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FOR MACHINE BUILDERS

I/O for an Expanding Machine Environment

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A cable, a connector, I/O and thee

Networks need application-specific devices that enable flexibility and empower data

Many industrial applications these days require a deterministic network. The applications can have one or more controllers talking with upward of 100 axes of motion and hundreds of I/O points. Often, the tension and torque to move materials have to adjust quickly. I/O control, motion commands and HMI updates all need to be in sync for the machine to run at an optimal level.

The key components of a machine's automation system are the input/output (I/O) devices. Input might be sensor data, and output could be actuator commands, but the scheme depends primarily on the analog or digital I/O.

Innovations have made devices more intelligent, not to mention smaller and faster. Previously, I/O systems were centralized and mounted on a DIN rail in an enclosure. In enclosed I/O modules, machine builders terminate wires with spring clamps, cage clamps, screw clamps or connectors. Enclosureless I/O systems provide new types of flexibility that cabinets can't offer.

New options for I/O continue to arise. As machines become more modular and adaptable, distributed I/O has become more attractive, as well as easier to install and commission.

TECH TRENDS, BACK TO BASICS AND CASE STUDIES

This State of Technology Report looks in greater detail at these trends and other technology trends in the arena of I/O. Drawn from the most recent articles published in the pages of *Control Design*, this special report includes articles on emerging trends, basic primers and case histories illustrating the latest technology in action. We hope you find it useful.

CASE STUDY:

Field logic controller solves a clean-in-place application

This field logic controller solves a clean-in-place application at an Idaho dairy and provides a glimpse of the future IIoT edge devices.

By Jason Clements, Landmark Industrial Service

When a dairy has an issue with an intermittent controller, it can cause imbalanced chemical application during the backflush period of its process. When one of our customers found itself in this situation, we decided to replace the failed controller with Turck's TBEN field logic controller (FLC) to get the dairy's backflush-cleaning process back on-line (Figure 1). The controller includes ARGEE software and pushes reliable control to the edge devices by adding logic to compatible I/O blocks without a PLC.

The FLC concept is every bit as revolutionary as IO-Link. Turck took what was once just a discrete I/O distribution block and gave it a brain—the ability to solve logic and make decisions. Giving a dumb edge device the ability to solve logic and communicate with other devices is an up-and-coming trend. This is an important step on the path to the Industrial Internet of Things (IIoT).

Our goal was to open our doors as an industrial distributor and get back on the road, knocking on doors with a boots-on-the-ground mentality. Doing that, we always asked a question to our customers: What do you need fixed? The customer wasn't used to that.

They started telling us their problems, and we used our knowledge to come up with solutions to help them to fix their problems. It turned into the customer asking us to help them specify the hardware and then asking us to design it and so on. We slowly turned into a

WHERE'S THE COW?
Figure 1: A common feature of all dairies is the milk parlor; cleaning the equipment is a critical process

value-added distributor. From there, we developed some of our own products and became an integrator.

Our specialties are in dairies and breweries. It's how we got started in our integration business. A lot of the automation in dairies is also found in breweries. There are many similarities in keeping the milk cool or the beer cool.

DON'T IRRITATE THE COWS

In this application, we worked with DeLaval Direct, a dairy service provider in Jerome, Idaho, and Glanbia Foods, which supplies raw milk product to Glanbia's three processing operations located near Twin Falls, Idaho. It was a team effort to correct the backflush problem.

The backflush process is a critical element in every dairy operation. The pipes that transport the milk from the vats to the siloes go through a clean-in-place (CIP) process to clean the pipes of any old milk for sanitary reasons. During CIP, several flushes of water, air and chemical cleaner run through the pipes and udder assemblies.

To avoid contamination of the milk, irritation to the cow and potential bacterial infection, the control sequence must be correct, allowing the proper amount of cleaning agent to flow through the assembly

THE SMART I/O BLOCK

Figure 2: The field logic controller is at home in a control enclosure or out in a harsh environment.

for the required amount of time. Run time is critical to a successful cleaning process. The control sequence must also ensure the proper amount of water and air is used to remove the cleaning chemicals.

Depending on the size of the dairy, you can typically milk from 16 to 170 cows. Each dairy has a similar process—when the cows are done being milked, the operators in the dairy switch the controls from "cows-to-vat milk collection" to the cleaning process. With the backflush controller working intermittently, the cows were irritated, so the dairy needed it fixed right away.

A SMARTER EDGE

One of the things that brought the Turck TBEN field logic controller into play is the dairy needed something that had the brains of a PLC, was small and compact and was very robust. The dairy environment is very harsh. Turck's FLC design includes an IP69K rating, which is very high, and it is washdown capable with an extended temperature range (Figure 2).

Something that makes the TBEN field logic controller unique is that it isn't just a digital block-I/O module; it has a brain—hence the field logic controller name. It has the appearance of a standard field-mountable I/O distribution block. Turck added a controller and added the ARGEE program to it, turning it into a small, rugged PLC.

With ARGEE software, a small program was written in a structured text type of program by Turck. A single FLC I/O block was added with eight configurable inputs and outputs. This single block solved the dairy's problem.

Although the Turck FLC uses multiprotocol technology, which is basically Ethernet gateways for Profinet, Modbus TCP or EtherNet/IP, simple digital I/O was used to interface to the dairy's main controller. A button press on the main PLC's HMI digitally triggered the cleaning process in the FLC. The field logic controller controlled the pumps and valves using digital outputs and a digital output notified the main PLC when the cleaning process was complete.

In a few hours, the dairy told us what it needed over the phone. We understood the process, which included a number of timed cycles and counters. Chemicals, water and air all needed to flow in the proper sequence, for a period of time and the correct number of cycles.

The customer defined the sequence and Landmark wrote the program, assigned the I/O and worked with and trained the installation team. With quick-disconnect cable connection to the FLC, the installation was completed quickly. In a couple hours it was done and the backflush cleaning of the milking parlor was operational.

A LITTLE PROGRAM AND TRAINING

The ARGEE program is a big benefit in the FLC. You start programming ARGEE by using a flowchart, which resembles ladder logic. It's simple to understand and learn. Once the flowchart/ladder logic-like program is accepted, it is converted to a structured text format such as AND, OR, IF, THEN. It was made even simpler by providing dropdown menus in the appropriate locations of the logic, which are helpful hints to flow the program together. This simplifies the ladder logic further. If a program can be accomplished via this flowchart, it keeps things straightforward for any user. ARGEE keeps the visual feel of ladder logic and adds dropdown boxes across the ladder rung. More complex functions are typically added once the structured text program is automatically created keeping all levels of programmers happy.

The ARGEE programming environment is accessed using an HTML5-compatible Web browser, which eliminates the need for complex third-party software or licensing.

The software is already in the field logic

> "There were six sensors that had to be monitored and decisions made based on the sensor's state and functions being performed."

controller, and it's free. To access the ARGEE software, a Google Chrome browser is used to log on. No need for Internet, just the Chrome browser, which it is designed for, but other HTML5-compatible Web browsers will work.

The TBEN field logic controller has really been refined over the past few years. The ARGEE program is getting easier and flashing the program to the FLC is simple and reliable. It's easy to activate and update the firmware in the device, so future improvements will be available. No special software is needed, as it is just a simple link sent via Dropbox.

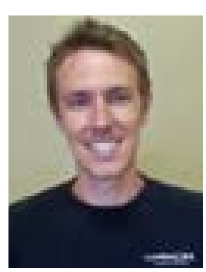
A SMARTER EDGE

The FLC provides a great way to add logic at the edge without investing in a PLC or installing a fragile smart relay in an enclosure. The FLC can operate stand-alone and out in the open, without a need to communicate with a PLC. It can also monitor a machine or edge sensors and interface with a PLC where needed.

We have also used this FLC to add I/O to existing PLCs in other applications. We did this in a mobile cart application where the PLC had only one spare input available. However, to operate properly, there were six sensors that had to be monitored and decisions made based on the sensor's state and functions being performed. More I/O was needed and program logic was required to monitor the sensors before turning on the output to the existing PLC. With the field logic controller, it was easy to add extra I/O and a little logic to applications that didn't have the spare space.

These TBEN field logic controller blocks also work well in agriculture applications, especially on farming equipment. People who may currently be using smart relays for control applications often have problems if just a little vibration, water, mud, dirt or dust is added to the control panel. With the TBEN FLC and its IP69K rating, environmental conditions are not an issue. It's nearly immune to shock, vibration and the elements, which makes it a great replacement to the fragile smart relay, and it doesn't need to be placed in a enclosure to do it.

For this dairy application, the following morning after installation, veterinary samples showed that the critical metrics were accurate and working well, and the dairy received perfect marks for cow health.



About the author

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How distributed I/O can work on packaging lines

Alternatives to running servo power and feedback cables, as well as wiring to sensors and solenoids.

By Control Design

A *Control Design* reader asks: I'm trying to reduce field wiring on the packaging lines that we build. Typically, I might have a dozen servo drives on the equipment. Instead of running servo power and feedback cables, along with wiring to solenoids and sensors, we're looking at using distributed methods.

Any recommendations on I/O methods for the major motion and sensing devices on the machines?

ANSWERS

EVERYTHING ON ONE NETWORK

Today there exist more options for distributed vs. centralized motion than ever, and the good news is that they can often be mixed and matched on the same network, even motors, actuators and drives from third-party suppliers that support a given network architecture.

Integrated servo motor/drives have been around several years now, with the drive electronics mounted on the motors. This frees up cabinet space and quite possibly will allow you to run one hybrid motor cable from the cabinet out to the motor/drives, typically in a daisy chain. These motor/drives can also provide onboard I/O options, which can be used in combination with both cabinet-mounted and machine-mounted IP67 I/O modules, all on the same industrial Ethernet network.

A newer distributed option is the machine-mounted drive. This allows you to distribute higher-powered motion out onto the machine because the separate drive doesn't face the same heat dissipation issues as a motor-mounted drive. It also allows you to use different motor types, such as linear or torque motors, third-party motors or stainless-steel motors.

For automated changeovers, there are now stepper drives in the IP67 remotely mounted I/O form factor. This also is great for retrofits on existing lines.

Likewise, distributed motor/drives are great for headless add-ons, such as leaflet inserters or smart belts, controlled by adding or activating a software module in the main automation controller.

Safe motion is also a huge opportunity for packaging machinery builders and line integrators to go into a safe mode instead of stopping the line. This isn't safe torque off, it's safe torque, speed, position, direction, robotics and more.

Integrated motor/drives are great for rotary machines, too, where power and communications go through a slip ring to turret-mounted motor/drives. Other options include micro drives mounted in the turret, both stepper and servo. A common power supply on the stationary portion of the machine saves space in the turret and allows simpler dc power distribution through the slip ring.

Among the latest developments are servo drives the size of a single-axis drive that can run two and now up to three servo motors, thanks to increasingly integrated electronics. Better yet, drives of this type may be designed to power single-cable motors, presenting another way to reduce both cabinet size and cable runs.

You should also be able to mix any and all of these form factors with conventional single and multi-axis drive systems. Some servo drives can also be used as frequency drives if you have some axes that can benefit from the lower cost of induction motors, with or without encoders.

Today's controllers and networks allow you to run everything on one processor and one network. So it's no longer necessary to buy multiple CPUs to run 12, 15, 20 or more drives and no longer necessary to have separate motion and device buses, even for high-axis-count systems.

— John Kowal, director, business development, B&R Industrial Automation,

DISTRIBUTED BY DISTRIBUTOR

For the case of distributed I/O and servo systems, you would best look into manufacturers that have an integrated motor drive system. Since you have not specified the type of machine, there are many options—

integrated motor and drive VFD for conveyors, integrated motor servo systems even stretching up to 10 hp. Now, if your machine design requires washdown, then I suggest redesigning the machine for a balcony or bathtub design so you don't have to use washdown on stainless steel motors.

There are a number of manufacturers offering machine-mounted servo drives and inverters now. Often these will have extensions/connection points for local I/O at the machine-mounted device for local sensors. I have even used noncontact wireless I/O sensor systems and just run 24 V along the machine. As long as the I/O is not time- or safety-critical, then does it have to have wires? There are many ways to approach the system design and accomplish your goal. I would recommend that you contact a distributor and make sure the communications system has one of these five fieldbuses—Profibus, Profinet, EtherCAT, EtherNet/IP, SERCOS III.

— David Arens, senior automation instructor, Bosch Rexroth Drives and Controls, www.boschrexroth.com

ISN'T IT OBVIOUS?

You mentioned one of the most obvious ways to reduce wiring: distribute the I/O devices and servo drives throughout the system to reduce the number of discrete conductors and reduce the length and number of power and feedback cables. A secondary benefit of distributing devices is control-cabinet size-and-cost reduction.

Two additional ways to reduce wiring include using a modern network like EtherCAT to replace discrete conductors with inexpensive CAT5/6 cable and choosing a servo solution that supports a single cable between servo drive and motor containing both motor power and feedback.

Used together, these can reduce system wiring by 80% or more. The more axes and sensors you have, the greater the savings will be. Many solutions support IP54 or higher-rated devices so it is easier than ever to distribute devices, regardless of the operating environment. Some distributed drives also have onboard I/O that can help reduce I/O devices. Distributed technologies that combine both servo power and EtherCAT into a single hybrid cable maximize savings and may result in only one cable going back to the control cabinet. EtherCAT makes it easy to add remote I/O devices and supports network updates of 0.25 milliseconds (4 KHz) or lower to meet requirements of time-demanding applications. Servo drive and I/O device configuration can be changed on the fly and real-time device operating and status information are continuously available to the machine controller.

— Carroll Wontrop, senior system engineer, Kollmorgen, www.kollmorgen.com

THINK IP67

You have a few options when transitioning to a distributed control network. The first option is to move the equipment from a single large cabinet to multiple smaller cabinets distributed along the conveyor system. Each of these cabinets can contain power distribution, servo and I/O for that section of conveyor. These cabinets can then be networked back to the PLC, reducing a large percentage of the parallel wiring.

The second option is to make the leap to a fully IP67 installation using servos and I/O with direct network connections back to the PLC. With this option, you need to look past the initial sticker shock on product cost and evaluate the time savings of not having to build the individual control boxes. In the end, a combination of both options may work out best. A good starting point would be to evaluate the cable savings by distributing IP67 I/O modules on the conveyor to pick up your solenoids and sensors.

— Jason Haldeman, lead product marketing specialist—I/O & light, Phoenix Contact USA, www.phoenixcontact.com

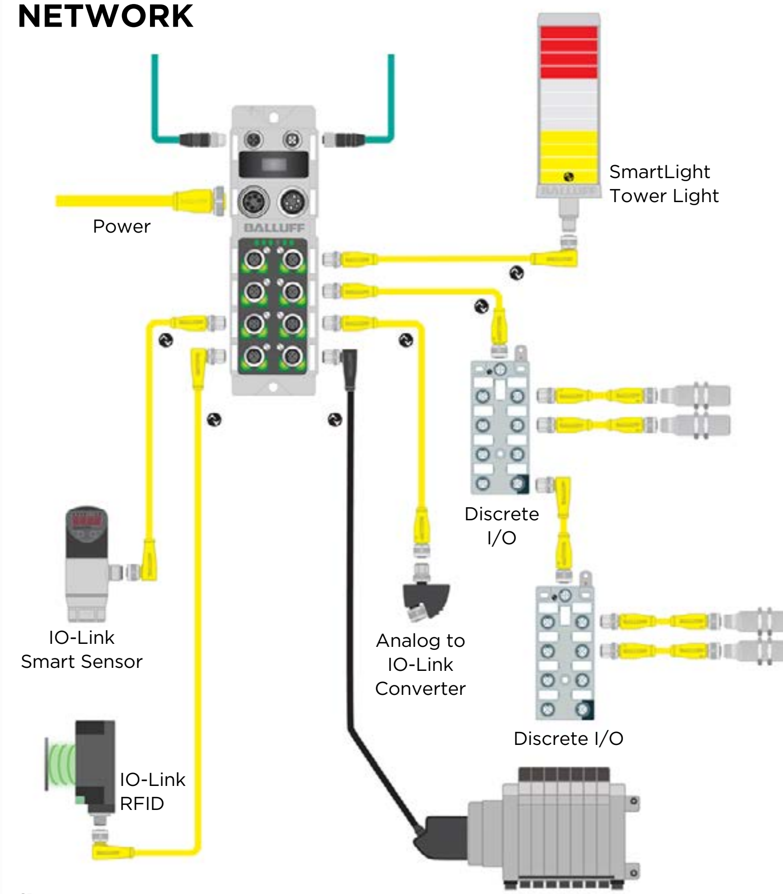


figure 1.

LINK TO IT

Distributed I/O for sensing and valve connections makes a lot more sense than bringing all the individual wires to the control cabinet. As you already know, the wiring that you currently have requires tremendous amounts of labor efforts, and it is more prone to human errors.

Distributed I/O naturally reduces complexity and wiring. Machine-mountable distributed I/O can further reduce complexity, as you can use standard M12 or M8 connections for all the I/O instead of terminating it. IO-Link-enabled machine-mount distributed I/O certainly adds even more value, as it simplifies connections and adds diagnostic capabilities for sensors and smart sensors, as well as I/O.

Furthermore, IO-Link adds flexibility as you build the I/O architectures. We generally refer to an IO-Link-based architecture as "distributed modular I/O." IO-Link is the first sensor actuator communication standard as described in IEC 61131-9. The communication with IO-Link is over three wires and utilizes a standard M12 prox cable; no special cables are required. An open IO-Link port on the field device can host as many as 30 I/O points or any smart sensor from over 115 IO-Link vendors from across the world. On the three-wire communication that IO-Link offers, you can have your process data, parameter data and even events data on the same line.

There are many more features and functions with IO-Link that a standard approach for a centralized wiring concept cannot offer—automatic parameterization, savings on labor, added diagnostics that can reduce downtime and most importantly reduction in human errors, so that as a machine builder you can get to market faster.

The picture in Figure 1 shows a quick view of the architectural design possibility with a machine-mount IO-Link modular design.

— Shishir Rege, marketing manager, industrial networking, Balluff, www.balluff.com

ALL IN ONE

The good news is that there is a wide range of servo and distributed I/O innovations available today that are designed precisely to tackle these kinds of field wiring and installation challenges. When simplifying difficult applications in the field, we increasingly point our customers to time- and space-saving one-cable solutions. The availability and reach of one-cable technology continues to expand, giving manufacturers the ability to instantly reduce cabling cost and effort by 50%. For example, options include:

- one-cable motors combining power and feedback into a standard motor cable (One Cable Technology servo motors)
- one-cable automation solutions combining industrial Ethernet communication and power in a single four-wire standard Ethernet cable (EtherCAT P)
- single-cable display solutions—DVI signal, USB 2.0 signal and 24 V power supply transferred through one cable (CP-Link 4).

Other options available to machine builders and system integrators include I/O terminals with special integrated functionality. For instance, DIN-rail-mounted servo drive terminals have been available for years that pack motion control functionality into an I/O housing as compact as 12 mm wide. This permits the drive to be simply added to the existing I/O rack, right alongside all the other I/O that connects to the rest of the field devices such as sensors and actuators. This dramatically simplifies installation in difficult,

> "There are numerous servo manufacturers today that have developed Ethernet-based servo systems with embedded servo control, such as CIP Motion, where an Ethernet connection is all that is required for both IP20- and IP67-based resolvers and servo signals."

space-constrained application areas. Even better, there are One Cable Technology-compatible versions of these I/O terminals, too, providing even more efficiencies and savings via one-cable control solutions.

— Matt Prellwitz, drive technology application specialist, Beckhoff Automation, www.beckhoff.com

FOR SAFETY'S SAKE

Traditional servo technology used separate cables for feedback, power and brake control, so each servo needed two or three cables for motor control. With the latest servo and motor feedback technology, users can combine the power, feedback and brake signals into a single cable, thereby reducing wiring cable requirements by up to 60%. This not only helps save on installation time and costs, but also reduces the chances of wiring mistakes and the resulting troubleshooting time.

In addition, modern servo drives leverage network-based safety implementation. Compared to a traditional, hardwired, servo safety system, the network approach helps to reduce overall system wiring, save time during installation and remove potential points of failure, which can result in less downtime and troubleshooting. Modern integrated safety systems allow users to change safety zoning and configurations without needing to physically rewire devices.

— Jim Grosskreuz, global product manager, Rockwell Automation, www.rockwellautomation.com

IN ENCLOSURE OR ON MACHINE

A distributed I/O system can be either an IP20 or IP67 system. IP20 I/O requires mounting inside an enclosure, while IP67 is mounted directly on the machine. Typically, servo controllers are located in the PLC rack and cabled to the servo motors located along the packaging lines. There are numerous servo manufacturers today that have developed Ethernet-based servo systems with embedded servo control, such as CIP Motion, where an Ethernet connection is all that is required for both IP20- and IP67-based resolvers and servo signals.

Power to the servo motors are also available in distributed IP65/67 power cabling or the traditional power feed from an enclosure. Today, many packaging line manufacturers are utilizing IP67 Ethernet-based digital and analog on-machine I/O modules to take advantage of the Ethernet network and reduce field wiring.

In an IP67-based on-machine distributed I/O system, reducing field wiring decreases the typical startup time of a new system installation by removing the field terminations and replacing them with IP67 connections. These on-machine control systems enable you to move into production quickly, which in turn negates the initial higher cost of distributed I/O within the on-machine IP67 system. This is accomplished by simply removing the field wiring terminations, which are typically where most problems occur due to incorrect wiring, improper cable jacket stripping and loose screw terminations from incorrect torque.

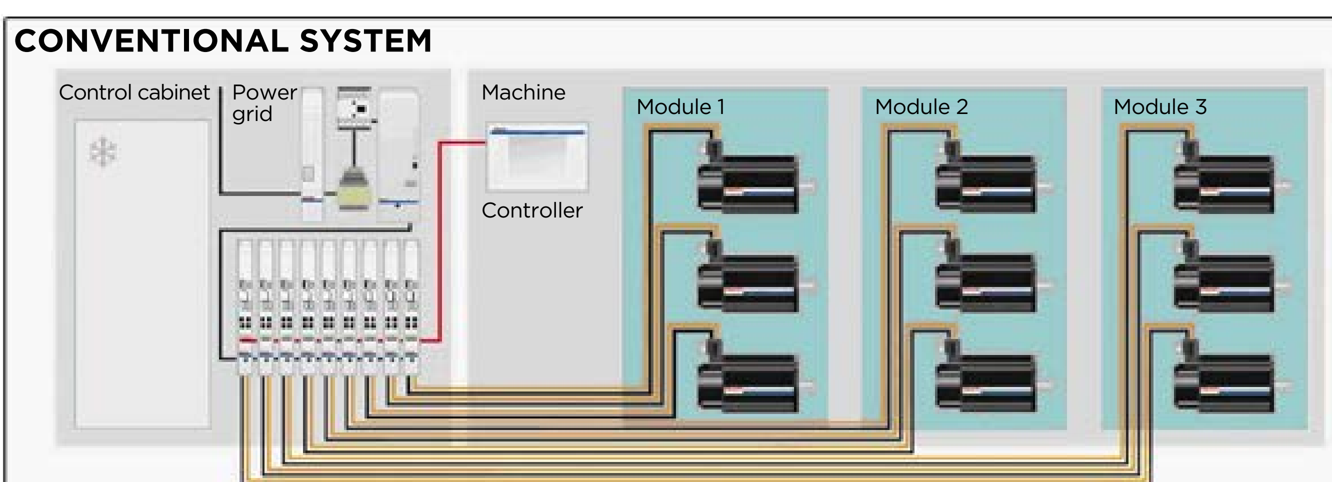
— Ray DiVirgilio, machine builder industry manager (North America), Belden, www.belden.com

NEXT-GENERATION SOLUTION

Today's packaging machines require flexible and decentralized solutions to compete and meet the needs of their customers for the future. Many of the major OEM packaging machine builders come to us with the same question: With the cost of engineering, labor and materials ever increasing, how can you help us to improve and simplify our machine design, layout and fabrication?

With the need for machines to be reconfigured on the fly in order to accommodate additional axes, multiple package sizes or products, the need for motion and discrete sensing devices distributed throughout the machine is on the rise.

We have examined the needs for these next-generation machines and designed a flexible motion control solution with distributed I/O to reduce the cabinet size by up to 90% and reduce wiring needs, thus saving costly floor space by reducing and, in some cases, even eliminating the electrical enclosure. Such

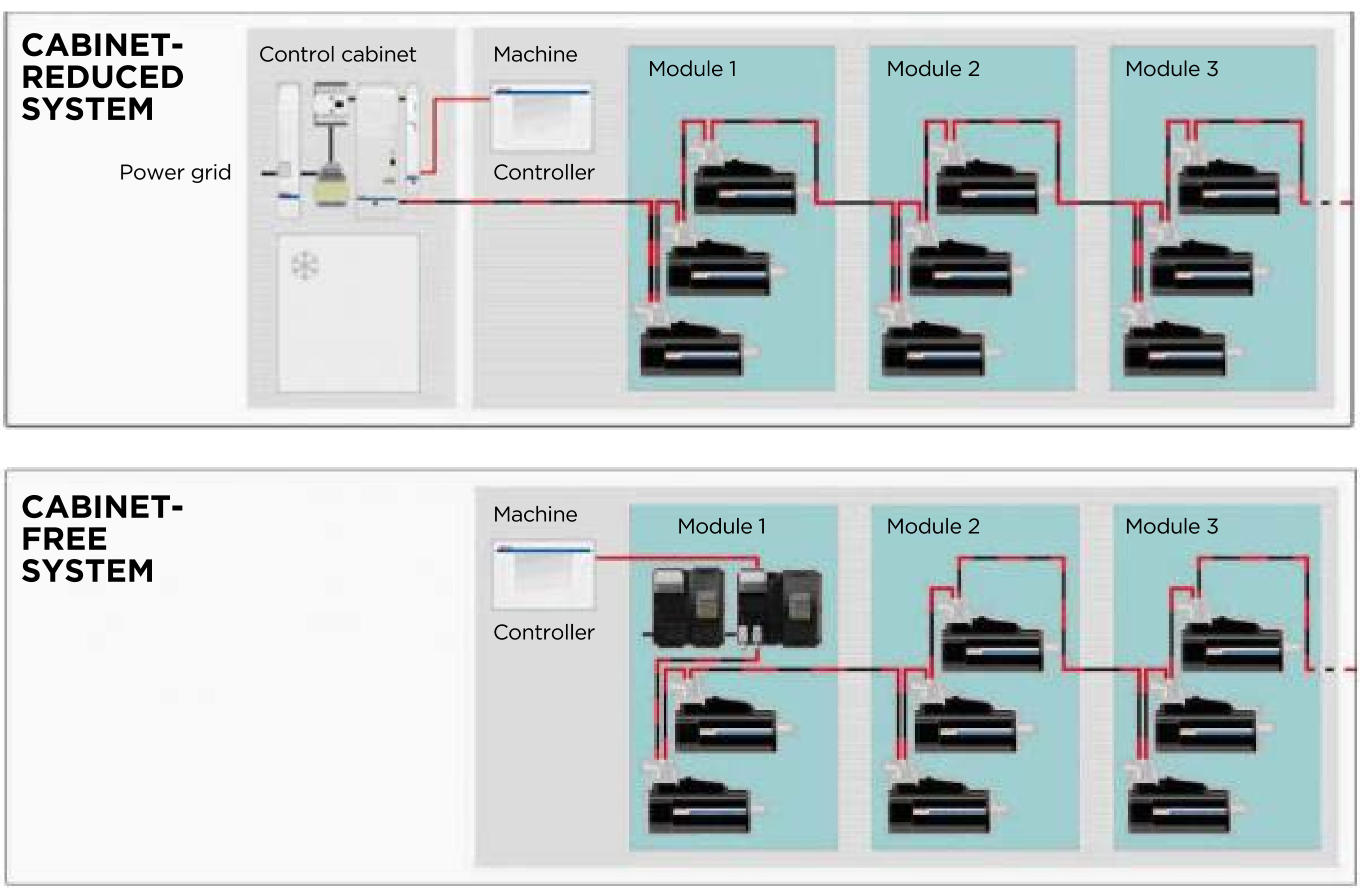


solutions encompass the entire machine, utilizing a single cable that is daisy-chained from drive to drive or I/O block. This eliminates the need to run every device back to the control cabinet, substantially reducing the wiring, complexity and cost.

The solution utilizes a single cable that transmits the main power for operating servo or induction motors, as well as EtherNet-based fieldbus communications for controlling the motion and I/O devices. This solution is extremely versatile as it utilizes a number of today's most popular protocols including SERCOS, EthernetIP, EtherCAT and ProfiNet with others on the way.

Instead of the machine design described by your reader with the servo controller, VFD and PLC I/O installed in the control cabinet and running costly cables out to each device, the solution mounts the servo controller directly onto the motor. Now, only a single cable is needed to be daisy-chained from drive to drive.

Each motor is equipped with four configurable input/output points that can be used at the OEM's discretion but also allow special functionality like high-speed capture of product or motor position that can be very costly to implement in many traditional PLC designs. Additionally, EtherNet breakout



ports are available that allow fieldbus I/O or devices to be connected to the network.

Cabinetless power supply modules eliminate the need for putting high power contactors, inductors, filters and power supply in the control cabinet. Instead, IP65 modules are mounted directly on the machine base.

On bigger machines, this can eliminate the need for air conditioning of the main control panel, as well as reduce its size. These units are fully line-regenerative, which means that the energy used to stop the load/motion is put back into the power line instead of being turned into heat, thereby eliminating the need for resistor banks and providing a greener, more energy-efficient solution that fits well with many of today's corporate mandates.

This cabinetless design also lends itself to some of today's modular designs where the machine designer has divided the machine into function sections that perform a specific task. These modules can then be mixed and matched to meet the specific needs of the end user on the production floor. This also allows a section to be pulled out and replaced if the process changes in the future without the need to rebuild the entire machine.

Another point to consider when evaluating fieldbuses are the emerging requirements to support machine safety. U.S. machine builders are no longer able to sell a machine into the European market without this implemented. Many of the large corporate end users here in the United States are upgrading the internal standards to include machine safety on new machine installations.

Only a few of today's fieldbuses allow support for safety functions to be intermingled on the same bus network as the standard I/O, thereby requiring two networks on the same machine. A good example of this is SERCOS III that has support for safety functions up to SIL3, according to IEC 61508 via CIP Safety for SERCOS. This allows for safe motion, guard doors and light curtains to be on a signal network that operates the indicator lights, pushbuttons and sensors throughout the machine.

— Jeff Bock, senior application engineer, Bosch Rexroth, www.boschrexroth.com

Don’t let poor wire and cable decisions slow down your next project

Since one bad wire can spoil the show, there are several essential considerations when selecting what type of wire to use in a control system.

By Tom Stevic, contributing editor

Wire, hookup wire to be specific, is the unsung hero of a control system. Making the connections is what ties all the electrical hardware together. Since one bad wire can spoil the show, there are several essential considerations when selecting what type of wire to use in a control system.

Unless some special requirement is needed, stranded copper wire is almost always used to supply power and control signals to most everything we connect. The wire size selected is not always based on ampacity—the maximum conductor current capability before damage—but is often dictated by an end-user specification. Although the specification may call for all signal wires to be 14 American wire gauge (AWG) or larger, that specification was likely written when control systems consisted of banks of multi-contact relays.

A modern PLC only requires a few milliAmps to change the state of an input. Since 24 AWG (0.2 mm2) wires can easily handle 0.5 A under normal circumstances, it makes little sense to use 14 gauge wire for signal inputs to a PLC, unless of course the wires will be run long distances, as a 24 AWG wire has about 10 times the resistance that a 14 AWG wire has.

As the wires get smaller, they also get increasingly harder to handle and to apply markings. A good compromise would be to use 18 AWG or 20 AWG wire for all signaling applications. These wires are large enough to apply legible identification and to be handled by a maintenance person wearing arc-flash-protection gloves. If the power requirements are greater than that of a signal wire, then all power and temperature requirements need to be factored into wire size selection.

In most cases, the type of wire used in machine control systems is machine tool wire (MTW) or thermoplastic high heat resistant nylon (THHN). THHN wire has an additional nylon coating over the main PVC insulation to protect it from water, gases and solvents.

> "Wiring should always be color-coded to reflect the voltage being carried by the wire and its use."

The nylon also provides a degree of resistance to abrasion, but, although it is less flexible, the slippery surface makes it easier to pull through conduit. MTW is popular for use within a control enclosure because of its flexibility, although it has a slightly larger outside diameter and less resistance to chemicals than THHN.

Wiring should always be color-coded to reflect the voltage being carried by the wire and its use. Unfortunately, the world standard organizations cannot seem to agree on what the proper color of any particular wire should be. NEC, NFPA, IEC and CSA all have their own ideas of color coding. Add to this, many corporations, manufacturing plants and even individual countries enforce their own specifications.

It's critical to determine the wire color code used by the end customer before designing and wiring the control system. I personally know of several automated machines that required considerable rewiring before they were compliant with EU regulations. The electrical integrator would have saved a considerable amount of time and money had he simply checked the local requirements before finalizing the design.

In industrial installations, individual wires located outside of a control enclosure are typically housed in conduit for protection. However, cables are not always enclosed in conduit for protection; instead the cable sheathing is relied upon. The cable sheath is required to offer resistance to environmental conditions such as chemicals, heat, UV light and temperature.

Resistance to abrasion and the ability to withstand constant flexing may also need to be considered. Robotic arms can quickly destroy a cable that was not designed to withstand the constant movement and flexing. If the robot also happens to be welding, resistance to weld splatter must be included when selecting the cable.

When the cable is being used for high-speed communication signals, it is usually best to follow the recommendations of the communication equipment manufacturer. It would be safe to say that a manufacturer tests and develops speed and distance specifications of the equipment using the cabling best suited for that job.

High-speed signal and communication cable are often required to be shielded. The additional conductive shield encases the signal wires to help keep electromagnetic noise energy from interfering with the desired electrical signals. Of the two types of shielding, a foil shielded cable is less expensive and easier to install. Braded shielding holds up better to cable flex and adds strength and abrasion resistance. However, without the proper hand tools, braded shielding is more difficult to install.

All industrial control systems require good wire identification. It's not just a good practice; the system should not be accepted without wire labels on all wires. A maintenance person working on a machine should be able to find a reference number on a wire and then quickly find that wire in an electrical schematic. Wires with no identification or that do not match the drawings only adds to the time it takes to troubleshoot and repair a problem.

Cabling also needs to be identified. For the sake of the maintenance electrician, identify both ends of the cable. One project I worked on not only identified the cables on both ends, but an additional label was added to identify which control or junction box the cable was attached to. I found this feature alone saved countless hours of searching through drawings.

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How time-sensitive networking enables the IIoT

Industrial Internet Consortium's TSN testbed brings suppliers together for interoperability and deterministic Ethernet.

By Mike Bacidore, editor in chief

Earlier this year, the Industrial Internet Consortium (IIC), National Instruments, Bosch Rexroth, Cisco, Intel, Kuka, Schneider Electric and TTTech announced a collaboration to develop the world's first time-sensitive networking (TSN) testbed to advance the network infrastructure that will support the future of the Industrial Internet of Things (IIoT) and Industry 4.0. Machine designers, builders and users need reliable and secure access to smart edge devices, and standard network technologies will evolve to meet the requirements of the next generation of industrial systems.

TSN is a set of IEEE 802 standards designed to enhance Ethernet networking to support latency-sensitive applications that require deterministic network performance

The goal of the IIC testbed is to display the value of new Ethernet IEEE 802 standards, referred to as TSN, in an ecosystem of manufacturing applications (Figure 1). TSN powers a standard, open network infrastructure that supports multi-vendor interoperability and integration, as well as real-time control and synchronization between motion applications and robots, for example, over an Ethernet network.

At the same time, TSN is designed to support traditional traffic found in manufacturing applications; this can't be accomplished without the convergence of IT and operational technologies.

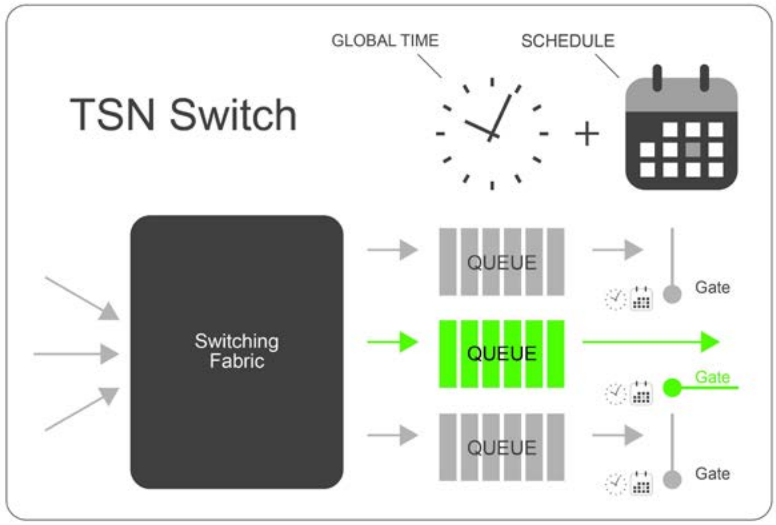
SENSITIVITY TRAINING
Figure 1: The goal of the IIC testbed is to display the value of new Ethernet IEEE 802 standards, referred to as TSN, in an ecosystem of manufacturing applications. (Source: IIC)

"This testbed seeks to discover and invent new products and services leveraging the Internet of Things in industrial systems," says Dr. Richard Soley, executive director of the IIC. "The testbed developers realize that their markets will be disrupted by IoT and are developing this testbed to discover and invent that disruption. This testbed will prove the value and functionality of IEEE 802 time-sensitive networks in machine-control applications."

Testbeds are a major focus and activity of the IIC and its members. "Our testbeds are where the innovation and opportunities of the industrial Internet—new technologies, new applications, new products, new services and new processes—can be initiated, thought through and rigorously tested to ascertain their usefulness and viability before coming to market," explains Soley.

The testbed will combine different critical control traffic, such as OPC UA, and best-effort traffic flows on a single, resilient network based on IEEE 802.1 TSN standards. It will demonstrate TSN's real-time capability and vendor interoperability using standard, converged Ethernet, and it will assess the security value of TSN and provide feedback on the ability to secure initial TSN functions. Equally important is the testbed's attempt to show the IIoT's ability to incorporate high-performance and latency-sensitive applications.

In the past, real-time control applications typically were deployed using nonstandard network infrastructure or unconnected networks that left the devices and data siloed and difficult to access. TSN's value is in unlocking data in real time and fulfilling the IIoT promise of improved productivity from big data analytics and smarter systems.



A SWITCH IN TIME
Figure 2: The testbed is physically hosted at the National Instruments campus in Austin, Texas. Cisco and TTTech are supplying the switching. The major components are scheduled to be integrated by the third quarter of 2016. (Source: TTTech)

IEEE 802.1 is the specification for switch operation. "One aspect we're focusing on in this testbed is scheduling," explains Todd Walter, chief marketing manager, National Instruments (NI), and industrial segment chair, AVnu Alliance. "The profile of IEEE 1588 for precision time protocol (PTP) is to distribute time and synchronize all of the end nodes and all of the switches, so they all have common concepts of time, or synchronized time. Switches already have the ability to look at a packet and put it in different queues. TSN creates a reservation for a particular packet at a particular time. The bridge can identify the packet and gives it a fully scheduled pass through the network. For control applications, that's ideal."

The testbed is focused around smart manufacturing because TSN will have applicability across a lot of industries. IIC member companies bring their own devices to the testbed. "One application we'll test will be machine-to-machine coordination between a robot and another machine," explains Walter. "A robot has a controller, sensors, actuators, drives and motors. We'll communicate through some standard interfaces and commands to coordinate the robot controller with another machine that has motion, sensor or vision integration; and we'll be able to put those multiple controllers together with multiple systems being coordinated—for example, coordinating a Kuka robot with a Bosch Rexroth motion system. We've structured the testbed to be able to support many standard protocols."

The testbed is physically hosted in Austin, Texas, at the National Instruments campus, where NI is handling the design. Cisco and TTTech are supplying the switching (Figure 2). The major components are scheduled to be integrated by the third quarter of 2016. "We plan to come out with feedback to the conformance bodies and then reference architectures and guidance by the fourth quarter," explains Walter.

SECURITY & SAFETY

For TSN, security has to be designed-in as a layered system, explains IIC's Soley. "One cannot add security as a new feature later," he warns. "Air-gapping, while the obvious approach to perimeter security, has major drawbacks—most obviously the loss of the air-gap, that is, the accidental or intentional connection of a supposedly air-gapped system to the Internet. But, more pervasively, air-gap security ignores the fact that the vast majority of security failures are perpetrated by insiders. Air-gap security, as a perimeter measure, cannot guard against insider threats. The developers for this IIC testbed are aware of the issues and developing their time-sensitive networks with security in depth designed-in."

The security level needs to be pushed as far down as possible, adds NI's Walter. "When there's a network infrastructure that's open, that creates a security hole," he cautions. "If you can get access to that layer, you can get everywhere. We want to push security all the way into the end node. In addition to being able to adopt all of the IT best practices for security, we can add another layer of security because we have information about the data flows. We know the timing and the path, and that can be another powerful tool for the layers of security. In the testbed, we want to figure out what we can apply that's already in use and what we also can add."

Because TSN is standard Ethernet, control networks can take advantage of best practices for security that have been developed into Ethernet for decades, says Walter. "Additionally, TSN enables an additional layer of security to the data," he explains. "The precise timing mechanism allows you to know exactly when the data was sent and when it is supposed to arrive, based on the packet information; therefore, you can see if someone else has accessed the network and intercepted or altered it. AVnu Alliance is evaluating additional security layers in TSN currently, as security is critical to these networks."

Expectations would be that security for time-sensitive networking would use the same black-channel principles for the current fieldbus solutions, notes Dr. Michael Hoffmeister, portfolio manager, software, at Festo. "The strength of Ethernet-based protocols in general is the layered approach where each layer in a protocol stack adds a certain functionality to the entire communication channel," he says. "The TSN layer adds the real-time capabilities to the communication channel while security is considered on higher protocol layers using, for example, the security mechanisms of OPC-UA."

For cybersecurity, various aspects, including authentication, encryption and data security are being considered. "The point is to protect critical data and block unwanted data," explains Sari Germanos, open automation business development manager, B&R Industrial Automation.

Security in time-sensitive applications is sometimes circumvented by using physical security, such as completely isolated and dedicated networks, instead of electronically derived security, such as public key encryption of the data, explains Doug Taylor, principal engineer, Concept Systems, a system integrator in Albany, Oregon. "Latency-intolerant paradigms are usually local by nature, lending themselves to physical security," he says.

One substandard for TSN is Time Based Ingress Policing (IEEE 802.1Qci). "This standard defines mechanism to count and filter frames, and it supports policing and service class selection," explains Dipl. Ing. André Hennecke, researcher at DFKI, a research center in Kaiserslautern, Germany. "These mechanisms help against different network attack vectors like 'man in the middle' attacks, but also against faulty network components. Even when a flow gets hijacked, the flow still relies on the reserved stream and all frames outside the stream time window get dropped, which leads to a more secure network."

TSN also will lead to a new challenge when it comes to security design. "To realize all functionalities of TSN successfully, a central network management component is needed," advises Hennecke. "This management component helps in coordinating stream reservation or path control, compared with a classic hop-by-hop method, but leads also to higher security threat. The penetration of this management component can influence the whole network, depending on the functionality and implementation, which is still open."

Protocols that reside on Ethernet and use the traditional TCP/IP protocol suite have security vulnerabilities, warns Sloan Zupan, senior product manager, Mitsubishi Electric Automation (us.mitsubishielectric.com/fa/en). "Customers should choose a deterministic network which has the benefits of traditional Ethernet networks but doesn't solely rely on the TCP/IP protocol suite," he says. "Networks such as CC-Link IE provide protection against cybersecurity risks, which aren't available from other Ethernet networks, and it is 100% deterministic."

If your network knows when it's supposed to be receiving information, it can more easily push away information when it's not anticipated, says Steve Zuponcic, technology manager at Rockwell Automation. "It's easier to filter out things that are not expected when they're not expected," he says.

However, in some ways, TSN doesn't change the dynamics of security in a network, says Paul Brooks, business development manager at Rockwell Automation. "You've got management software and devices and switches," he says. "Changes in the performance of those also changes the performance of the system. Those changes have to be secure. We would expect many of the same techniques to be used. The threat vectors are very similar."

Deterministic Ethernet also can influence the way that safety systems are implemented, claims Markus Plankensteiner, vice president, sales industrial, North America, and global alliance manager, TTTech Computertechnik. "The fact that scheduled traffic flows can be isolated and not disturbed by other traffic on the network is very important," he states. "By scheduling messages from safety applications, we can ensure high availability of safety systems even when converged with the wider network infrastructure." Plankensteiner believes this will lead to a streamlining of safety systems and associated overheads without affecting the safe performance of the overall system.

"Safety always will take a path using older technology that has proven itself, rather than embrace newer technology, primarily because the decision makers in the safety field are risk-averse," cautions Taylor. "Once the technology is commonplace and the failure modes are all well-known, then it will be considered for safety, regardless of the advantages it offers."

The first phase of the TSN testbed, for instance, hasn't factored in safety. "The most common way to do communications over any network infrastructure is black channel, where you build your safety structure, assuming the communications medium is not certified," explains Walter. "It allows you to use off-the-shelf, but what is the latency through the network? You're encapsulating in a safe domain, and then you decapsulate on the receiver and make sure it matches. That black-channel concept theoretically should apply very well to a TSN infrastructure. This is a long-term testbed so we could add it in the future. It's just not part of this first phase."

Brooks, however, thinks deterministic Ethernet will have no impact at all on system safety. "Safety protection systems are designed to move to a safe state in the event of any interference. TSN delivers some benefits. It's easier to architect a system with no disturbances. The likelihood of a disturbance will be reduced. It also brings redundancy to the table. It's a more reliable

network, so the safety protection system will be less susceptible to trips or disturbances," he notes.

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"Safety is a vital part of our industry, and, as Ethernet becomes more and more prevalent, the two will have to cross paths at some time," predicts Bill Dehner, technical marketer, AutomationDirect. "Safety is time-critical and as such will undoubtedly force Ethernet further into the deterministic realm. As seen with precision motion applications, protocols such as EtherCAT that use precision time protocol synchronization—IEEE 1588—are already being used to accommodate time-sensitive applications, and safety will further this effort."

TO BE DETERMINED

Deterministic Ethernet is one of the foundation technologies for the industrial Ethernet, explains Paul Didier, solutions architect manager at Cisco. "We'll be able to connect up a lot more devices and a lot more machines," he says. "Because of that, it will enable this IIoT. Initially it will be preventive maintenance, then operational, then robot as a service and then car as a service. A lot needs to come into the IIoT, but none of it works if you can't access the devices. You need that access to the devices and data and control loops. Fanuc is now becoming an engineering company providing a service, not just a robot company. I see this as being one of the big challenges for the IoT—getting these devices interconnected. I don't want to say TSN is the key to these IoT models. Getting connectivity access is important because so many are still not connected. And all of the proprietary little schemes mean the data is really hard to get to."

Deterministic Ethernet already exists, says Phil Marshall, CEO of Hilscher North America. "Standard Ethernet chips provide a level of determinism that is quite good at many slower application requirements—for example, in the 10 ms response time offered by standard Modbus TCP," he explains. "To provide determinism for high-speed applications, the Ethernet protocol standard organizations have used IEEE 1588. The industry issue is that the IEEE 1588 functions are not interoperable. Profinet, EtherNet/IP and other deterministic IEEE 1588-based Ethernet protocols are incompatible with each other. TSN may perhaps provide a common clock mechanism to create a universal protocol suitable for high-speed discrete parts manufacturing."

Joey Stubbs, P.E., North American representative, EtherCAT Technology Group, agrees. "Specifically, EtherCAT is a widely used Ethernet protocol for machine control using standard 100Base-TX Ethernet as the physical layer for high-speed, highly deterministic control of extremely complex and sophisticated machines and processes used across a wide range of industries and applications."

Deterministic Ethernet will make it easier to consolidate multiple control systems onto a larger compute node, thereby reducing the complexity of hardware on manufacturing floors, predicts Mark Hermeling, director, product management, VxWorks, Wind River. "It will also facilitate connectivity between machines, providing the capability to do tighter integration of manufacturing lines," he says.

It will lay the communications platform for Industrial IoT, says TTTech's Plankensteiner. "The Industry 4.0 initiative has explicitly set out to use open standards for its reference architecture model," he explains. "TSN now imbues IEEE Ethernet with the real-time features that were previously only available in proprietary protocols," he says. "This means standard Ethernet being used all the way from the enterprise cloud down to the machine sensors for applications including low-latency motion, high-availability processes and safety control. If the goal of Industrial IoT can be somewhat bluntly condensed to 'better use of machine data,' then it is deterministic Ethernet that will enable the collection and use of this data in a standard, interoperable way."

Deterministic Ethernet will have a tremendous impact on certain specialized users but will have a minimal impact on the general user, says Concept Systems' Taylor. "Most people feel that their processes are time-critical, but they are thinking in human time and not computer time. In human time, 50 ms is the blink of an eye. To a computer, 50 ms is nearly an eternity," he explains.

The impact of deterministic Ethernet on industrial communication is twofold, says Armin Pühringer, business development manager, Hilscher Gesellschaft für Systemautomation. "The real-time synchronous mechanisms are of interest, also for the existing real-time Ethernet standards which are used in industrial environments today," he explains. "If, and only if, deterministic Ethernet will contribute to a simplification of industrial communication in the future, then there is potential to form a globally used technology base in industrial applications."

A well-architected network is deterministic today, advises Rockwell's Brooks. "TSN will provide engineers a tool to build that well-architected network," he explains. "Bringing fast lanes to the network will make it easier to build."

TSN is driving the whole concept of a system view of the network, explains Rockwell's Zuponcic. "You lay things out more at a higher level, versus components, which allows you to design at a system level and make it easier to design those networks," he says.

"If, and only if, deterministic Ethernet will contribute to a simplification of industrial communication in the future, then there is potential to form a globally used technology base in industrial applications."

—Armin Pühringer, Hilscher Gesellschaft für Systemautomation"

Ultimately, what deterministic Ethernet enables is intelligent networked components' ability to communicate with one another with dedicated time intervals and bandwidth, says Mitsubishi's Zupan. "Machines have a wealth of information in them that can be used to improve operational efficiencies, but pulling this information from sensor devices and other automation components can burden the nondeterministic networks used in today's automation networks," he explains, adding that deterministic networks should handle cyclic and transient messages separately and with different priority.

Much of the existing network infrastructure is not equipped to handle time-sensitive data such as critical control and fault detection data that must be processed, shared and acted upon immediately, regardless of other network traffic. "Many industrial systems and networks were designed according to the Purdue model for control hierarchy in which multiple, rigid bus layers are created and optimized to meet the requirements for specific tasks," says NI's Walter. "Each layer has varying levels of latency, bandwidth and quality of service, making interoperability challenging and flexibly changing data connections virtually impossible." In addition, proprietary Ethernet derivatives have limited bandwidth and require modified hardware.

APPLICATIONS ACCEPTED

One example of an application that requires a deterministic network is a web printing press, offers Mitsubishi's Zupan. "In this application, you have one or more controllers talking with upward of 100 axes of motion and hundreds of I/O points,"

> "Huge amounts of data from the robots then would be visible to higher-layer networks without the need for gateways, enabling machine-as-a-service (MaaS) type of business models."

he says. "The tension of the material and the torque to move the material through the press must quickly adjust as the roll of material is consumed. I/O control, motion commands and HMI updates, for example, all need to be in sync for the machine to run at an optimal level."

"The first meeting for the IEEE 802 standards was held in 1980," says Walter. "It's been continually added to. That's definitely going to be true with the time-sensitive features. I fully expect these capabilities will be built on forever. One thing the Ethernet community has been extremely good about is ensuring the backward- and forward-compatibility. We can start building on this right away."

Deterministic Ethernet allows machines to synchronize and interoperate in a standard way, especially when combined with an open architecture such as OPC UA, explains B&R's Germanos.

Its use as a control network could replace other networks such as Profibus and DeviceNet, predicts Mike Justice, president, Grid Connect.

Many examples of latency-sensitive applications already are kept separate from the wider infrastructure by gateways or proprietary solutions. "In a discrete automation plant with multiple robots working on production lines, TSN will enable far greater operational flexibility," predicts TTTech's Plankensteiner. "Today, these robots are controlled locally, with limited synchronization between them and bottlenecks for data access from beyond the factory floor. Where there is connectivity, it is either done

NETWORKS, UNITE!
Figure 3: By using a TSN connection, the controls communication is guaranteed across the network, even when converged with noncritical traffic. Controls networks can be integrated with data networks, and many control functions can be centralized where greater computing power can be utilized. Huge amounts of data are visible to higher-layer networks, enabling machine-as-a-service (MaaS) business models. (Source: AutomationDirect)

over proprietary networks or via gateways. By removing local control functions or converging noncritical traffic in the same network, one could jeopardize the guarantees for communication of critical messages."

By using a TSN connection between robots, the controls communication is guaranteed across the network, even when converged with noncritical traffic, and all robots are synchronized to the same global time, explains Plankensteiner. "This means that controls networks can be integrated with data networks, and many control functions can be centralized away from the robot cell into a controls cloud where greater computing power can be utilized," he says. Huge amounts of data from the robots then would be visible to higher-layer networks without the need for gateways, enabling machine-as-a-service (MaaS) type of business models, which simultaneously improves service and maintenance from machine builders and lowers capital expenditure for end users (Figure 3).

"Vision systems that use Gigabit-Ethernet (GigE) cameras often are completely isolated networks where the entire network consists of a network interface controller (NIC) card and a camera with no switches," offers Concept Systems' Taylor. "Using a time-sensitive network could lead to camera networks where multiple cameras live on a network in harmony, allowing multiple control systems to utilize their data in real time. In this paradigm, a smart device can morph from a basic source of information to a preparer of key information, thereby reducing the required bandwidth. A case in point would be a camera system that only reported the elements of the image that are changing between frames to the various smart concentrators that can provide real-time full-frame images to clients at the same speed as a dedicated camera-computer network with perhaps less latency than the dedicated full-frame network."

Obviously, motion applications are latency-sensitive and would benefit from TSN, says Hilscher's Pühringer, but, more than that, there might be a potential for sensor networks with an extremely high number of nodes.

"Our hope is that everything works better in a TSN environment, whether that's voice communications, video surveillance or motion control," says Rockwell's Brooks. "There are potential benefits, for instance, a 10% increases in axes through a single link for motion control, most of which is delivered through preemption. The strategy is that everything works better with TSN."

According to DFKI's Hennecke, latency-sensitive applications that would benefit most from TSN include:

- safety-relevant communications, which are today mostly done by hardwired solutions—for example, safety-certified communication like safety-stop

- motion and robot controls: with a standard communication in these applications, accessing data gets a lot easier, which helps to improve techniques such as predictive maintenance and system optimization
- machine-to-machine communication, which needs low latency and a high synchronization

- high-level applications, which need a more deterministic communication to monitor and control machines in real time—for instance, condition monitoring or high-speed manufacturing execution systems.

"The number of applications that require minimum latency is in the thousands," says IIC's Soley. "Machine control systems are the obvious application and the target of the testbed. Systems for which control signals must be received in time, especially for safety and security reasons, require minimum latency. But there will be other, everyday applications of minimum-latency requirements in the Industrial Internet of Things."

THE EDGE AND THE CLOUD

The rise in the number of intelligent devices has made it very clear that decentralized control is within reach. "They demonstrate how functions can be distributed over a network," explains Festo's Hoffmeister. "Edge computing will give a better-defined infrastructure to make use of these technologies. Maybe edge nodes can also serve for holding data and functions of passive devices, joining these data and functions with the ability of those intelligent devices. Additionally, they can serve for database and data-intelligence functions, allowing for closed loops in data analytics. In this sense, edge computing and its framework definitions can leverage the vision of autonomous, self-aware production systems."

Edge computing has piqued the curiosity of many Mitsubishi customers. "We consider sequence CPUs, C-language controllers and IoT gateways to be examples of edge-computing devices that are commonly used by customers to aggregate data and convert it into useful information," says Mitsubishi's Zupan.

"It is the habit of every manufacturer to "gild the lily' in order to drive sales," warns Concept Systems' Taylor. "Coupling this with the steady march of technology that is driven by consumer electronics leads us to products that are offered to us to solve problems we didn't even know we had. This new technology and our lack of familiarization with the myriad offerings is fertile ground for innovators to connect the dots and come up with very desirable features in modern solutions. This edge-computing category is just one of the LEGO blocks that innovators are using, and most of the resistance to the innovations is being offered by experts within the industry, since the designs do not respect well-defined areas of responsibility."

TSN DEFINED

For an in-depth explanation of what exactly time-sensitive networking is, read "What is time-sensitive networking?"

But edge computing is not new. The programmable automation controller (PAC) is the manifestation of edge computing, says Rockwell's Brooks. "What the proliferation of intelligent devices is going to do is give companies the capability to build more into edge-computing devices and share more data with the cloud, more prognostic information from the cloud and present to the operator at the edge level," he explains.

Cloud computing already is moving closer to the edge of the network in the form of fog computing, which is bringing greater intelligence and analytics to the machine world, says TTTech's Plankensteiner. "Theoretically of course there is no reason why machine control can't also be executed in this fog/cloud environment," he explains. "In order to achieve this, there must be guarantees for both the latency and the jitter of communication between machines and the fog/cloud. Deterministic Ethernet in the form of TSN logically extends the cloud concept of virtualization into and through the network. This means that sensor data and actuator commands can be processed from the fog/cloud as multiple virtual machines, each with a dedicated logical communication channel, but over a single converged network. Machine control from the cloud is much closer than you might think."

Before you can talk cloud, you've got to talk Layer 3 network and look at the work by the Internet Engineering Task Force (IETF) on deterministic networking (DetNet), explains Brooks. "For the cloud to happen, there has to be dramatic changes to the performance in wide area networks (WANs)," he says. "Never is a really, really big word, but, in the foreseeable future, it's hard to imagine real-time control through the cloud. If we had infinite bandwidth in the Internet and infinite processing power in the cloud, we might have a different answer."

Hilscher's Marshall points out that HVAC from the cloud exists today, but he agrees high-speed motion control can't be done yet. "If the motion control systems can be made more autonomous, you do have the ability to move the larger control system to the cloud," he says.

Whether machine control from the cloud will become a reality depends on the type of machine and the type of cloud, says Wind River's Hermeling. "There are many levels of "real-time-ness," varying from minutes to control a device to microseconds or nanoseconds," he explains. "Controlling your Nest thermostat from the cloud doesn't have a tight real-time requirement, and that is already a reality. Controlling an industrial robot or manufacturing equipment that requires response times in the low microseconds requires a different architecture." TSN with an on-premise cloud can reach these types of timeliness, but remote cloud control would be much more difficult.

"It's foreseeable to provide new recipes from a cloud into a machine, but real-time machine control from the cloud may not be a practical application of the technology," warns B&R's Germanos.

First, you must differentiate the term "cloud," says DFKI's Hennecke. "There are private, public and hybrid solutions," he explains. "When it comes to private clouds, which means that the cloud functionalities are located in the private network, machine control from the cloud can become a reality in the near future. There are already solutions to map classic control components such as software functions and the virtualization of control components into cloud computing systems."

Machines and stations are already executing a large number of different tasks: human-machine interface, recipe management, tracking and tracing, OEE measures, reporting, statistical process control (APC/ SPC), machine control, help and assistance systems and further, Hoffmeister points out. “In this sense, the real-time-enabled machine control is only a fraction of all tasks a machine has to fulfill,” he says. “A cloud technology can address many of these topics in an efficient and user-friendly way. Therefore, ways should be identified how cloud technology can be implemented for many topics while linking and maintaining the real-time excellence of machine control.”

But nothing that’s technically feasible is also practical, warns Hennecke. “Controlling machines from the cloud can also lead to a few issues, especially when the network is faulty or not available,” he cautions. “Commissioning and troubleshooting will be more complicated, and, when the network is not available, the machine stops without the option of further or emergency operation. One concept to overcome these issues is the principle of apps in manufacturing. The idea behind this is to keep the basic operation functionalities in the local machine control and get more process-specific functionalities from the cloud, for example.” Beside these technical issues, data confidentiality, integrity and security become major issues when it comes to public clouds, preventing suitable solutions from emerging, says Hennecke.

Whether machine control from the cloud will ever become a reality depends on the understanding of what the cloud is, agrees Hilscher’s Pühringer. “Hilscher refers to cloud as a technology—as in using the cloud stack and technologies being developed for cloud applications—and not as topology, such as where cloud means connection to the Internet,” he explains.

It’s unlikely that clouds will be used to do machine control, says Zupan. “There are a couple of factors that need to be considered. The first and most important is human safety. Network communication is susceptible to interruptions and outages. If this were to happen in a machine, people can get hurt. Second is the designed purpose of the cloud environment. Cloud services are excellent resources for aggregating data from various sources and providing fast data analysis. But they don’t operate nearly fast enough to handle machines with complex motion capabilities,” he says.

“Machine control, which is inherently time-sensitive—hard real time—is difficult to achieve with the most common networking technologies and thus with most of today’s cloud architectures,” says IIC’s Soley. “Local, private clouds, however, are already controlling machines.”

When a machine is working somewhere in the world, the control is going to have to stay close to that, assures Cisco’s Didier.

"There are physics and economics and reliability that drives all of that," he says. "A lot of data is going to come out. One of the cool concepts out there is that people will want to have a cyberphysical representation of the equipment in the cloud. That doesn't mean the physical plant will be controlled in the cloud. Optimization and maintenance can be done in the cloud and will filter its way back to the machine. Most machines will have to have some close physical control because of physics, latency and economics. You'll see highly distributed systems, but a lot of cloud data will be generated. I do think you'll see cases for doing machine control, but these will be based on these cyberphysical concepts."

EVERYTHING THAT RISES MUST CONVERGE

"The controls industry is conservative and will follow the IT market in a few years after security issues are well-addressed," predicts Grid Connect's Justice.

"Look at what the IIoT really means," says NI's Walter. "What is the value of a control system converged with standard IT? How do I take my control system and start to separate the functions? If I'm trying to close a loop at 100 KHz, it's better to push that all the way to the edge. But for IoT, if I have information from a lot of control systems and edge devices, I can put that in an analytics package. Maybe it's an on-site cloud, or fog. I can get very clean access to the data for on-site computing and have multiple layers of control running concurrently."

Shop-floor control already executes a large number of tasks, many of which already demand a dependable connection into the office. "A greater convergence between shop floor and office floor will give the system architects a greater flexibility to decide where specific tasks or parts of tasks should be fulfilled," suggests Festo's Hoffmeister. "We'll see a greater integration, fewer gateway solutions and more systems that will benefit from the data richness of shop-floor applications."

The obvious advantages of a convergence between information technology (IT) and operational technology (OT) include access to cloud services, improved security and integration with ERP/MES. "It can also include the wider benefits that come from the standardization of technology, such as a deeper engineering talent pool, increased resource sharing and faster innovation," offers TTTech's Plankensteiner.

"The convergence of operational systems with information systems can only be of tremendous value in all industries," explains IIC's Soley. "It's amazing that the operational control systems—programmable logic controllers— in most factories have not been connected to the information systems of those factories, despite the need to track just-in-time delivery of factory-floor inputs and outputs."

Mitsubishi Electric Automation has customers in virtually every industry who have integrated production machines with business systems to some degree, says Zupan. "It is used to keep the business system updated on the actual status of work in process, production asset health, inventory management and quality control," he explains. "A business system can become much more intelligent when production information is provided to it on a regular basis. However, many of these benefits are better delivered by the edge-computing capabilities of the automated assets." Data can be transformed into useful information and sent to a variety of business system consumers.

AUTO INDUSTRY PIONEERS

For an explanation of how automobile makers and manufacturing engineers have pushed and pulled each other into time-sensitive networking, read "From AVB to TSN in the automotive industry."

With automation and control, multiple networks are deployed, explains Rockwell's Brooks. "If they're wireless, having them in the same space makes them interfere with each other," he says. "We allow cloud-centric applications, discrete devices and service-based delivery of analytics. You get the ability to start having other services that were never in place before. All of those promises are hard to deliver without a converged network architecture in place to support them."

Connecting the controls network with the enterprise network also enables equipment health monitoring and maintenance. "The ability of connecting entire machines into the cloud allows for real-time data massaging and data analytics and improved overall factory performance, including capabilities such as predictive maintenance," says B&R's Germanos.

"Unifying the network communications at the control level with your IT gives you access from remote sites and gives you analytics," explains Rockwell's Zuponcic. "It's required to enable the IIoT. You can't accomplish it without it."

ABOUT THE AUTHOR

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