A. Mills graduated from Ohio University in Athens, Ohio with a Bachelor of Science degree in computer science. He started at Rockwell Automation in 2013 with a focus on integrating intelligent devices into industrial control systems. Working as a principal system architect, Mills continues to focus on device integration within traditional operational technology (OT) networks in the OT/IT (information technology) boundary.

Closed-Loop Control Fundamentals

By Jack Smith

A trip through past issues of *InTech* reveals a wealth of resources for understanding closed-loop control fundamentals.

As I wrote in my August 2023 *InTech* article on temperature measurement and control fundamentals, "Automatic control in continuous processes uses industrial control systems to achieve a production level of consistency, economy, and safety that could not be achieved by human manual control only. It is implemented widely in industries such as oil refining, pulp and paper manufacturing, chemical processing, and power generating plants, to name a few. The "big four" process control parameters are temperature, pressure, flow, and level."

Although that article was primarily about controlling temperature, closed-loop control concepts are fundamentally the same. Only the sensors and processes are changed.

Allan Kern, PE has 35 years of industrial process automation experience and has authored dozens of papers on more practical, reliable, and sustainable advanced process control solutions. Kern helps companies improve process efficiency, quality, and profits on-site or with online consulting complementing in-house resources, helping bridge a skill shortage at many sites. He is the founder of APC Performance LLC.

In his Feb. 2019 *InTech* article, Kern wrote, "Advanced process control (APC) refers primarily to multi-variable control. Multivariable control means adjusting multiple single-loop controllers in unison to meet constraint control and optimization objectives of an additional set of related process variables. Multivariable control is a central aspect of nearly every industrial process operation."

While Kern's article delves into more complex subject matter that most of our readers are familiar with, APC and multivariable control still depend on single-loop controllers. Understanding the fundamentals and/or reviewing the basics can be beneficial to technicians and operators who need a refresher.

"APC continues to rely on the lowly flow control loop, the most basic single-loop control, as the best rejector of unmeasured disturbances and the most stable platform for the APC/optimization control hierarchy."

Jim Ford's article in June 2019 *InTech* describes how single-loop control is still the mainstay of advanced process control. He says, "Today, even after 50 years, APC continues to rely on the lowly flow control loop, the most basic single-loop control, as the best rejector of unmeasured disturbances and the most stable platform for the APC/optimization control hierarchy."

Again, although Ford was writing about flow, the concepts still apply to the other three of the big four.

It starts with the sensor

Process control parameter measurements start with the sensor. The aforementioned temperature control uses thermocouples, resistance temperature detectors (RTDs), and associated transducers and transmitters. Pressure measurement requires pressure transducers, flow requires flowmeters, and level requires a level measurement system. Much can be—and has been—written on each of these technologies.

A transducer converts a physical phenomenon into an electrical signal. In effect, thermocouples and RTDs are types of transducers. The use of the term is more common in flow and pressure control.

Transmitters convey a measured signal to a control device. The signal coming directly from the sensor is at a low level. The job of a transmitter is to convert the sensor output into a strong standardized signal and transmit it to a control system. Sophisticated transmitters can perform diagnostics on the sensor to determine if there is degradation of the actual element. The transmitter connects to the control system to provide the process variable (PV) measurements.

Maintaining a digital signal to the control system maximizes accuracy. Digital communications avoid the errors of converting the digital signal to analog 4-20 mA on both the transmitter end and the control system end. Digital options include HART, Modbus, Profibus, and FOUNDATION Fieldbus.

Accuracy and stability are fundamental traits of any process measurement. Although closed-loop control can be accomplished in many ways with many technologies, such as programmable logic controllers (PLCs) or distributed control systems (DCSs), this article assumes a stand-alone single-loop controller (Figure 1). This theoretical controller includes a signal processing front end that converts low-level input from the

Figure 1. This single-loop controller can control both heating and cooling simultaneously, and can accept signals from a thermocouple or RTD, or from a pressure/flow/level sensor, and maintain a setpoint using a relay, voltage pulse, current, or linear voltage output signal.

Courtesy: AutomationDirect

sensor to a usable signal, which is compared with a setpoint (SP). The resulting output depends on the amount of error between the measured temperature, or process variable PV, and the setpoint.

Single-loop controllers are used in small facilities, or for some isolated stand-alone processes. Large continuous process facilities, such as refineries and chemical plants, use DCS to control pressure, temperature, flow, and level, and how they affect the operation of the plant. In some cases and some industries, PLCs instead of—or in addition to—DCSs are used. Sometimes, PLCs control subprocesses via signals obtained from a main DCS.

PLCs have been used to control temperature for decades. It should be noted that if only temperature control is required, a DCS or a PLC is gross overkill. These systems are designed to control the entire process plants or parts of plants. Either of these devices is capable of having hundreds of control loops—temperature, flow, pressure, and level.

Closing the loop

Regardless of the type of controller (PLC, DCS, or single-loop controller), the measured signal from the sensor and/or transmitter is compared to a setpoint. The resulting output depends on the amount of error between the measured temperature, or PV, and the setpoint.

In addition to accurately measuring a process, there must be a way to control the amount of correction applied to that process. The process itself "ties" the system together.

The output of the controller must have a means of actuating the controlled process. This can be heaters or burners, control valves, or positioning devices. Then the closed-loop control system begins again with the process being sensed and the controller adjusting its output.

Single-loop control gets more complicated with the introduction of proportional-integral-derivative (PID) functionality. PID is a topic for a future column.

ABOUT THE AUTHOR

Jack Smith is senior contributing editor for Automation.com and *InTech* digital magazine, publications of ISA, the International Society of Automation. Jack is a senior member of ISA, as well as a member of IEEE. He has an AAS in Electrical/Electronic Engineering and experience in instrumentation, closed-loop control, PLCs, complex automated test systems, and test system design. Jack also has more than 20 years of experience as a journalist covering process, discrete, and hybrid technologies.