Advancing the future of automation | Volume 3

We get technical

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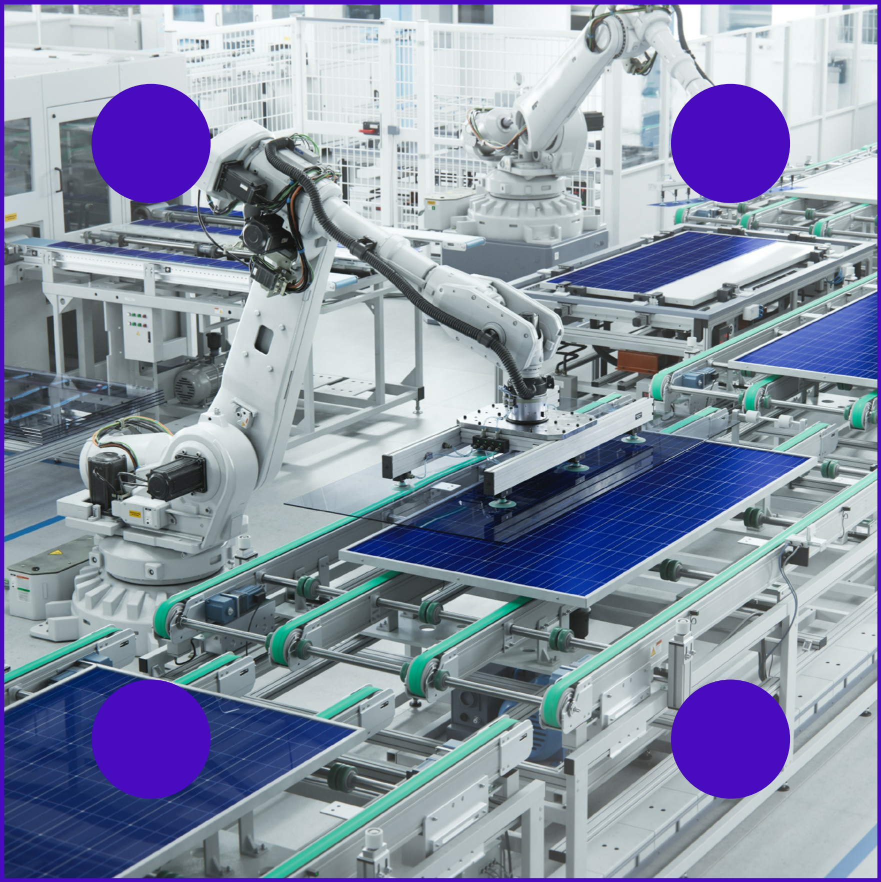
Connectivity – the backbone of sustainable automation

How to use traceability 4.0 Solutions for improved product safety, compliance, and tracking

How to optimize intra logistics to streamline and speed industry 4.0 supply chains



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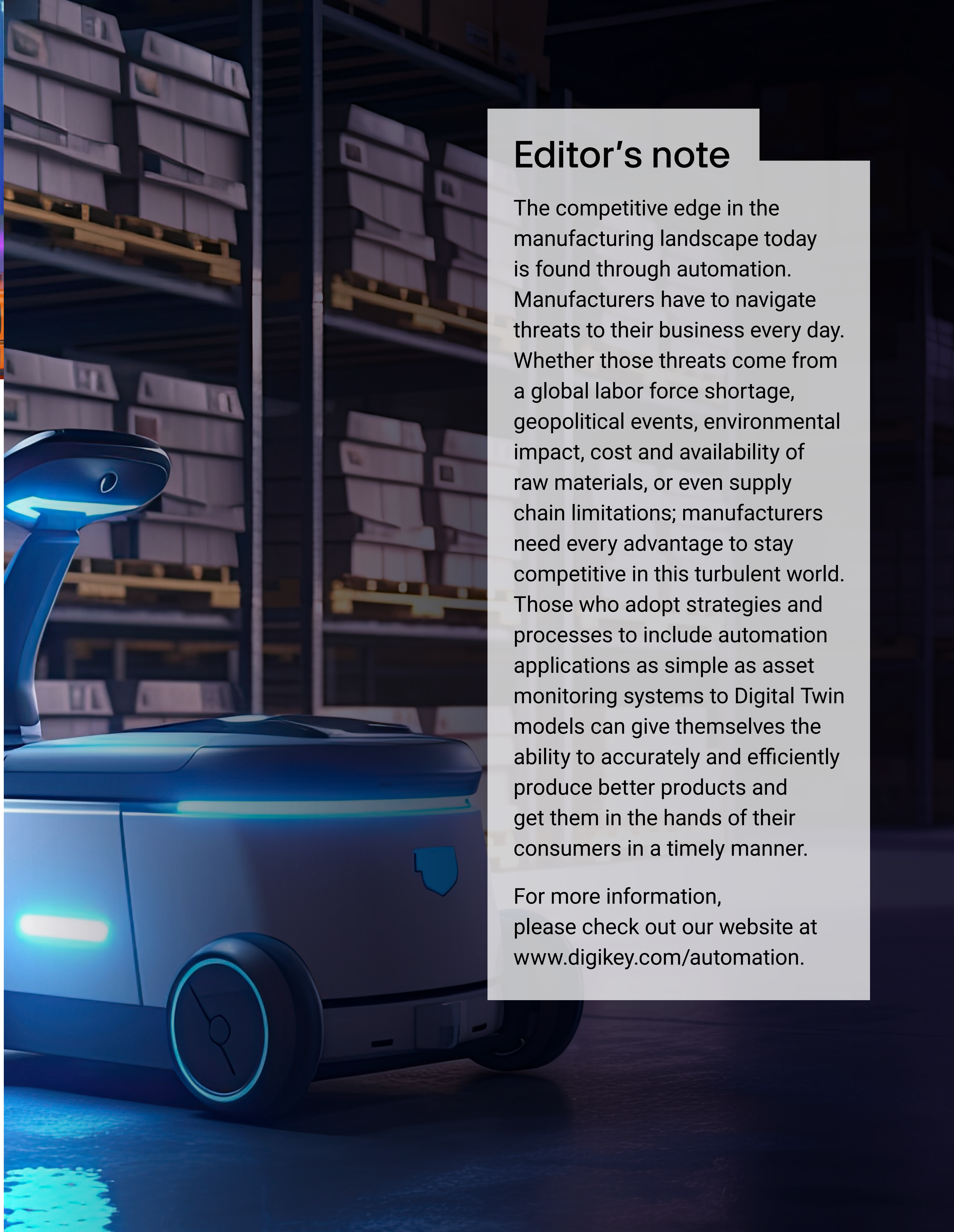


Editor's note

The competitive edge in the manufacturing landscape today is found through automation. Manufacturers have to navigate threats to their business every day. Whether those threats come from a global labor force shortage, geopolitical events, environmental impact, cost and availability of raw materials, or even supply chain limitations; manufacturers need every advantage to stay competitive in this turbulent world. Those who adopt strategies and processes to include automation applications as simple as asset monitoring systems to Digital Twin models can give themselves the ability to accurately and efficiently produce better products and get them in the hands of their consumers in a timely manner.

For more information, please check out our website at www.digikey.com/automation.

Moving into 2024 with tempered optimism

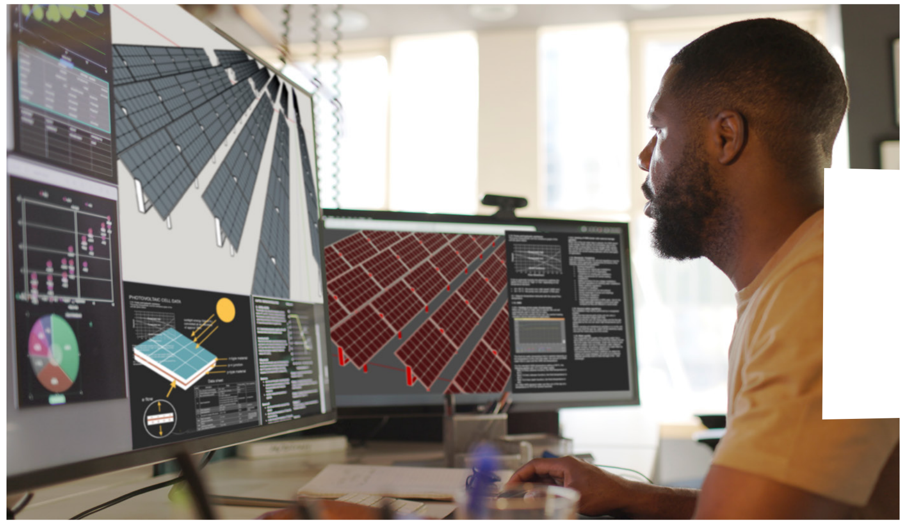
By Eric J. Halvorson Segment
Marketing Manager II -
Automation & Control

Introduction

As we look back on 2023 in preparation for 2024, we can finally breathe a sigh of relief. 2022 and the first half of this year has been difficult for every point in the supply chain. We are now beginning to see an easing of normal stated factory lead times. Inventory across the channel is increasing and finally coming back into a state of normalcy. Over the past year and a half, it wasn't uncommon to hear lead times on drives, PLCs, HMIs, and other advanced products to be well over 52 weeks. As a result, we're looking with a degree of optimism in 2024 for industrial automation across the industry. To that point, here are some trends I see continuing into 2024.

Smart manufacturing

Smart, sustainable manufacturing will continue to lead the conversation in industrial automation. When we look at the world's total energy consumption, we see manufacturing representing a large percentage of our total energy resources. Manufacturers are in a difficult but unique position that comes with a huge opportunity. Consumers now more than ever demand high quality, sustainable products manufactured through smart and sustainable practices. As manufacturers look to be more competitive in getting goods in the hands of these consumers, environmental stewardship is more important than ever before. To add to the complexity, manufacturers continue to face a labor shortage epidemic. In order to meet the demands of the consumer, manufacturers need to be more nimble, more efficient in their processes, and constantly looking to improve. We see manufacturers doing this through the use of solar powered microgrids, carbon capture projects, asset monitoring, the use of AI and cloud computing, and many other technologies to meet net-zero goals.



Asset monitoring

Asset Monitoring is one of the easiest, effective ways to introduce automation on the factory floor. Manufacturers today, whether they are just beginning their journey into automation or have a state of the art, fully automated factory, need to maintain their equipment. This is by no means a new problem. Manufacturers need to protect their assets and minimize downtime. In the past, this meant scheduled maintenance plans that meant taking production lines offline to maintain compressors, tooling machines, motors, etc. Today, we can do it all from with the ease of a tablet. The integration of IIoT onto the factory floor has enabled manufacturers to communicate with their assets in real time. If a motor is vibrating out of spec, they can address it immediately reducing downtimes, costly repairs, or replacements, and still maintain production levels. This also helps in reducing energy consumption greatly. The introduction of 5G has made asset monitoring even more achievable. By adding a wireless component with reliable, high speed, machine to machine communication, manufacturers can monitor every machine on the floor without the need to run more wire into sometimes very difficult to reach locations. The end result is the ability to take older factories and bring them into Industry 4.0.

Artificial Intelligence (AI)

The introduction of AI has really taken the entire world by storm. It's all around us. It has now made its way into industrial automation. We are seeing it being utilized to program PLCs, Robotics, making accurate forecasts on production scheduling, and much more. Over the past couple of years, we have been seeing Digital Twin becoming more and more utilized across factory floors. Digital Twin gives the manufacturer the ability to accurately view their entire floor in a simulated environment. This provided the manufacturer to see how changes in programming, would affect real world production. This reduces design cycle time, testing, and improves outcome. Adding AI can enhance the accuracy and realism of digital twins by using computer vision, machine learning, and deep learning to analyze data from sensors, cameras, and other sources. AI can also generate realistic 3D models of physical objects and environments using generative adversarial networks (GANs) and other techniques. AI can enable digital twins to run simulations and scenarios to optimize performance, efficiency, and sustainability. AI can also help digital twins to learn from their own experiences and adapt to changing conditions. AI can also provide insights and recommendations based on the data and outcomes of the simulations.

Robotics

The next trend we will continue to see in 2024 and beyond are robotics. AMRs (Autonomous Mobile Robots), Cobots (Collaborative Robots), and AGVs (Automated Guided Vehicles) will all continue to grow in popularity. AMRs provide the ability to work around tight spaces where toxic chemicals, heavy machinery in manufacturing environments. Utilizing sensors, AI, and machine vision, the AMR s capable of navigating its surroundings accurately and completely independent of human control. AGVs are a fantastic solution for material handling in warehouses and distribution facilities. They move on pre-programmed paths through software programming and the use of sensors such as LiDAR. AGVs are designed to handle tasks such as moving pallets or removing trash. Cobots have been around for some time now. These are Robots designed to work in the presence of their human counterparts. They handle menial and even dangerous tasks to free up the human to work on more complicated tasks. Cobots are designed with an array of sensors to detect the presence of obstacles or workers. Utilizing laser scanners, the Cobot will reduce speed by predetermined zones to ensure the worker's safety.

Immersive Technology

Another trend that is growing in popularity is Immersive Technology in industrial automation. The use of Augmented Reality (AR) to help workers throughout the manufacturing process and even in the MRO space. I personally attended an expo last year where I was able to witness how an electrician utilized AR to diagnose a problem in a cabinet and make the repair. The AR provided the electrician a step-by-step process and enabled them to get the cabinet back up and running in a very short amount of time. It was quite impressive. Immersive technology is also being used in other ways. Virtual Reality (VR) can be utilized for training employees in factory operations and maintenance skills. This helps to reduce time to competency and transfer a high level of skill, factory knowledge, and situational awareness.

Reshoring Manufacturing

Manufacturers continue to look to be more competitive while controlling quality and creating more sustainable processes. As a result, there is a trend in manufacturing reshoring to North America and Europe. The threat of intellectual property theft, geopolitical threats, and environmental destruction are also considerations for the move. To be competitive, manufacturers look to automation as a means to meet demand. The US recently passed the CHIPS Act. This is a long-term project to bring back semiconductor manufacturing and research to the US as means to protect national security and make the US more competitive in this space. But semiconductors aren't the only industry making the change. We see a shift in everything from pharmaceuticals to household appliances. This means more higher quality jobs in higher cost labor markets. To achieve a balance, automated processes are implemented to ensure production quotas are met while maintaining a higher quality product.

Conclusion

2022 and 2023 have been difficult years. We see economic pressures such as high inflation, high energy prices, and a tattered supply chain. Looking ahead into 2024, there appears to be a light at the end of the tunnel as we move toward normalcy once again. Industrial automation is a rapidly evolving field that leverages various technologies to improve the efficiency, productivity, and quality of industrial processes. To recap, we will see continued efforts to move toward smart manufacturing, Increased adoption IoT enabled Asset Monitoring technologies, the use of AI in Digital Twin, Robotics, Immersive Technologies, and a concerted effort to reshore manufacturing. These trends indicate that industrial automation will continue to grow and innovate in 2024, driven by the convergence of IoT, edge computing, AI, ML, and 5G. These technologies will enable industrial companies to achieve higher levels of performance, efficiency, and competitiveness in the global market.

(Image source: AzmanJaka via Getty Images)

Empowered by cutting-edge automation technology: the sustainable journey

Connected sensors, robotics, adaptive drives – advanced automation concepts are key to energy-saving and resource-efficient production. To system integrators and plant operators, they provide a powerful lever for optimizing their infrastructure and processes in terms of sustainability.

By Dr. Matthias Laasch,
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editorial consulting

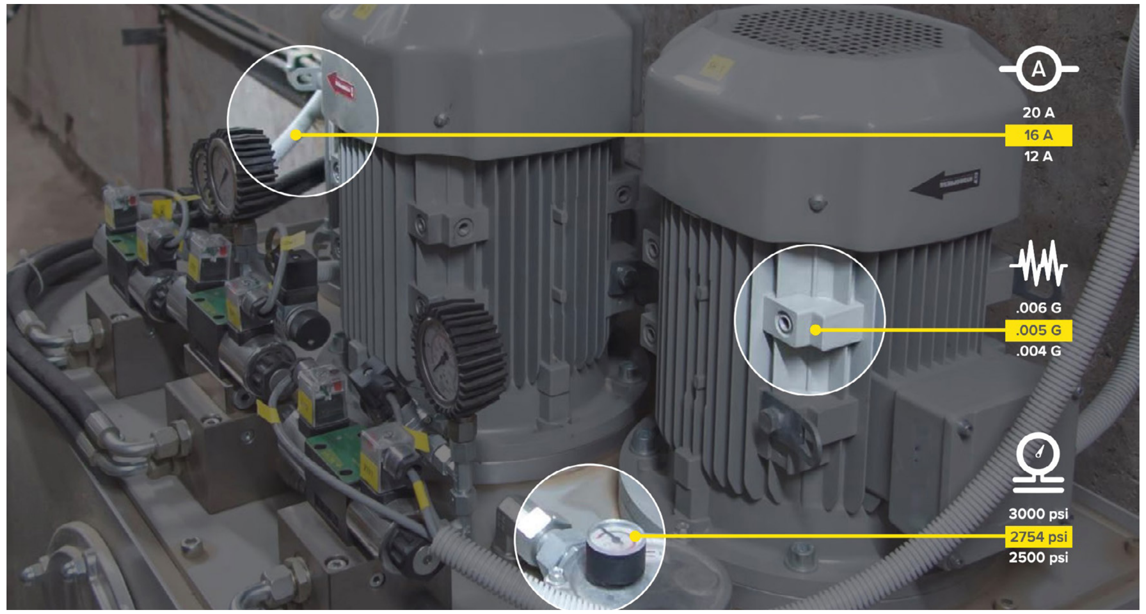


Figure 1: Capturing and analyzing the condition data of machines holds potential for more sustainable processes. (Image source: Banner Engineering)

The demand for energy, the use of raw materials, and – particularly in metropolitan areas – the size of the land required are the most critical factors of industrial production. On the one hand, they determine the economic efficiency of factories and plants; on the other, they are crucial for sustainable operation.

In many regions of the world, enormous efforts are being made towards limiting the use of conventional fossil fuels and replacing them with renewable alternatives. The successes to date are considerable thanks to the commitment of politics, industry, and the private sector. In Germany, for example, which aims to evolve renewables into the prevailing energy source within the framework of its energy revolution, their share of total energy consumption reached a value just above 48 percent last year. According to the Federal Network Agency, the manufacturing industry accounts for more than a quarter of the energy consumption; its share of electricity demand is also comparable. Production and processing of chemicals and metals are the leading sectors.

These and many other manufacturing industries, including electrical and mechanical engineering as well as food production, are driven by the progress made in factory and process automation. In addition to optimizing productivity and costs, the focus is shifting more and more to parameters that result in improved sustainability of products and processes: In the context of digitalization and through the concept of Industry 4.0, they are increasingly targeting energy efficiency, the economic use of resources, waste avoidance, and the smallest possible carbon footprint.

Optimize for sustainability

Automation technology offers a range of approaches that system integrators in mechanical and plant engineering, as well as manufacturing companies, can utilize to leverage the optimization of their infrastructure, plants, and processes in terms of sustainability. The comprehensive use of sensors and their integration into the Industrial Internet of Things (IIoT) opens up a wide range of possibilities here by means of continuously monitoring energy consumption, environmental parameters, or inventories. With the help of connected sensors, manufacturing companies can, for example, track the transport of goods in real time, monitor filling levels or record condition data of machines and tools in production lines (Figure 1).

An excellent example of sensor product families that holistically support the IIoT approach to production is the Snap Signal portfolio from US supplier Banner Engineering. In general, the users' challenge is to first identify relevant data and, in the next step, to extract it from existing equipment. If the need is identified to integrate additional sensor technology for measuring further variables, such as vibration and temperature at a drive, this should not require any changes to the existing control architecture. It is also important to standardize communication and convert all sensor and control data to a common protocol. For this purpose, the Snap Signal product line (Figure 2) offers smart sensors, signal converters, controllers, signal adapters, and wireless communication modules, as well as wired connectivity technology that enables automation engineers to plug-and-play to resolve these tasks.

Figure 2: Supporting the IIoT approach to production: smart sensors, converters, and controllers from the Snap Signal family. (Image source: Banner Engineering)

The processing and analysis of such sensor data – performed either centralized in a cloud or directly in the field – then allows conclusions to be drawn regarding error and optimization potential in the processes or the need for maintenance. In this way, energy losses can be reduced and the use of resources minimized. On the other hand, predictive maintenance makes it possible to plan service work in advance and thus reduce downtime, which in turn helps avoid additional expenditure on energy and materials.

Energy-saving drive technology

With regard to the energy demand of production plants, for example, drive technology plays a major role. Efficient drive systems equipped with advanced variable frequency drives (VFDs), for example, are able to precisely match motor speeds to the true demand of a system, which significantly reduces power consumption, particularly in variable-load applications. Regenerative drives can further reduce consumption by capturing and reusing braking energy. They are becoming increasingly important in the course of modularization and flexibilization of production plants, which is considered one of the core components of Industry 4.0. In the concept of the modular factory, automated guided vehicles (AGVs) and mobile assistance robots take on supporting functions, for example in handling and assembly. Low weight and recuperation are essential features here because they not only ensure economical energy use and a small eco-footprint, but also a long range for AGVs and cobots.

French manufacturer Schneider Electric is addressing this market segment of highly efficient drive technology with its compact VFD Altivar ATV320. It is suitable for controlling three-phase synchronous and asynchronous motors in the power segment from 0.18 to 15 kW at variable speeds. According to the supplier, it combines integrated safety with numerous ready-to-use functions designed to support application efficiency. These include low-speed torque and speed accuracy, high dynamic response featuring flux vector control without a sensor, and an extended frequency range for high-speed motors. The ATV320 (Figure 3) is particularly notable for its improved resistance to polluted atmospheres typical to many industrial processes, and meets IP20 as well as IP6x protection degree specifications. The VFD is designed to be fully integrated into different system architectures. It is equipped with RJ45 connectors for integrated Modbus and CANopen connectivity. Other communication options include Ethernet IP and Modbus TCP, Profinet, EtherCAT, DeviceNet, and PowerLink.

Figure 3: Altivar ATV 320 VFD for controlling three-phase synchronous and asynchronous motors at variable speed. (Image source: Schneider Electric)

Smarter control

In the quest for a more sustainable use of energy and industrial resources, optimizing control technology is an inevitable part of the equation. When it comes to collecting, processing, and analyzing production data in automated plants, state-of-the-art edge controllers play a key role today. Compact, scalable and connected via Industrial Ethernet, these devices can be used to implement both cloud-based and local solutions. Dedicated functions for diagnostics and energy management help automation engineers analyze manufacturing processes, identify bottlenecks, and initiate optimization measures based on industrial controllers such as the Simatic S7-1200. Advanced control algorithms as well as integrated communication and safety functions make a decisive contribution to precise process execution.

Figure 4: Efficient process execution based on manufacturing data analysis using the Siemens Basic Controller, both cloud and local solutions can be implemented. (Image source: Siemens)

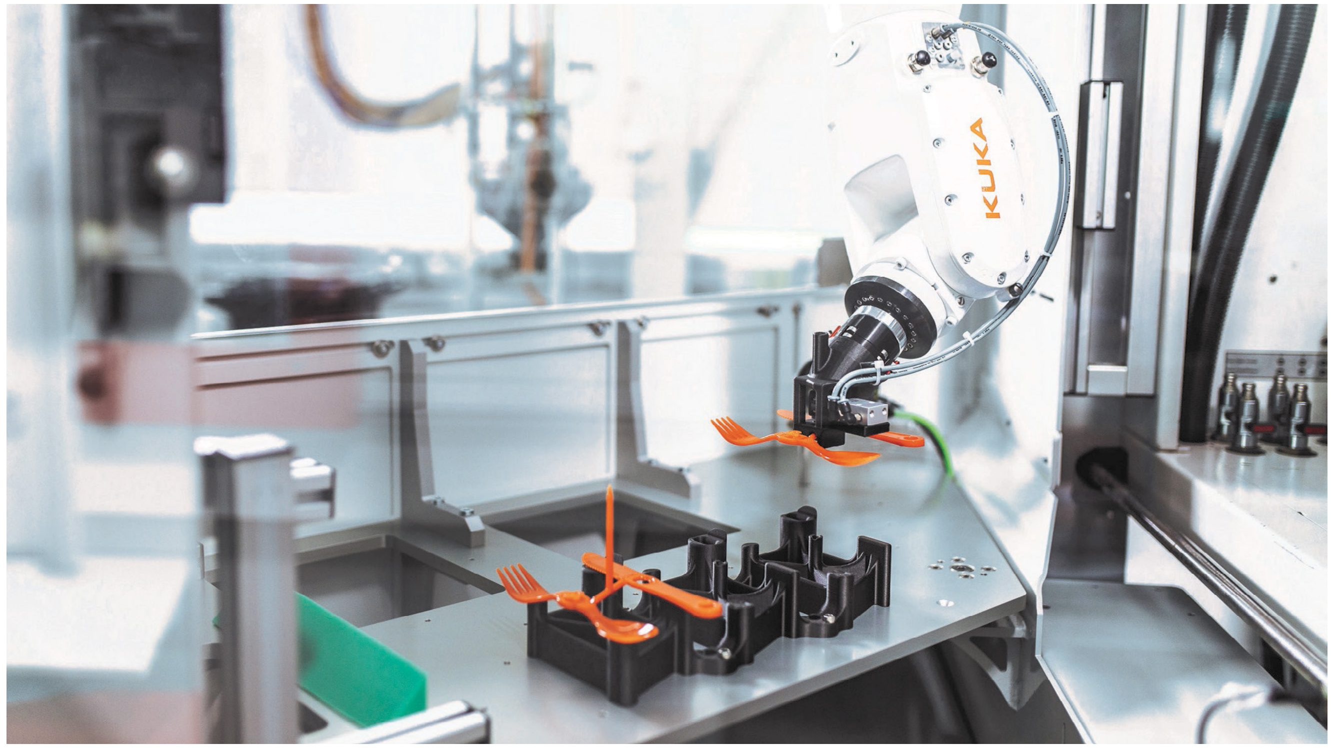


Figure 5: KR Agilus in a project at the University of Reutlingen/Germany. Here, students work with industry partners on developing sustainable alternatives to disposable plastic cutlery. (Image source: KUKA Deutschland)

Efficient by precision

Small, agile and extremely versatile, with their compact, lightweight design and intelligent control technology, robots have a significant impact on the sustainable use of production resources. The robust and highly adaptable devices of German manufacturer KUKA's Agilus family are an outstanding example of this (Figure 5). They come with an integrated energy supply and in several variants, some are offered as cleanroom robots, others for hygiene-critical applications or potentially explosive environments. Designed for human-robot collaboration, the robots enable highly efficient processes thanks to their very precise and repetitive accurate motion control. For example, they are ideal for minimizing the need for rework in machining processes as well as the level of rejects.

The use of such compact and variable assistants also makes sense for small and medium-sized companies as the manufacturer documents in various success stories [4]. These include a university project in which students at the University of Reutlingen/Germany are researching reusable alternatives to disposable plastic cutlery. They are supported by German injection molding expert Gindele as well as by KUKA and their system partner Robomotion. All handling around injection molding is covered by a highly flexible robotic cell, the core of which is an Agilus compact robot equipped with a 3D-printed gripper.

According to the data sheet, the KUKA Agilus KR6 R900-2 six-axis robot features a maximum reach of 901 mm and a payload of 6.7 kg and it achieves a pose repeatability of ±0.02 mm in accordance with ISO 9283. Possible usage ranges from handling in conjunction with other machines, through test and measurement technology, and the application of adhesives or sealants, to assembly, pick-and-place, packaging, and commissioning. The robot occupies a footprint of 208 mm x 208 mm, weighs approximately 54 kg, is IP56/67 and ESD-protected (Electrostatic Discharge), as well as suitable for floor, ceiling, wall, and angle mounting.

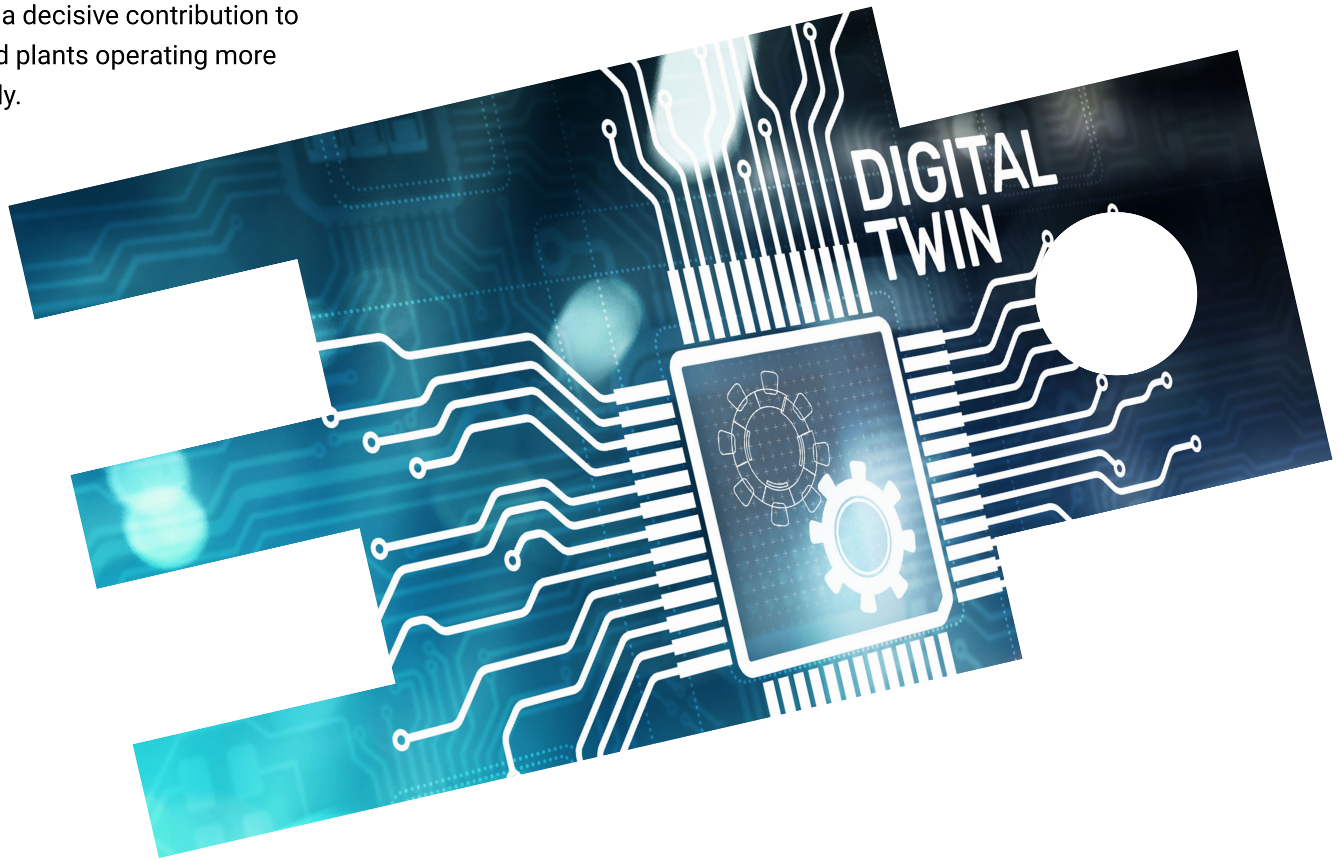
Digital models, materials, and more

Beyond the approaches shown here, engineers can leverage further optimization potential by applying sustainable materials, circular economy techniques and the latest developments in the field of digitalization. The aim of circular economy is to avoid waste and residual materials and to recycle and reuse as many raw materials, components, and packaging materials as possible. Its principles can make a decisive contribution to automated plants operating more sustainably.

The concepts of the digital twin and the digital shadow are promising approaches towards identifying optimization potential without testing on real machines or plants with a high expenditure of resources. Thanks to the comprehensive digital representation of real products, plants or processes - and of their life cycles - maintenance measures can be initiated or correlations established between development, production and all other stages of the value chain. Engineers can thus simulate the behavior, functionality and quality of real objects or processes in detail - and improve their sustainability, for example by eliminating the need for physical prototypes.

Summary

Automation holds major advantages for process and production engineering in terms of productivity and costs. It is thus a crucial economic factor. Beyond this, however, advanced automation concepts and products are also key to improving the sustainability of industrial processes. From predictive maintenance to the modular factory and human-robot collaboration – this article, along with selected examples, gives an impression of the manifold possibilities.



Using electrification and automation to create more efficient and sustainable power grids

– part one of two

By Jeff Shepard
Contributed By DigiKey's
North American Editors

Replacing traditional power grid energy sources with sustainable, green ones is called electrification. In this article, Part 1 of 2, some of the challenges associated with electrification are discussed along with how automation can aid in its efficiency and sustainability. Part 2 of this series will discuss leadership in energy and environmental design (LEED) and zero energy building (ZEB) certifications and how they can reduce carbon emissions and improve sustainability.

Electrification is the replacement of systems that use fossil fuels like oil, coal, and natural gas for electricity generation with photovoltaics (PVs) and other green technologies and replacing internal combustion engine (ICE) vehicles with electric vehicles (EVs). Electrified systems, plus the use of automation that ties them all together and supports smart grids and microgrids, are important factors moving society toward a more sustainable and greener future.

Today's electric grid was not designed to charge large numbers of EVs, and smart grids and microgrids are expected to be critical technologies needed to support the widespread replacement of ICE vehicles with EVs. In California, the governor recently issued an Executive Order requiring that by 2035 all new car and passenger light truck sales be zero-emission vehicles (EVs). Developers of smart grids and microgrids must meet a daunting array of international standards to tackle these sorts of mandates. For example, the IEEE has over 100 standards approved or in development relevant to smart grids, including the more than 20 IEEE standards named in the National Institute of Science and Technology (NIST) Framework and Roadmap for Smart Grid Interoperability. In addition to IEEE standards, microgrids are governed by the IEC 62898 microgrid series and other standards.

This article is the first of two parts. It looks at challenges related to implementing electrification, integrating distributed energy resources (DERs), the similarities and differences between smart grids and microgrids, and how automation enhances their efficiency and sustainability, including supporting the universal adoption of EVs. It begins by digging into what DERs are and where they fit in and closes by looking at how the emergence of utility microgrids is blurring the distinction between microgrids and smart grids. Whatever the implementation, DigiKey supplies a wide array of industrial automation products that support electrification and DER integration. The second article examines how electrification and automation can be used in green buildings to achieve Leadership in Energy and Environmental Design (LEED) and Zero Energy Building (ZEB) certifications.

What's a DER?

The North American Electric Reliability Corporation (NERC) definition is: "a Distributed Energy Resource (DER) is any resource on the distribution system that produces electricity and is not otherwise included in the formal NERC definition of the Bulk Electric System."

The term distribution system in North America refers to electric lines carrying 34.5 kilovolts (kV) or less that typically run from substations to end users. The bulk power system (BPS) includes the lines coming into the substation that often carry 100+ kV over long

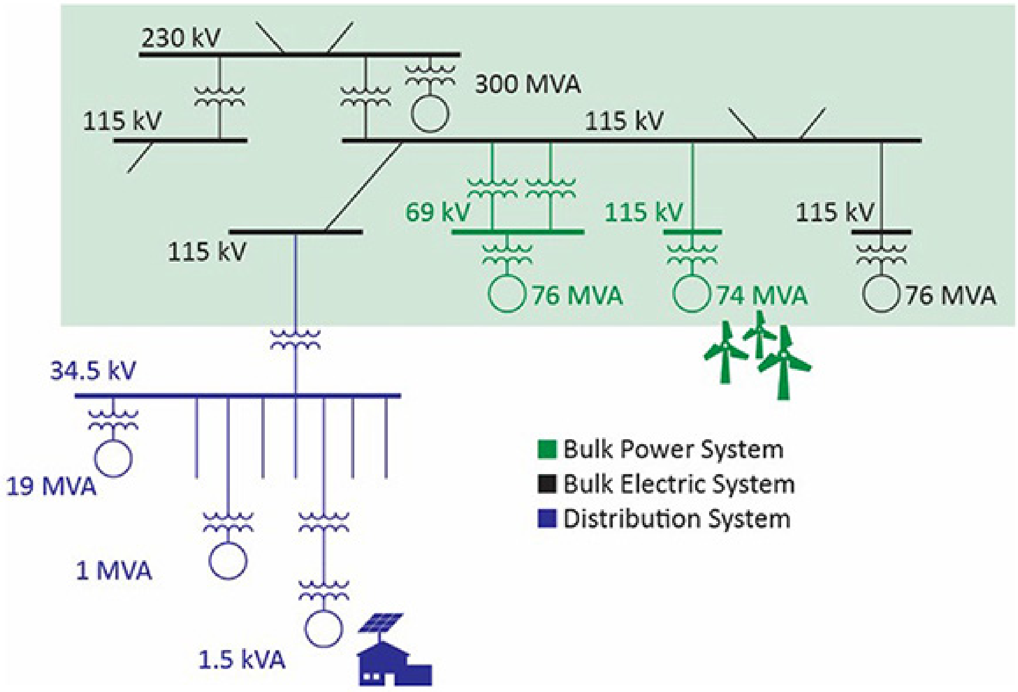


Figure 1: DERs exist in the distribution system (blue); other renewable energy resources are in the bulk power system (green). (Image source: NERC)

distances, connecting large-scale bulk electricity generation facilities with interconnection resources and substations (Figure 1).

DERs are any non-bulk system resource, including generation units like wind turbines and photovoltaic installations, energy storage units, most battery energy storage systems (BESS), EV battery chargers — also called electric vehicle service equipment (EVSE)— and microgrids. DERs exist behind the utility meter as well as directly on the distribution system. Behind the meter, DER sources include photovoltaic arrays, BESS, grid-connected EVs, and standby backup power sources like large diesel generator installations at data centers and other locations. A microgrid is a particular type of DER.

Smart grids, microgrids, and electrification

A microgrid is a DER, but not all DERs are microgrids. From the perspective of the BPS, the terms microgrid and DER refer to types of power generation or storage resources. The term smart grid refers to the communication and control technologies used by the BPS to ensure resilient and efficient operation. Another differentiating factor is that microgrids include generating and storage resources plus loads. A smart grid is comprised primarily of generation resources, with some storage but no loads. The smart grid can communicate with loads, but they are separate from the grid.

Electrification affects microgrids, the BPS, and smart grids in different ways. In the BPS, electrification is being added to an existing grid and, if not properly managed, can have unintended negative operational consequences. That's where smart grid technology comes in.

Two-way communications and control are the primary differentiator of smart grids. Those control systems include sensors to monitor the stability of the grid and advanced meters to monitor electricity demand. They also use a variety of controllable power switching and power quality devices to manage electricity flows. The sensors are critical to enable greater penetration of renewable energy (RE) sources and electrification into the BPS and ensure grid stability. In addition, the sensors and control elements support faster and more effective responses to power disturbances and enable balancing and securing the grid, especially during peak demand periods and with variable RE availability. Smart grid technologies also support the coordination and integration of microgrids with the distribution system and BPS.

Conversely, a microgrid is designed to accommodate electrification technologies like RE sources, BESS, and EVs. Microgrids and smart grids require automated controls, including a distributed energy resource management (DERM) system.

DERMs are a must

DERMs and automation are defined and implemented differently in smart grids and microgrids. Smart grids include diverse generation sources and electricity users spread over a wide area with a centralized control center for grid management (Figure 2). Grid management is the key concept for smart grid control in the BPS. Existing BPSs were designed and built before there was a need to support electrification, and they can experience unreliable operation as dispatchable (controllable) fossil-fuel-powered generation is increasingly replaced by unpredictable (and therefore less controllable) RE sources. In addition, charging large numbers of EVs will be mostly non-dispatchable and not directly controllable by the utility. The centralized, automated control enabled by smart grid technology is needed to compensate for the fact that the RE sources used for electrification and EV charging are not as predictable as conventional utility grid elements.

Smart grid and microgrid controllers need information from various sensors to monitor connected resources in real time. With the advent of EVs and EVSE, the controllers are also used to help manage power demands of charging, and they can use vehicle-to-grid (V2G) communication to coordinate the connection of EVs to the grid or a microgrid to provide incremental energy storage capacity.

In addition to monitoring the status of connected resources, controllers for grid-connected microgrids must also monitor the status of the local utility grid. Switchgear is an essential component of smart grids and microgrids and must respond in milliseconds to ensure robust operation. Switchgear sizes vary from a few kilowatts (kW) for small microgrids to multiple Megawatts (MW) for large microgrids and the utility grid. The switchgear and controller can be in the same cabinet for small microgrids, reducing costs and speeding installation. Smart grid and microgrid DERMs include intelligent metering of energy production and energy consumption that is used by cloud-based analytics to maximize the

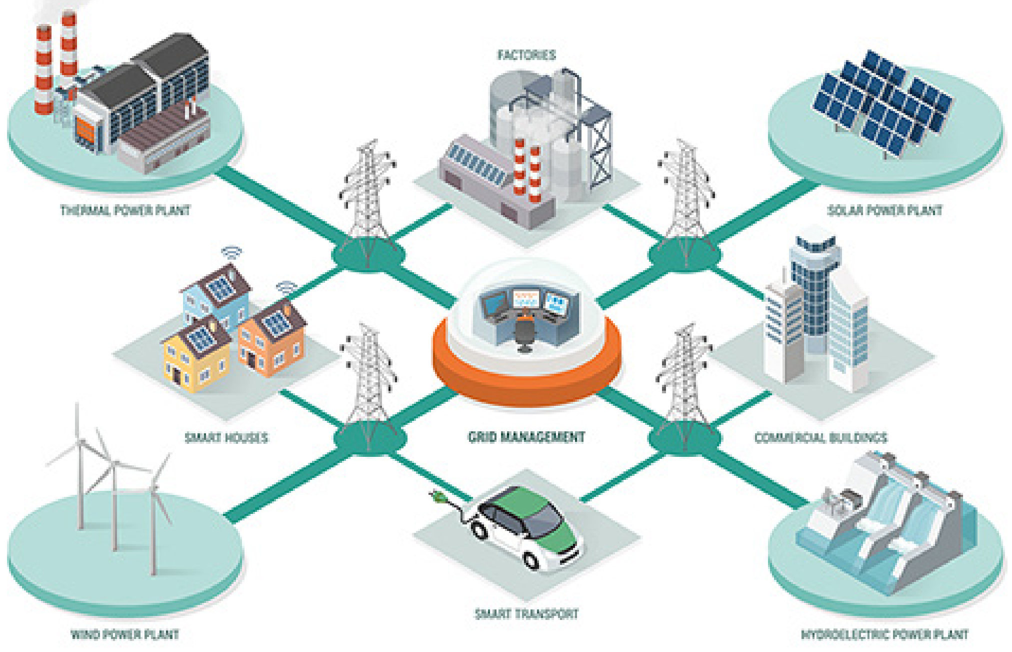


Figure 2: A smart grid relies on automated controllers and DERMs for real-time grid management. (Image source: ETAP)

economic benefits of DERs and support high levels of resilience. The exact architectures of DERMs can vary for different varieties of microgrids.

Microgrid varieties

Microgrids can be classified by their applications and architecture. The three microgrid architectures are remote, networked, and grid-connected. Remote microgrids are in places like islands or remote mining and agricultural operations. They are also called off-grid microgrids and are physically separated from any utility BPS. They must be completely self-sufficient.

Networked or nested microgrids are networks of several individual DERs or microgrids connected to a common utility distribution system. They are usually controlled by a centralized supervisory system that balances the needs of the microgrid operation with support for the wider utility grid. The controller often assigns a hierarchy of importance to the microgrids and DERs to ensure that the most critical elements are protected. Applications for networked microgrids include community microgrids, smart cities, and the emerging category of utility microgrids.

Networked microgrids are a subcategory of grid-connected microgrids. All grid-connected microgrids are physically connected to the distribution grid, and they have a switching device at the point of common coupling (PCC) where the connection to the distribution grid occurs. During normal operation, a grid-connected microgrid is connected to the distribution grid. It can provide services to the grid, such as frequency and voltage regulation, real and reactive power support, and demand response to mitigate capacity imitations.

The microgrid is not connected to the utility distribution grid in an islanded operation. Islanding can occur because of a disruption in the distribution grid or for other needs like maintenance. When transiting from islanded to grid-connected operation, these microgrids need to sense the frequency of the distribution and synchronize operation before reconnecting.

There are numerous microgrid applications, including campuses, hospitals and medical centers, commercial installations, communities, and industrial facilities. The newest application category is utility microgrids (Figure 3).

Figure 3: Microgrids are often categorized by their application. (Image source: Siemens)

Blurring the line

Utility microgrids that blur the line between smart grids and microgrids are being deployed. In the process, the definition of a DER changes from a distributed energy resource to a dedicated energy resource. Utility microgrids are designed to reduce power outages due to extreme weather events, wildfires, and other unforeseen challenges. With existing grid architectures, large sections of the grid are de-energized for safety during extreme events.

An important and unfortunate impact of those unscheduled and extensive power outages is to discourage the use of EVs. Utility microgrids are seen as a key to widespread EV adoption. Utility microgrids are being proposed and deployed across the U.S. For example, Southern California Edison (SCE) has proposed the development of Public Safety Power Shutoff Microgrids to help maintain electricity availability as widely as possible during wildfires. Other utilities refer to the new grid architecture as community microgrids (Figure 4).

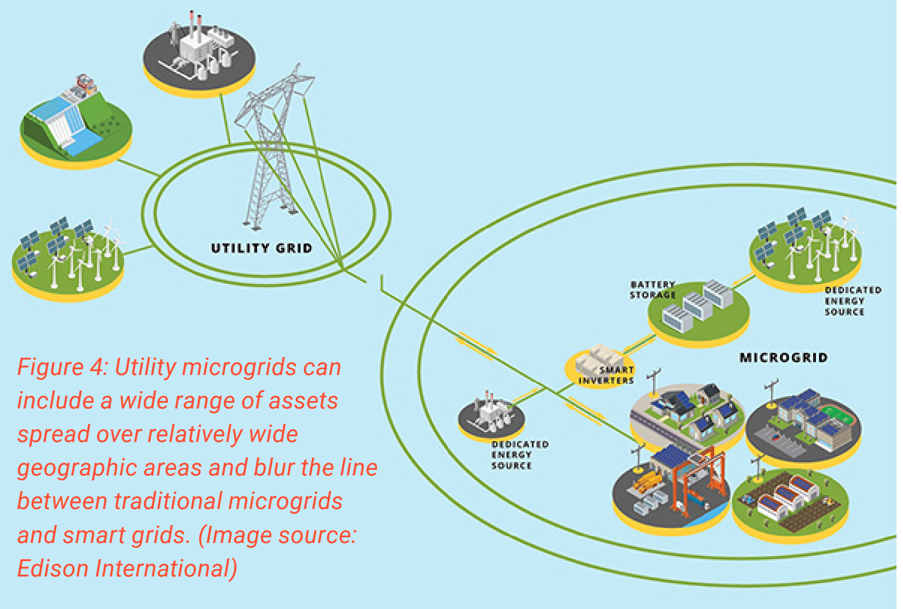
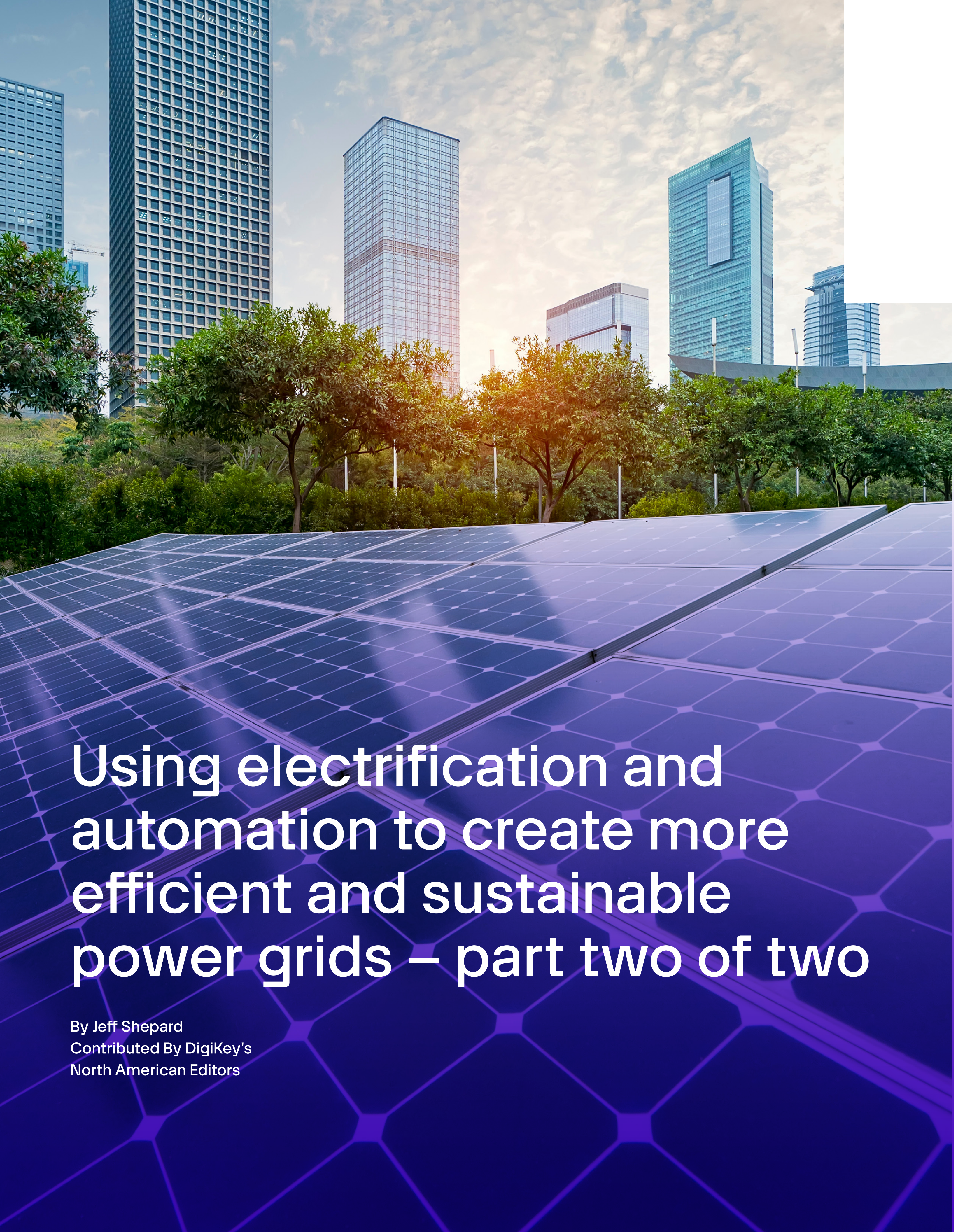


Figure 4: Utility microgrids can include a wide range of assets spread over relatively wide geographic areas and blur the line between traditional microgrids and smart grids. (Image source: Edison International)

The islanding capability of utility microgrids is key to improving electricity availability on a more granular level than is currently possible. It's expected to be deployed in a wide range of microgrid sizes, from complete residential communities to public places, including schools and other strategic locations like fire stations, medical centers, and evacuation centers. EVSE installations are a crucial part of the designs of most of these community microgrids. As envisioned, the EVSE will support the grid connection of EVs as additional sources of backup power as well as for EV charging.

Conclusion

Electrification is necessary to ensure more sustainable power grids and drive reductions in CO2 emissions. Many electrification technologies like PV energy and EVs are not as predictable as the traditional resources they are replacing. That means electrification must be supported with advanced sensor networks and automated control systems in smart grids and microgrids.



Using electrification and automation to create more efficient and sustainable power grids – part two of two

By Jeff Shepard
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Replacing traditional power grid energy sources with sustainable, green ones is called electrification. In Part 1 of this series, some of the challenges associated with electrification were discussed along with how automation can aid in its efficiency and sustainability. This article, Part 2 of 2, will discuss leadership in energy and environmental design (LEED) and zero energy building (ZEB) certifications and how they can reduce carbon emissions and improve sustainability.

Leadership in energy and environmental design (LEED) and zero energy building (ZEB) certifications represent significant efforts supporting society's desire to reduce carbon emissions and improve sustainability. Achieving LEED and ZEB certifications requires a holistic approach that combines electrification that replaces fossil fuels-based energy systems with green alternatives like photovoltaics (PV) and electric vehicles (EVs) with advanced automation and control systems.

The LEED program from the U.S. Green Building Council (USGBC) includes decarbonizing existing buildings and new construction. ZEB efforts are coordinated by the Energy Efficiency and Renewable Energy (EERE) office of the US Department of Energy. Achievement of LEED and ZEB certifications requires architects and contractors to take new approaches to how buildings are designed, built, and operated. Compared with ZEB, which focuses solely on energy consumption, LEED is a more expansive concept that addresses carbon, energy, water, waste, transportation, materials, health, and indoor environmental quality.

Figure 1: Rooftop PV generation was a key factor enabling this Phoenix Contact facility to achieve LEED Silver and ZEB certifications. (Image source: Phoenix Contact)

This second of a two-article series on electrification and sustainability begins by looking at the LEED and ZEB certification levels and what it takes to get those certifications for commercial and industrial buildings, including a comparison of several definitions of a ZEB. It then details an example of how Phoenix Contact used automation and on-site PV electricity generation to achieve LEED Silver and ZEB certification for a 70,000-square-foot addition on its main campus, including how some of the company's own products contributed to the success of the project (Figure 1). It closes with a glance at how LEED buildings can contribute to the United Nations' Sustainable Development Goals.

LEED is holistic

LEED is a comprehensive system that factors in all elements needed to create high-performance buildings. LEED certifications are based on credits or points awarded to a project using detailed performance criteria. The performance categories and their relative importance (from most- to least important) are[1]:

- Reduce contribution to global climate change.
- Enhance individual human health.
- Protect and restore water resources.
- Protect and enhance biodiversity and ecosystem services.
- Promote sustainable and regenerative material cycles.
- Enhance community quality of life.

The most essential criteria, reducing contribution to global climate change, accounts for 35% of all points. The levels of LEED certifications include Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), and Platinum (80+ points).

In the newest version of LEED, v4.1, most points are related to operational and embodied carbon. Operational carbon is the carbon dioxide (CO_2) emissions generated by heating, ventilation and air conditioning (HVAC), lighting, and other energy-consuming building systems. Embodied carbon are emissions associated with the production of building materials and building construction processes throughout the whole lifecycle of a building.

LEED certification is important for the creation of a greener society. Buildings account for 39% of global CO_2 emissions, with 28% from building operations and 11% from embodied emissions (Figure 2). Since the buildings sector is the most significant contributor to global CO_2 emissions, special programs have also been developed to encourage the development of zero energy buildings.

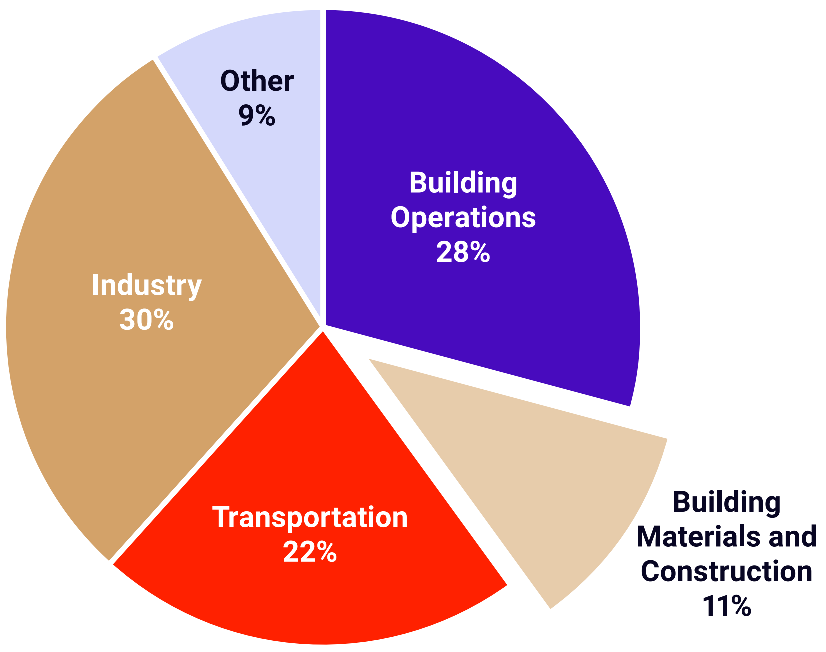


Figure 2: Building operations plus materials and construction are major contributors to global CO_2 production. (Image source: new buildings institute)

Defining zero

Zero energy seems like a straightforward concept, but it has several definitions. The three most cited are the LEED Zero Energy program, International Living Future Institute (ILFI) Zero Energy, and the Zero Code Renewable Energy Procurement Framework (Zero Code) — an initiative of the Architecture 2030 organization that has been adopted as a California building energy standard. There are significant differences in how "zero" is defined.

To achieve LEED Zero Energy certification, a building must have an energy balance of zero for 12 months, including on-site generation and externally generated (sourced) energy. On-site fossil fuel combustion is not prohibited. The total energy consumption must consist of on-site or externally generated renewable energy or carbon offsets.

ILFI Zero Energy Certification is the most restrictive standard. It requires on-site renewable sources to supply 100% of the building's energy needs. No combustion is allowed, and certification is based on actual performance; modeling is not allowed.

Zero Code specifically targets new commercial, institutional, and mid-to high-rise residential buildings. It defines a zero-carbon building as one that uses no on-site fossil fuels and produces on-site or procures enough of carbon-free renewable energy or carbon credits to meet building operational energy needs. Zero Code also requires that buildings meet the ASHRAE Standard 90.1-2019 for building efficiency. Zero Code allows the substitution of other energy efficiency standards if they result in equal or greater energy efficiency.

LEEDing by example

Phoenix Contact recently installed a 961-kilowatt (kW) PV system on the roof of the logistics center on the company's main US campus. The system generates enough power to satisfy about 30% of the facility's energy needs, or the equivalent energy consumption of about 160 homes per year. The building earned LEED Silver and Zero Energy certifications.

The on-site, natural gas-fired 1 MW microturbine cogeneration system was integrated with the PV system. The central energy control system monitors the PV plant's output and the building's energy consumption in real time. The microturbine generator is used when overall energy demand exceeds the PV system's output. There are times when the PV system and the microturbine are used together to provide electricity to the grid through net metering, generating income for the company.

The system was designed to reduce natural gas consumption during daylight hours and run the microturbine generator mostly at night, maximizing overall energy efficiency and minimizing overall CO2 generation. On some days, it's possible to reduce natural gas consumption to almost zero. Some statistics of the PV system include:

- 2,185 solar panels
- 1,214,235 kWh generated annually
- 1,939,279 pounds of CO_2 footprint reduction

Continuous monitoring and control of individual PV system segments in large installations like this one is necessary to achieve maximum efficiency and availability of power production.

Automation needs actionable information

Effective automation and control for electrification systems like PV installations requires extensive and actionable information. Real-time monitoring of each string of PV panels maximizes production and supports preventative maintenance. If a string goes down unexpectedly, it could lose thousands of kW of power with corresponding monetary losses.

The 961 kW PV system at Phoenix Contact's main US campus includes twelve inverters with six strings of PV panels feeding each inverter, and it incorporates several of the company's products, starting with second-generation EMpro energy meters like the panel mount 2908286. These meters are designed to measure and transmit key energy parameters to cloud-based platforms that support remote monitoring of all the system elements. EMpro energy meters are available for various power system designs, including one-, two- and three-phase installations and configurations. The system monitors numerous system elements and operational conditions in real-time, including:

- Inverters are individually monitored for DC input power, AC output power, active and reactive power, faults, and operational status.

- Each PV string is monitored for current and voltage output. That data is evaluated to determine string health and possible maintenance needs.
- Panel temperatures are monitored with numerous sensors spread throughout the installation.
- Weather conditions like wind speed and direction, temperature, relative humidity, and air pressure are collected.
- Solar irradiance is measured with two pyranometers, one at a 10-degree angle matching the installed angle of the panels and one installed horizontally.
- Soiling sensors measure the light loss caused by dust and dirt on the surface of the PV panels.
- Cameras provide security monitoring of the system.

The system also needs data loggers and interfaces. For example, the company's Radioline wireless modules, like the model 2901541, communicate wirelessly with PV module temperature and soiling sensors using the RS-485 protocol without cables. In other cases, power over Ethernet (PoE) is used to transmit power and data at the same time. Intrusion protection can be provided by FL mGuard 1000 Series Security Routers, like the model 1153079, that provide firewall security and user management.

Figure 3: DIN-rail mount controller suitable for large-scale PV generation systems. (Image source: Phoenix Contact)

Tying it all together takes a controller like the DIN-rail mount model 1069208 from Phoenix Contact based on the company's PLCnext Technology (Figure 3). When paired with an input/output (I/O) module like the model 2702783, the controller aggregates data from the sensor network and transmits it to a cloud service provider. In addition, an industrial PC runs Phoenix Contact's Solarworx software. The included software tools and libraries support communication protocols and standards the solar industry adopts. The system enables customized automation and visualization of PV system operation, and it's compatible with third-party software packages that can analyze historical and real-time data for performance optimization. The libraries include functional blocks that meet the requirements of IEC 61131 standard for programmable controllers.

Feed-in control is the final piece of the electrification puzzle for integrating distributed energy resources (DERs) like PV arrays with the power grid. PGS controllers from Phoenix Contact can monitor the voltage and reactive power levels at grid connection points and determine the required control values for the inverters to support feed-in management of power into medium- and high-voltage grids.

LEED and sustainable development

The United Nations (UN) has identified 17 Sustainable Development Goals[2] (SDGs) intended to end global poverty by 2030. According to the USGBC, the electrification and automation inherent in LEED buildings can contribute toward meeting 11 of the 17 SDGs, including:

Goal 3: Good health and well-being

Goal 6: Clean water and sanitation

Goal 7: Affordable and clean energy

Goal 8: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all

Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation

Goal 10: Reduce inequality within and among countries

Goal 11: Sustainable cities and communities

Goal 12: Responsible consumption and production

Goal 13: Climate action

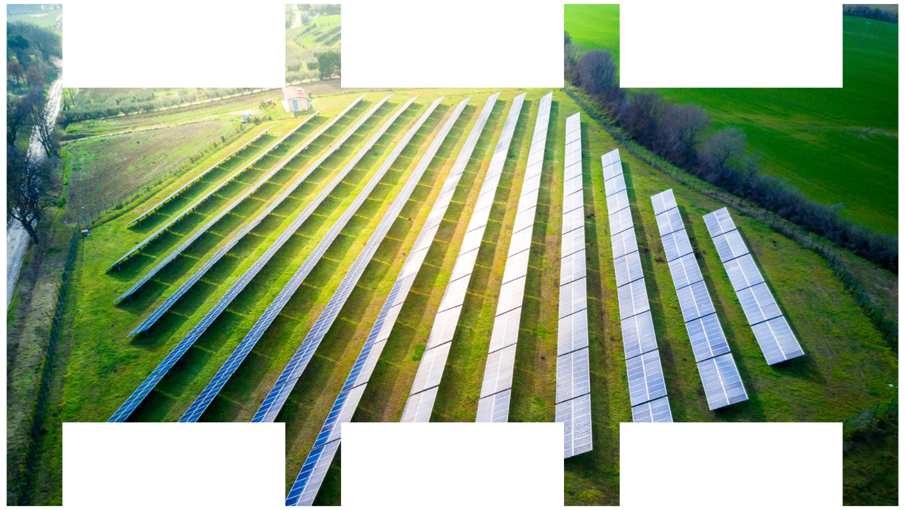
Goal 15: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation andbiodiversity loss

Goal 17: Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Corporate strategies can also contribute to a more sustainable society. For example, Phoenix Contact's gaining LEED Silver and Zero Energy certifications for its logistics center for the Americas was one part of the company's initial goal to achieve carbon neutrality at all of its worldwide locations. The company's next target is to create an entirely climate-neutral value-added chain before 2030.

Conclusion

The building sector is the most significant contributor to global CO_2 production. LEED and ZEB certifications are important tools for measuring the success of using electrification and automation to create more efficient and sustainable buildings. As shown, large-scale PV generation installations integrated with on-site cogeneration capacity can contribute to a greener society. LEED-certified buildings also support achievement of the UN's seventeen SDGs and the goal of eliminating global poverty by 2030.



References:

[1] LEED rating system, Green Building Council

[2] Sustainable Development Goals, United Nations

How microgrids and DERs can maximize sustainability and resilience in industrial and commercial facilities

By Jeff Shepard
Contributed By DigiKey's
North American Editors

Distributed energy resources (DERs) like solar energy, wind energy, combined heat and power (CHP), battery energy storage systems (BESS), and even conventional generators can be significant contributors to improvements in sustainability and resilience in commercial and industrial facilities, especially when combined into a microgrid using an automated control system to intelligently coordinate and manage energy generation, flow, storage and consumption.

To maximize microgrid environmental and economic benefits, the controller must balance the operation and integration of DERs in real time, manage smart loads like lighting, heating ventilation, and air conditioning (HVAC) systems, electric vehicle (EV) charging and information technology installations, use historic demand information to project future load profiles, provide safe and efficient connections to the utility grid and provide support for demand response functions with real-time energy pricing data.

This article reviews the elements that comprise a microgrid, looks at microgrid architectures, presents an overview of IEEE 1547, which establishes requirements for interconnection of DERs, and IEEE 2030 that provides a comprehensive technical process for describing the functions of a microgrid controller, then considers how microgrid controllers can enhance sustainability, resilience, and economic benefits, and closes with a brief overview of cyber security concerns for microgrids.

What does it take to make a microgrid?

Microgrids are diverse in their implementations and components. To discuss how microgrids and DERs can maximize sustainability and resilience, it's best to start with a definition and a few examples of microgrid components and architectures. The U.S. Department of Energy (DOE) defines a microgrid as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in grid-connected and island-mode." [1]

While the definition of a microgrid is straightforward, there's a range of microgrid categories, operating modes, and possible subsystems to choose from when building a microgrid, and realizing a microgrid's maximum sustainability and resilience involves numerous architectural and operational choices.

Automation is an important consideration. Examples of automated subsystems include (Figure 1):

- Generation within the microgrid, including a diverse range of DERs and CHP
- Power distribution networks
- BESS
- Loads like HVAC systems and machines and motors in industrial facilities
- Managing electric vehicle charging and vehicle-to-grid (V2G) connections
- Microgrid controllers and switchgear
- Interconnects to the utility grid for grid-connected installations

Microgrid categories

Microgrids can be categorized by whether they are off-grid or grid-connected:

Off-grid facility-led is the most common category. Use cases include remote areas not served by the commercial utility grid, like mines, industrial sites, mountain homes, and military bases.

Off-grid community-led are also found in remote locations. Use cases include remote villages, islands, and communities. While facility-led microgrids are controlled by a single entity, community-led microgrids must cater to the needs of a group of users. They can require more complex command and control systems.

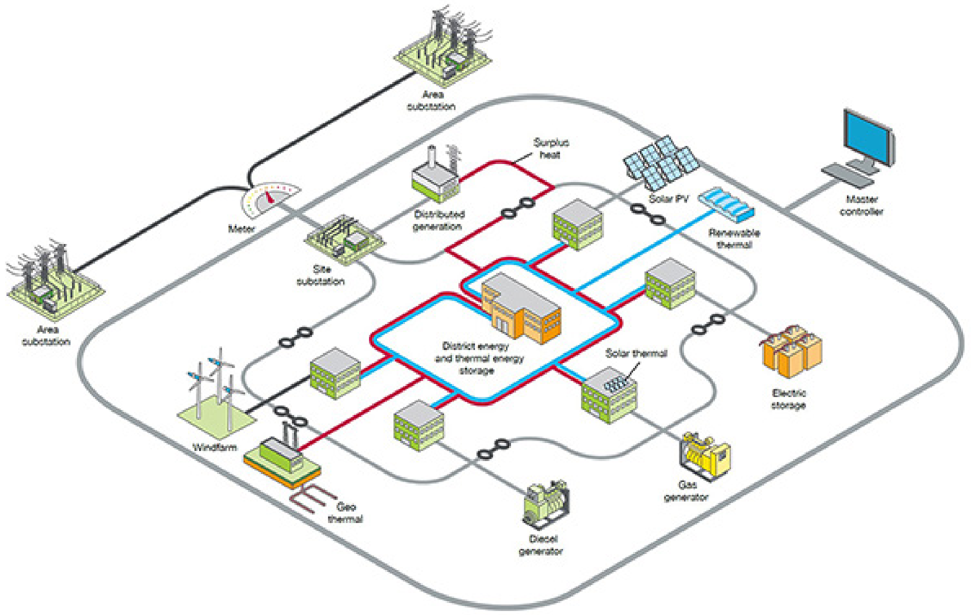


Figure 1: Microgrids can include various DERs, CHP, and loads. (Image source: Schneider Electric)

Grid-connected facilities have a single owner and are used to improve reliability in areas where the main grid is unreliable and power is necessary, or in cases where there are economic incentives for sheddable loads and other services from the microgrid owner. Use cases can include hospitals, data centers, continuous process manufacturing plants, and other high-availability buildings.

Grid-connected communities have multiple energy users and producers connected to the main grid and managed as a single entity. Use cases include business or university campuses, villages, and small cities. These can have a diversity of energy users, producers, and storage facilities and can be the most complex to control.

Sometimes microgrids are islands

In addition to discussing the components of a microgrid, the DOE definition refers to microgrid operation in "both grid-connected and island-mode." The definitions of those modes are straightforward, but implementation is more complex and is addressed in some IEEE standards.

IEEE 1547-2018, Standard for Interconnecting Distributed Resources with Electric Power Systems, details technical requirements for the interconnection and interoperability of DERs with the power grid. IEEE 1547 is an evolving standard. Earlier versions of IEEE 1547 were designed for low DER penetration levels and did not consider the potential aggregate regional impact of DERs on the bulk power system. IEEE 1547-2018 added stricter requirements regarding voltage and frequency regulation and ride-through capability to help the reliability of the transmission system. More recently, the 1547a-2020 amendment was added to accommodate abnormal operating performance.

IEEE 2030.74 describes the functions of a microgrid controller in terms of two-steady state (SS) operating modes and four types of transitions (T) (Figure 2):

- **SS1**, steady state grid-connected mode, has the microgrid connected to the utility grid. The controller can use the components in the microgrid to provide services like peak shaving, frequency regulation, reactive power support, and ramp management to the grid.
- **SS2**, stable island mode, also called "islanding" mode, is when the microgrid is disconnected from the utility grid and operates in isolation. The controller is required to balance the loads and microgrid generation and energy storage services to maintain stable microgrid operation.

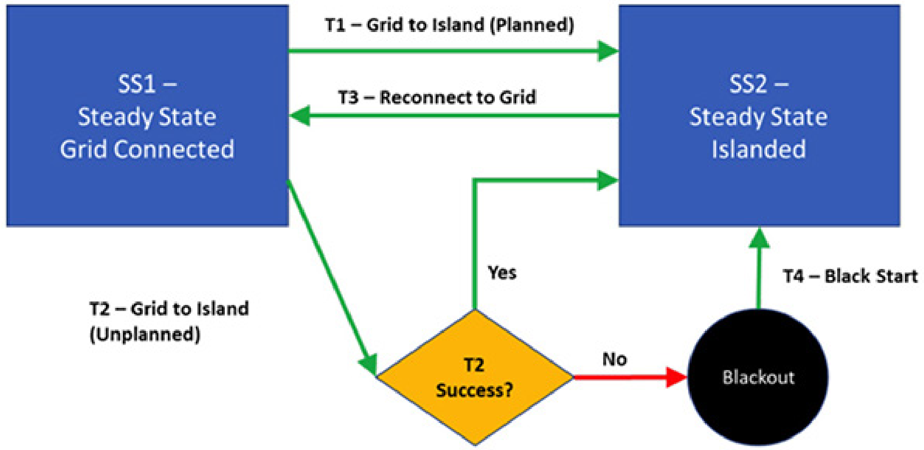


Figure 2: IEEE 2030.74 requires microgrid controllers to accommodate two steady-state conditions and four types of transitions between those states. (Image source: National Rural Electric Cooperative Association[2])

- **T1**, refers to a planned transition from grid connected to steady state island mode. Even when the utility grid is available, there may be economic or operational incentives to switch to island mode. In addition, this mode can support testing of microgrid operation.
- **T2**, is an unplanned transition from grid connected to steady state island mode. This is analogous to the operation of an uninterruptible power supply in a data center and is often used when the main grid fails. The microgrid seamlessly disconnects and operates as an independent power network.
- **T3**, refers to steady-state island reconnection to the utility grid. This is a complex technical procedure with a 'grid-forming' generator on the microgrid sensing the frequency and phase angle of the grid power and exactly matching the microgrid with the main grid before reconnecting.
- **T4**, is a black start into steady-state island mode. In this case, the microgrid has gone down and must be isolated from the utility grid and restarted in island mode. This situation could occur because of an unexpected outage that the microgrid controller cannot handle using a T2 stable transition, or it might be necessary if the island does not have sufficient generation or energy storage reserve to continue to supply all the loads and must shut down all nonessential loads before bringing the generator online. In addition, any BESS on the microgrid must be at least partially recharged before being reconnected.

Implementing microgrids

There are almost as many combinations of DERs and loads as microgrids, but automated controllers and switchgear are common elements. In large microgrids like the one illustrated in Figure 1 above, they are often separated into a centralized control room, distributed switchgear for DERs and loads, and for grid-connected designs, a substation that serves as the switchgear between the microgrid and the utility grid.

Microgrid controllers need information, and to maximize resilience and sustainability, they need to be quick. The controllers use a network of sensors to monitor the functioning of the DERs and loads in real time. For grid-connected microgrids, the controller also monitors the status of the local utility grid. Should any anomaly occur, the controller responds in milliseconds and sends a command to the associated DER, load, or switchgear.

Switchgear sizes range from a few kW to multi-MW and need to respond to controller demands in a few milliseconds or risk a serious fault condition. Some switchgear features smart circuit breakers that operate autonomously to provide an additional layer of protection.

Figure 3: ECCs combine the microgrid controller (left) and switchgear (right) into a single piece of equipment. (Image source: Schneider Electric)

For smaller installations, the controller and switchgear can be combined into a single piece of equipment, sometimes referred to as an energy control center (ECC). ECCs are available pre-wired, assembled, and factory tested. ECCs simplify and speed up the installation of microgrids and can manage multiple energy sources, including grid power and DERs with prioritized loads. For example, Schneider Electric offers the ECC 1600 / 2500 line of ECCs for building-scale microgrids (Figure 3). Some features of the ECC 1600 / 2500 line include:

- Configurable to order with power ratings from 100 to 750 kW and can be optimized for existing or new buildings
- Works with multiple DERs like PV, BESS, wind, gas, and diesel generators
- Controller enables resilience during outages, including using PV with an anchor resource such as a standby generator or BESS
- Automated intelligent metering gives insights into power quality, energy usage, and DER production
- Switchgear with a 1,600 to 2,500 A power distribution bus
- Cloud-based analytics to maximize resilience and return from investment from DERs

Safe and secure energy

Cyber security is an important aspect of energy security and resilience. The International Energy Agency (IEA) defines energy security as “the uninterrupted availability of energy sources at an affordable price” [3]. Microgrids can significantly contribute to ensuring low-cost, secure, and resilient energy supplies.

Communication is an essential element of microgrids. This means communication to the cloud, and possibly with the local utility grid, to optimize performance. In addition, the various DERs and loads that comprise a typical microgrid come from different manufacturers and employ heterogeneous communication protocols and technologies. Internet connectivity and wireless technologies like Wi-Fi are found in almost all microgrids and can be essential for maximum benefits. They also support ancillary functions like gathering weather forecasts and real-time fuel and energy prices.

Ensuring cyber-security is complex. In addition to secure hardware, policies, procedures, and people are required to address cyber vulnerabilities that can enable attackers to access sensitive networks and data and even manipulate control software resulting in damaged microgrid operation. Terrorists are only one concern; there are also competitors or unscrupulous employees to consider. Operator errors can occur, networks can have unknown loopholes due to outdated software, and so on (Figure 4). Cyber security can’t be an afterthought. It must be designed into all aspects of microgrid hardware, software, and processes from the beginning to be effective.

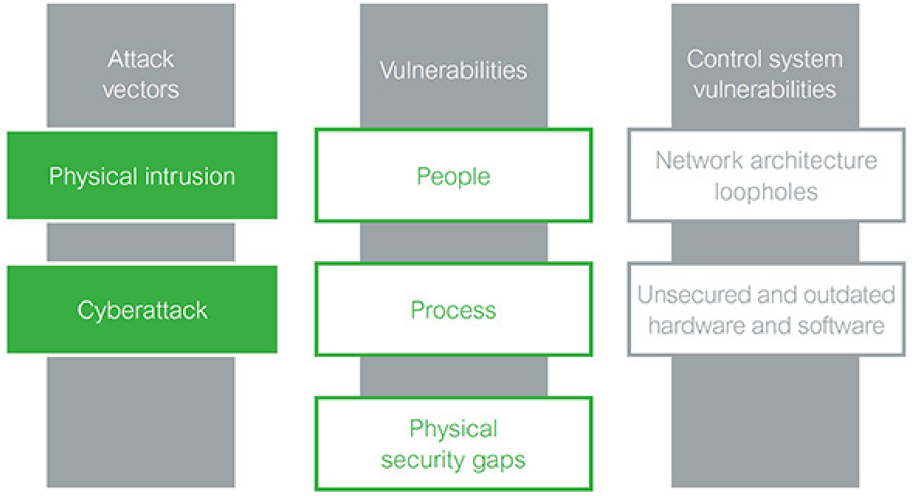


Figure 4: Vulnerabilities from people, processes, and holes in physical security can present microgrid attack vectors. (Image source: Schneider Electric)

Summary

Microgrids integrate numerous DERs and loads into a single system to maximize energy sustainability and resilience. Several microgrid architectures can be used to support specific energy and connectivity needs. The increasing number of microgrids and the growing penetration of DERs has resulted in an evolution in the IEEE 1547 interconnection standard and is driving an increased focus on microgrid cyber security.

References:

[1] The U.S. Department of Energy’s Microgrid Initiative, DOE

[2] Defining a Microgrid Using IEEE 2030.7, National Rural Electric Cooperative Association

[3] Energy security - Ensuring the uninterrupted availability of energy sources at an affordable price, IEA

Connectivity – the backbone of sustainable automation

By Dr. Matthias Laasch,
laasch:tec technology
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(Image source: PeopleImages via Getty Images)

Technologies such as SPE, PoDL, and Ethernet APL overcome traditional limitations of industrial communication. Advanced interfaces for signals, data, and electrical power are essential here: they help automation providers save resources and costs when networking production equipment.

Digitalization and seamless data networks penetrating corporate processes right down to the field level of production are a lasting trend in automation technology. Their goal is to create highly flexible production environments that can be customized to achieve an unprecedented level of diversification and productivity. For this purpose, the manufacturing industry is experiencing a disruptive transformation under the umbrella of 'Industry 4.0', with the sustainable use of all available resources being one of the most important aspects.

From field to cloud seamlessly

Seamless connectivity between machines, products, and – in the final instance – people is characteristic of this transformation, which is beginning to massively penetrate the traditional boundaries between Operational Technology (OT) and Information Technology (IT). With Industrial Ethernet, a technology is available today that can seamlessly interconnect even field-level devices via TCP/IP to companies' cloud-based data infrastructures broadband and cost-efficiently. Unlike fieldbuses, Industrial Ethernet crosses all levels of automation – end-to-end, from the field device to the cloud. Factory and plant operators can thus access device data in real time and use it for their production planning, process control, and data analysis.

The Industrial Ethernet enables, for example, the real-time acquisition and analysis of data from sensors, power supplies, or drives. Information about temperature change or vibrations at critical points as well as load profiles allow conclusions to be drawn for the optimization of process parameters. They announce when overload situations are to be expected and signal the need for maintenance at an early stage. Predictive maintenance is of particular importance here, as it helps operators to improve the availability of their plants and machines, as well as to minimize energy consumption and use of resources – which, on the one hand, lowers operating costs but, on the other hand, makes a decisive contribution to the sustainability of process and factory plants.

Rugged RJ45 alternative

The physical backbone of these networks, particularly of Industrial Ethernet, is high-performance interconnect technology that allows for reliable transmission of signals and data between the various nodes of the automation networks. In addition to the physical robustness they require in industrial use, such solutions face a number of new challenges today, resulting, for example, from the sheer quantity of network nodes, their miniaturization, or the high transmission bandwidth. These include, in particular, compact form factors, reduced installation and cabling effort, high signal integrity – i.e., sophisticated shielding against electromagnetic interference – and reliability over long transmission distances. The latter is particularly relevant in extended plant fields. Increasingly, the power supply of devices using data connectors is also required.

The standard interface for Ethernet communication is the widely used RJ45 connector. Users frequently report problems with the contacts or broken latching elements; RJ45 also limits miniaturization due to its size. In contrast, alternatives

Figure 1: Considerably smaller and more robust than standard RJ45 connectors: HARTING's industrial Ethernet interface ix Industrial. (Image source: HARTING)

such as the ix Industrial interface from German supplier HARTING (Figure 1) are substantially smaller and much more robust, particularly resistant to shock and vibration. According to the manufacturer, space savings of up to 70% on the circuit board are possible compared to standard RJ45. The 360°-shielded connector is designed for 10-Gbit/s Ethernet communication and is compatible with PoE (Power-over-Ethernet) as well as PoE+ for power transmission.

ix Industrial is an interface developed by HARTING in conjunction with Japanese connector specialist Hirose. Its dimensions, electrical properties, and coding comply with the IEC 61076-3-124 standard. Other manufacturers, such as the US company Amphenol Communications Solutions, also offer products with comparable properties that are intermateable with ix Industrial: for example, push-pull connectors for harsh environments in protection degrees IP65/66/67, ix Mag connectors featuring integrated magnets (Figure 2), or Ethernet-to-RJ45 cable assemblies with angled RJ45 connectors; they provide both 100-Gbit Ethernet and PoE/PoE+ functionality.

ix Industrial use case

The following example illustrates the enormous potential of high-performance, miniaturized Ethernet interfaces for Industry 4.0 applications:

The XTS linear transport system from automation specialist Beckhoff is a drive solution that uses magnetically driven movers traveling along a track of fully integrated motor modules. According to Beckhoff, their independent control allowing for individual motion profiles is the starting point of new machine concepts that enable more flexible manufacturing processes with shorter downtimes, such as retooling.

Figure 2: Amphenol ix Mag: Ethernet communication up to 10 Gbit/s, 360° shielding and PoE++ up to 90 W (Image source: Amphenol Communications Solutions)

In order for the movers to follow their movement pattern, a computer must constantly calculate the switching and current supply of the respective motor modules. For this purpose, a total of three computer boards can be combined, each of which previously had four RJ45 sockets as ports. To allow more movers to be operated in the latest generation of the XTS system without having to change the dimensions of the system, the RJ45 sockets were replaced by the ix Industrial interface from HARTING. Reliable shielding and high data throughput were the main requirements here. Unlike RJ45, each ix Industrial connector allows for two 100-Mbit/s Ethernet connections. Thus, eight instead of four ports could be mounted on the same board, and two Ethernet channels could be installed per port instead of one.

As a result, 48 instead of twelve ports were implemented on the three computer boards. Accordingly, with the latest XTS generation, 48 instead of twelve XTS lines can now be used per unit, corresponding to a 400-% increase in the performance of the transport system.

Two wires – instead of four or eight

One distinctive attribute of today's industrial automation technology is its migration from hierarchical to decentralized architectures. These are considered advanced and particularly productive and, moreover, promise increased network security. This is because intelligent nodes such as smart sensors or edge computers, which are capable of performing certain data processing tasks autonomously, reduce sensitive data traffic between the edge and the cloud. The advantages of decentralization are self-evident, but the number of connected devices in the field is growing enormously, and so are the efforts for cabling and connectivity. Their economic use, both in terms of material and installation effort as well as energy consumption, is becoming a strong criterion for the sustainability of manufacturing facilities.

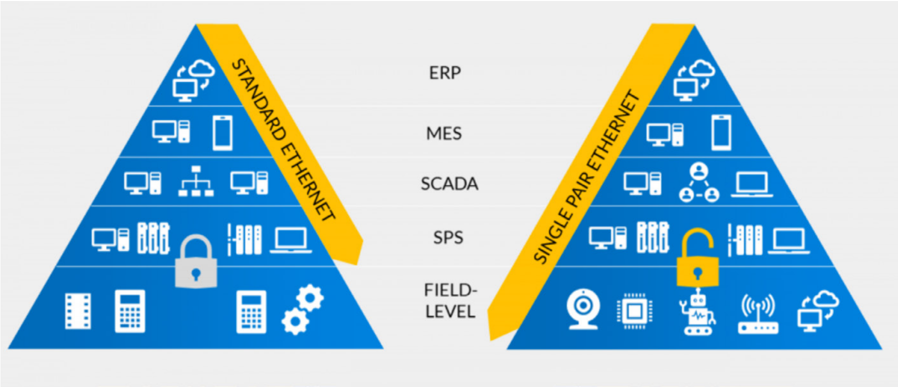


Figure 3. Single-Pair Ethernet allows for resource- and cost-efficiently integrating the field level into broadband Ethernet communication. (Image source: SPE Industrial Partner Network)

Single-Pair Ethernet (SPE) is considered a decisive breakthrough in efficiency and cost-effectiveness. The communication technology is defined by the IEEE 802.3 standard; the IEC 63171-x series of standards applies to the respective connectors. Essentially, it enables field components to be connected via just one twisted pair, i.e., two wires instead of the previous four or even eight: low-cost, resource-efficient, and therefore extremely sustainable. Originally developed for automotive electronics, SPE meets the requirements of many automation providers: The single pair of wires enables them to integrate a large number of instruments, controllers, and other devices into Ethernet networks at gigabit data rates (Figure 3).

Another advantage: thanks to PoDL compatibility (Power-over-Data-Line, IEEE P802.3bu), the same pair of wires is able to deliver not only data but also electrical power to the field devices. In addition to actuators and sensors, in the power range of the previous PoE supply, camera-based instruments can be connected and powered via PoDL, for example.

Products for Single-Pair Ethernet

In the SPE segment, HARTING is taking a position with its T1 connector, including locking and 360° EMI shielding (Figure 4). The PoDL-capable T1 is available in circular designs, including M8 and M12. In terms of protection degrees, the product spectrum ranges from IP20 to IP67, and according to the manufacturer, the respective interface counterparts are designed to meet the protection classes and ensure interoperability.

Phoenix Contact also provides a comprehensive SPE portfolio for field cabling to and from control cabinets, sensors, switches, and gateways. This supplier's products include, for example, board connectors or cable assemblies for use in industrial IP20 to IP67 environments.

The open-source tool provider SparkFun Electronics offers an SPE function board to support developers in designing applications with Single-Pair Ethernet (Figure 5). The board, called MicroMod COM-19038, includes an ADIN1110 Ethernet transceiver from Analog Devices, passive components from Würth Elektronik, and a HARTING T1 connector. An integrated MAC (Media Access Control) interface enables serial communication with a host controller at 10 Mbit/s in full duplex mode. The board supports network nodes via 1700 m cable lengths, but it is not designed to supply power to the nodes via this cable. Kirk Benell, CTO of SparkFun, presents the development board in a demo video.

End-to-end networking in process technology

The technical advantages of Single-Pair Ethernet, for example, concerning condition monitoring and predictive maintenance, are also beneficial for process automation. However, an extended requirements profile for Ethernet connectivity applies here. In addition to robust and broadband real-time communication, as it is also required on a shopfloor, wide-ranging process plants require data transfer over long distances. Furthermore, automation components must be intrinsically safe for use in potentially explosive environments. This is where the so-called Ethernet Advanced Physical Layer (Ethernet APL) enters the scene: it defines a physical transmission layer for Ethernet communication at 10 Mbit/s as well as for power supply via one twin wire – as with SPE – over distances of up to 1000 m. Like SPE, Ethernet APL is perfectly suited for universal, multipurpose field instrumentation.

Figure 4: Shielded and equipped locking functionality – the PoDL-compatible T1 is offered for protection degrees IP20 to IP67. (Image source: HARTING)

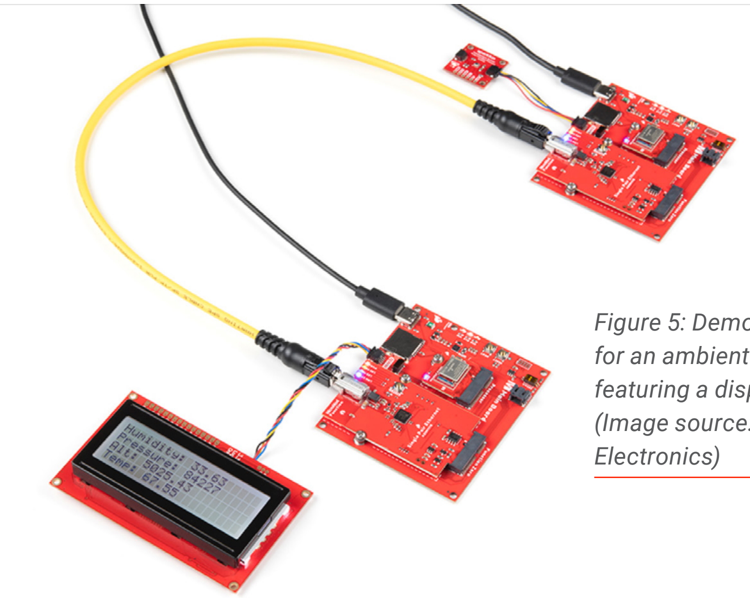
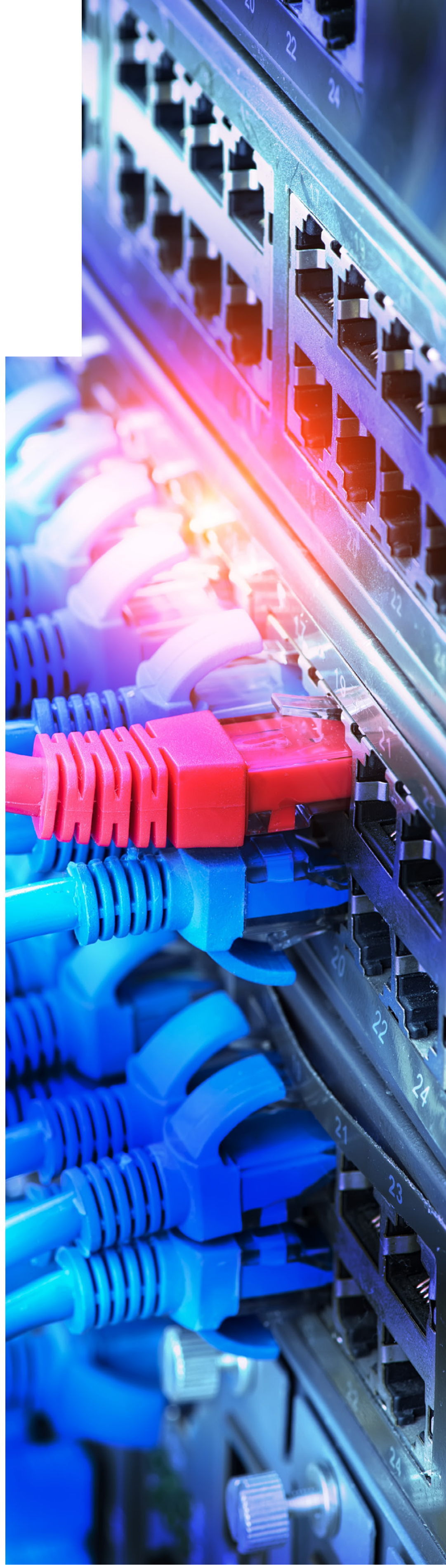


Figure 5: Demonstrator for an ambient sensor featuring a display. (Image source: SparkFun Electronics)

Summary

Industrial Ethernet, and particularly Single-Pair Ethernet, support broadband networking of production equipment. They enable seamless communication from the field level to the cloud and allow real-time access to device data, which supports operators in plant and process optimization. Their benefits are clearly evident in reduced operating costs, higher availability, and optimized use of energy and resources. Advanced connection technologies such as ix Industrial interfaces and SPE connectors with PoDL capability ensure reliable data and power transmission between all network nodes. This makes them key components of Industry 4.0 and a backbone of sustainable automation concepts.



Use IO-Link for increased flexibility, availability, and efficiency in industry 4.0 factories

By Jeff Shepard
Contributed By DigiKey's
North American Editors

Supporting the data gathering and analysis that are the hallmarks of Industry 4.0 can frequently require line and process changes that include adding, removing, or reprogramming digital sensors, actuators, indicators, and other devices. This can be difficult to implement efficiently across legacy automation networking protocols with their various characteristics. Industry 4.0 installations need another layer of connectivity and flexibility between the installed networks and the growing mass of localized sensors, actuators, and indicators.

To address these challenges, IO-Link has been developed as an open standard that can connect signals from devices like sensors, actuators, and indicators to higher-level networks like Ethernet IP, Modbus TCP/IP, and PROFINET, and from there to programmable logic controllers (PLCs), human-machine interface (HMI) devices, supervisory control and data acquisition (SCADA) systems, and to the cloud. IO-Link serial connectivity is standardized as IEC 61131-9 with simple unshielded three or five wire standard cables defined in IEC 60974-5-2. Designers of automation systems will find IO-Link to be particularly suited to support the rapid deployment and remote configuration, monitoring, and diagnostics of connected devices required for Industry 4.0 factories.

This article reviews the capabilities and benefits of IO-Link and looks at the structure and operation of IO-Link networks, including the use of various types of IO-Link devices for building local networks of sensors, actuators, and indicators to support Industry 4.0. It presents real-world examples of IO-Link master, hub, and data-converter devices from Banner Engineering that designers can use to efficiently deploy masses of Industry 4.0 edge devices.

Where does IO-Link fit?

IO-Link provides a lower-level network that captures data from distributed sensors, actuators, and indicators, connects to converters that convert the data into the IO-Link format, and then distributes it to IO-Link hub or master devices as needed for connection to higher-level factory networks like Ethernet, Modbus, and PROFINET (Figure 1).

IO-Link's key attributes include the following:

- Open standard
- Supports fast integration, configuration, and commissioning of local devices to speed changeovers and enable increased flexibility with minimal need for hands-on support from technicians
- Compatibility with existing automation networks
- Robust two-way communications that can be either synchronous or asynchronous to maximize communication efficiency
- Remote diagnostic support down to the device level
- The ability to dynamically change sensor or actuator parameters to speed process optimization
- Integrated device identification and automatic parameter reassignments to maximize availability

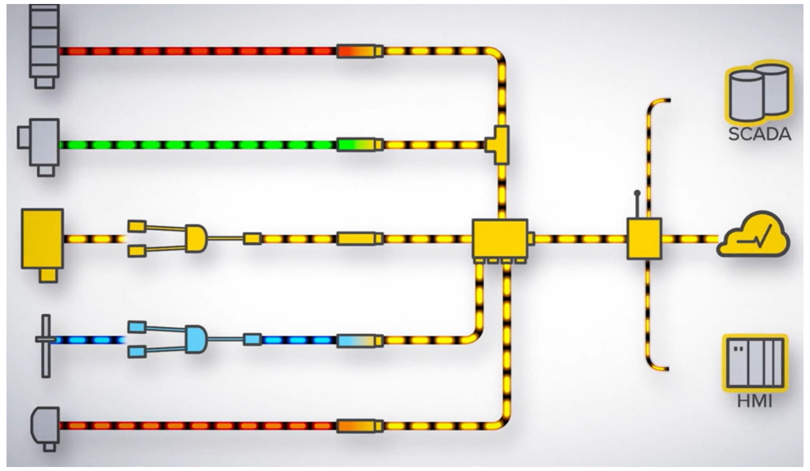


Figure 1: IO-Link provides a complete solution for connecting legacy and other sensors, actuators, and devices (left) with existing SCADA, HMI, and the cloud (right) in Industry 4.0 networks. (Image source: Banner Engineering)

How to connect IO-Link devices

Devices in an IO-Link network are connected using three or five conductor unshielded cables up to 20 meters (m) long. IEC 60947-5-2 defines the master and device pin assignments. Male connectors are assigned to the device, and female connectors are used for the master. Connectors can be M5, M8, or M12 with up to five pins. At the master, 24 volts direct current (VDC) at up to 200 milliamperes (mA) is provided between pins 1 and 3 to act as an optional power supply for devices. Pin 4 is defined as a digital input (DI) or digital output (DO) based on IEC 61131-2, and it supports backward compatibility with legacy devices according to IEC60947-5-2.

There are two master port classes, A and B. In class A ports, pins 2 and 5 are not connected (NC), and in class B ports, those pins can be configured as DI, DO, not connected (NC), or can provide an additional power supply. In most industrial installations, M12 quick disconnect connectors are used. A summary of the pin assignments as defined in IEC 60974-5 is shown in Figure 2:

- Pin 1: +24 VDC, 200 mA maximum (L+)
- Pin 2: Digital I/O (PNP only)
- Pin 3: 0 volts (L-)
- Pin 4: Digital I/O (NPN, PNP, or push-pull) and IO-Link communication
- Pin 5: Center pin NC (optional)

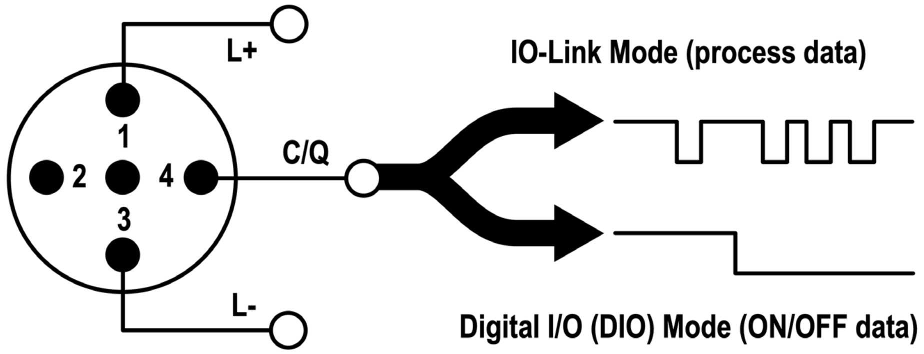


Figure 2: IO-Link is a simple solution for providing power and data connectivity to devices at the edge like sensors and actuators. (Image source: Banner Engineering)

Why IO-Link?

IO-Link contributes to substantial performance improvements in Industry 4.0 networks using simple device installation or replacement with standardized, reliable, and low-cost wiring. In addition, it's designed to simplify the integration of isolated sensors into existing networks. Benefits of IO-Link include:

Data availability is enabled using IO-Link to connect isolated devices and islands of automation into a unified network. Sensor-level data is not always available or easy to acquire. With IO-Link, data becomes easy to acquire and can be available in real time to optimize processes and support proactive machine and sensor maintenance. IO-Link supports three primary data types that can be further categorized as either cyclic data that is automatically transmitted on a regular schedule, or acyclic data that is transmitted upon request or as needed:

- Process Data: This refers to information like sensor readings that the device transmits to the master, as well as information from the master to control device operations, like lighting specific segments on a tower lighting fixture. Process data can be cyclic or acyclic.
- Service Data: This includes information about the device and is sometimes called device data. Service data includes device parameter values, device description, and model and serial number. It is acyclical and can be read from or written to a device as needed.
- Event Data: This includes error handling and includes error messages like parameter settings being exceeded or maintenance warnings like a dirty lens on an imaging sensor. They are transmitted acyclically whenever a triggering event occurs.

Remote configuration enables network operators and technicians to read and change device parameters through software control without physically going to each individual device. Sensor parameters can be dynamically changed as needed to refine existing processes, speed product and process changes, support mass customization, and minimize machine and line downtime.

Simplified device replacement is enabled by the ability to remotely configure devices. The Auto Device Replacement (ADR) function in IO-Link can provide automatic parameter adjustments and reassignments for replaced devices. With ADR, network operators can import existing parameter values into a replacement device or update the parameters as needed to ensure rapid and accurate network modifications and maintenance.

Extended diagnostics takes advantage of the cyclic and acyclic communications capabilities of IO-Link to provide network operators with extensive information about the operational status of each device in the factory. The ability to remotely diagnose device operation can speed the identification of devices that are deteriorating or operating out of specification. This allows more efficient scheduling of maintenance or device replacement.

Standardized and simple wiring is a key feature of IO-Link. Unlike other network protocols, IO-Link devices, converters, hubs, and masters are all connected using simple and low-cost unshielded cables and quick disconnect connectors. The master-slave architecture of IO-Link further simplifies wiring requirements and eliminates network configuration concerns.

Figure 3: The DXMR90-4K IO-Link master device can combine data from four local sources and connect with a higher-level network. (Image source: Banner Engineering)

Getting started: IO-Link master/controller

Automation system designers adding or extending the use of IO-Link can start by selecting an IO-Link master (or controller) like the DXMR90-4K from Banner Engineering that consolidates data from multiple sources, provides local data processing, and enables connectivity to the higher-level network (Figure 3).

The four ports of the DXMR90-4K support concurrent communications with up to four IO-Link devices. It supports data collection, edge processing, and protocol conversion for connection to industrial Ethernet or Modbus/TCP, and can transfer data to web servers. Other features of the DXMR90-4K include:

- Compact and lightweight housing that saves space and simplifies deployment
- IP67 rating eliminates the need for a separate control cabinet, contributing to reduced installation costs

- Facilitates consolidated cable runs that minimize cabling complexity and weight, which can be particularly important in applications like robotics
- Expandable internal logic controller using action rules and ScriptBasic programming that supports high levels of flexibility

For simpler installations, designers can turn to devices like the R45C-2K-MQ two-port IO-Link Master for Modbus connections.

Figure 4: The R90C-4B21-KQ hub can consolidate communications from four devices and connect them with an IO-Link master device. (Image source: Banner Engineering)

IO-Link hubs

When numerous sensors or actuators need to be connected to a single IO Master, designers can use an IO-Link hub to aggregate sensor and actuator signals and transmit them to an IO-Link master via a single cable. For example, the R90C-4B21-KQ features four input ports and connects to the master using a standard M12 connector (Figure 4). It's a compact bimodal (PNP or NPN) to IO-Link device converter that connects discrete inputs and sends the value to an IO-Link Master. It features:

- Delay modes that include ON/OFF Delay, ON/OFF/Retriggerable One-shot, ON/OFF, Pulse-stretcher, and Totalizer
- Measurement metrics include Count, Events Per Minute, and Duration
- Discrete mirroring enables the signals (in and out) to be mirrored to any of the four ports
- Discrete I/Os can be independently configured as NPN or PNP
- Rugged over-molded IP68 rated design

IO-Link signal converters

Various types of converters are available for IO-Link networks to connect sensors and other devices that may use a range of signal types, such as discrete PNP or NPN signals, analog 0 to 10 VDC signals, and current transducers. Examples of IO-Link signal converters include:

- R45C-K-IIQ IO-Link to analog current in or out converter (Figure 5)
- R45C-K-UUQ converter for analog voltage in or out
- R45C-K-IQ converter for analog current out
- R45C-K-UQ converter for analog voltage out

IO-Link inline converters are also available that are about the size of a single AA battery. These converters can handle various signal types and convert them to IO-Link, Modbus, or other protocols. For example, the S15C-I-KQ is an analog current to IO-Link converter that connects to a 4 to 20 mA current source and outputs the value to an IO-Link master. The small size of these converters simplifies the addition of legacy sensors into networks with standard protocols for process or environmental monitoring. Their IP68 ratings enable them to be broadly deployed in industrial settings.

Conclusion

IO-Link provides the connectivity needed to gather the data necessary to optimize the performance of Industry 4.0 factories by connecting legacy and other edge devices with the main Ethernet IP, Modbus TCP/IP, or PROFINET network. It supports high levels of data availability, extended diagnostics, remote configuration, and simplified device replacement, speeding process and line changes using connectivity that is standardized in IEC 61131-9 with simple unshielded 3 or 5 wire standard cables defined in IEC 60974-5-2.

Recommended Reading

1. How to Design a Modular Overlay Network for Industry 4.0 Data Processing Optimization in the IIoT
2. How to Ensure Gigabit Ethernet Signal Integrity in Long-Distance Industrial Automation Deployments

Figure 5: The R45C-K-IIQ IO-Link converter can connect a master device with local devices using analog inputs and outputs. (Image source: Banner Engineering)

How to use traceability 4.0 solutions for improved product safety, compliance, and tracking

By Jeff Shepard
Contributed By DigiKey's
North American Editors

Real-time asset tracking and traceability in warehouses and factories is an important aspect of Industry 4.0 and supply chain management for automotive parts and sub-assemblies, consumer white goods, aerospace, transportation, and electronic system production. Traceability is especially important: It includes location tracking and documenting the history and usage of raw materials, components, subassemblies, and finished goods. In addition to supporting production efficiency and product quality, traceability 4.0 is an essential aspect of product safety, including safeguarding against counterfeit components, supporting accurate recalls, and ensuring regulatory compliance.

Traceability 4.0 solutions rely on marking every individual component, often using 1D or 2D barcodes on labels or directly marked on the items, and actively tracking the movement of items throughout the production process. That can be quite a challenge. For example, a typical automobile has over 20,000 components that must be tracked. Traceability 4.0 implementation can be complex. It's not enough to simply mark every component. Using a single imaging platform for bar code reading and visual inspection of the items is desirable. Additionally, the imagers need to operate in harsh industrial environments and under variable lighting conditions.

To support the traceability needs of Industry 4.0, designers can turn to industrial smart imagers that can read 1D and 2D barcodes for visual inspection and are available with autofocus to improve imaging performance. These smart imagers include advanced decoding algorithms that can read even damaged barcodes. They have double front window construction to minimize issues with condensation, as well as IP65/67 protection to ensure performance in harsh environments.

This article reviews the development of traceability 4.0 and how it supports product safety, product tracking, and regulatory compliance, reviews the basic barcode types and reconstruction software to read damaged barcodes, looks at system integration issues and the tradeoffs between mechanical and liquid lens autofocusing systems and closes by presenting smart industrial imagers from Omron along with a software development tool for setting up barcode reading and machine vision applications.

Where does traceability 4.0 fit?

Traceability 4.0 is an integral part of industry 4.0. But not every manufacturing operation is an industry 4.0 operation. Other use cases, like retail and warehousing, don't require traceability 4.0. So, how did traceability 4.0 arise (Figure 1)?

- Traceability 1.0 usually relies on barcodes to automatically identify products to improve accuracy and efficiency.
- Traceability 2.0 moved into supply chain management using date and lot codes. It was designed to support higher levels of quality, and consumer confidence and support targeted product recalls. It's still used in the retail industry. In addition, the U.S. Food and Drug Administration (FDA) uses it for unique device identifiers (UDIs) for medical devices. This is when the International Standardization Organization (ISO) began developing barcode quality specifications.
- Traceability 3.0 marked the beginning of tracking individual devices instead of date and lot codes. Direct part marking (DPM) technologies for plastic and metal parts were developed for use in harsh industrial environments. The basis for anti-counterfeiting programs was developed to ensure product and component authenticity.
- Traceability 4.0 is the complete implementation, including comprehensive part history and individual part geometric dimensioning and tolerancing (GD&T). GD&T is vital in precision manufacturing like aerospace and automotive manufacturing and enables the installation of parts based on their exact GD&T values, ensuring high precision assemblies and supporting high-quality systems.

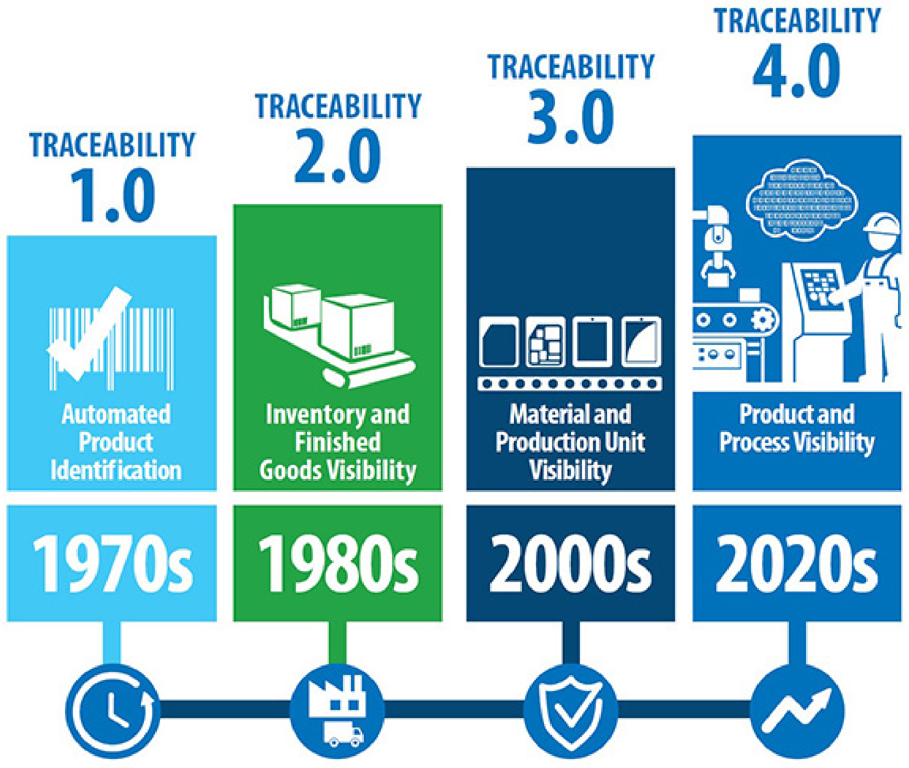


Figure 1: Traceability 4.0 is an integral part of industry 4.0 but does not entirely replace previous generations of traceability. (Image source: Omron)

Bar code types and standards

Barcode types have evolved and expanded as traceability becomes more sophisticated. Today, there are multiple common barcode types, including linear, 2D (like Data Matrix, QR Code, and Aztec Code), and stacked linear (like PDF 417, Micro PDF, and Composite Codes) (Figure 2). They can be printed on labels attached or directly marked on the part. There's a wide range of standards. Examples include:

- AIAG B4 – Automotive Industry Action Group Parts Identification and Tracking
- AS9132 – Society of Aerospace Engineers, Data Matrix Quality Requirements for Part Marking
- EIA 706 – Electronics Industry Association, Component Marking
- ISO/IEC 16022 – International Symbology Specification
- ISO/IEC 15418 – Symbol Data Format Semantics
- ISO/IEC 15434 – Symbol Data Format Syntax
- ISO/IEC 15415 – 2D Print Quality Standard
- ISO/IEC 15416:2016 – 1D Print Quality Standard
- ISO/IEC TR 29158:2011 – Direct Part Mark (DPM) Quality Guideline
- SPEC 2000 – Air Transport Association, Electronics Commerce, Including Permanent Part ID
- IUID – U.S. Department of Defense, Permanent & Unique Item Identification
- UDI – FDA medical device identification

What about damaged barcodes?

Barcode marking is subject to variations; it's not perfect. Even well-printed barcodes can become damaged or skewed as a part moves through the manufacturing process. Lack of contrast between the part surface and the barcode and highly variable lighting in industrial environments contribute to the challenges that must be addressed when developing a traceability 4.0 infrastructure.

To address the challenges of accurately reading a wide range of barcodes under widely varying conditions, Omron offers its X-Mode algorithms that can read virtually any code on any surface, including shiny, textured, or curved. Using X-Mode can minimize so-called "no reads," minimizing delays and downtime.

X-Mode uses advanced digital image processing and pixel analysis to make distorted, damaged, poorly printed, or skewed symbols readable. For DPM codes like inkjet printed codes on cardboard and other packaging or dot peen marks on reflective metal surfaces, X-Mode enhances contrast and sharpness of the image to reliably read and interpret codes in even dynamic environments (Figure 3). X-Mode also supports omnidirectional decoding, increasing the range of usable mount angles and simplifying the integration of barcode readers.

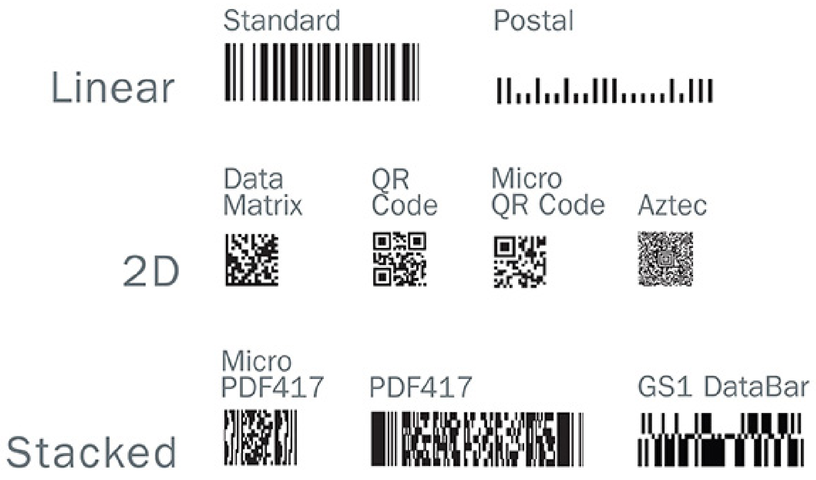


Figure 2: Traceability 4.0 can support using various barcode styles. (Image source: Omron)

System integration

Real traceability 4.0 systems require multiple cameras integrated into an easy-to-use and easy-to-manage system. With these smart industrial imagers, process engineers can combine up to eight readers using an Ethernet switch to support 360-degree code reading and product inspection when a combined output of multiple codes is needed or when the code location is unpredictable.

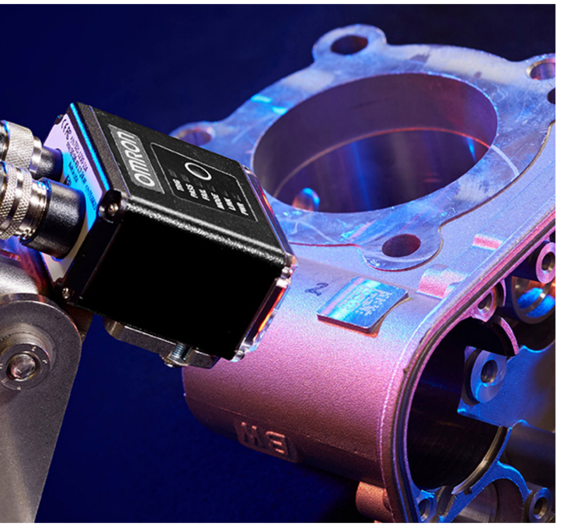


Figure 3: Advanced digital imaging and pixel processing enable X-Mode software to read codes under challenging conditions. (Image source: Omron)

High-mix manufacturing that's typical of industry 4.0 operations can be supported by automatically selecting from multiple settings to maximize read rates and line speed using the best options based on barcode size, type, lighting and contrast, and location. The system uses ISO standard grading methods for inline monitoring of barcode quality and can trigger an alert if the quality falls below a user-set threshold.

These smart industrial imagers have an integrated web-based barcode reader interface. Each imager is securely accessible on any web-enabled device using its IP address. The open protocol structure simplifies device integration and eliminates problems with device incompatibility. Web integration includes three user access levels. At the highest level of security and access, users can edit settings that can be saved to the reader's internal memory or on external devices and transferred to other devices to speed the integration of new equipment and changing environment needs.

To reduce overall equipment costs, the inspection status of multiple readers can be monitored with a single device. While standard imagers require one display per device, these smart industrial imagers require only one display for multiple devices. That simplifies installation and monitoring of multiple imagers. In addition, web monitoring software is integrated into each smart industrial imager, enabling remote monitoring of multiple imagers using a tablet or personal computer.

Autofocusing choices

Autofocusing capability can significantly impact the performance of barcode reading systems in challenging environments. These smart industrial imagers offer a choice of mechanical and liquid lens autofocusing. Mechanical autofocus is implemented with a small motor. Its mechanical nature means it's subject to wear and metal fatigue and can require replacement on an annual basis. Liquid lens autofocusing changes the lens's focal length by applying a voltage to change the shape of an internal structure consisting of oil and water (Figure 4). Since there's no mechanical wear, liquid autofocus mechanisms can have operating lifetimes of multiple years. With liquid lens technology, the imager can automatically adjust the focus from 50 millimeters (mm) to 1,200 mm and read even high-density data matrix symbols on complex printed circuit boards. Imagers with either type of autofocus can read any code in seconds after being connected, with no setup required.

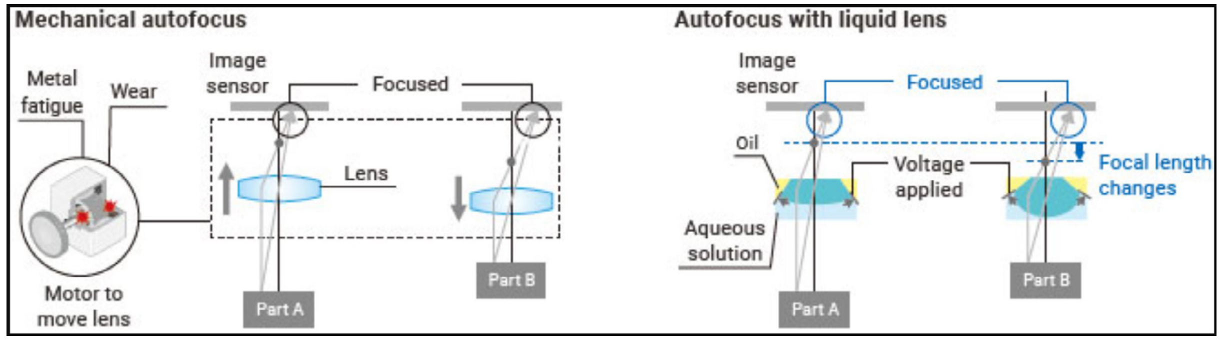


Figure 4: Mechanical autofocus (left) requires more maintenance resulting in more downtime than liquid lens autofocusing (right). (Image source: Omron)

Smart industrial imagers

Omron MicroHAWK code readers provide fast and reliable operation and have a rugged, ultra-compact housing with double front window construction to help avoid moisture condensing inside the window. Depending on the model, they are available with IP65/67 protection to assure performance in challenging environments. Image resolutions are available from 0.3 to 5 megapixels. These imagers are available with optics, lighting, and filtering options to optimize the device for the specific operating environment and imaging needs. MicroHAWK features include:

- Ethernet/IP, Ethernet TCP/IP, and PROFINET connectivity
- 5 to 30 V_{DC} power input with option for power over Ethernet (PoE)
- 800 MHz processor speed to support fast image processing
- Non-linear calibration (NLC) function improves measurement and locator performance by a factor of 20 by canceling out lens distortion. It outputs measurements in mm and pixels.

The same device can support up to 60 frames per second for barcode reading and visual inspection.

Examples of MicroHAWK code readers include:

- V430-F000W12M-SRP, 1.2 MP imager with wide field of view 5.2 mm focal length lens, plus standard autofocus, standard red outer light, and plus-mode imaging (Figure 5)
- V430-F000L12M-SRX, 1.2 MP imager with narrow 16 mm lens and autofocus to 1,160 mm, standard red outer light, and X-Mode imaging

Efficient setup

Omron's AutoVISION software can speed the setup and installation of MicroHAWK imagers. With AutoVISION, users can connect to and configure a device, as well as program and monitor a job. AutoVISION jobs are scalable across multiple MicroHAWK imagers, software packages, industrial systems, and tablets and PCs. It can integrate up to 8 imagers into a single system. With AutoVISION, these smart imagers can be used for machine vision inspection functions like part presence, part location, part counting, color detection, and making dimensional measurements. Implementing AutoVISION is a three-step process:

- Capture an image with one click
- Specify inspection area and assign outputs with drag and drop tool
- Start the inspection process with the run button
- AutoVISION development software is suitable for a range of applications:
- Inspection and general machine vision
- Packaging lines
- Assembly processes
- Defect detection

Figure 5: This 1.2 MP imager has a wide 5.2 mm focal length lens and plus-mode imaging software. (Image source: DigiKey)

Summary

Traceability 4.0 supports Industry 4.0 manufacturing processes and supply chains but does not completely replace earlier versions of traceability in other applications. High-performance imagers are a critical element in the deployment of traceability 4.0. Smart industrial imagers are available with autofocusing capabilities and the ability to operate reliably under challenging environmental and lighting conditions. NLC software improves measurement accuracies by up to 20X, and available auto-configuration software speeds the deployment of high-performance traceability systems.

How SCARA, six-axis, and cartesian pick-and-place robotics optimize and streamline electronics manufacturing processes

By Lisa Eitel
Contributed By DigiKey's
North American Editors

Introduction

By some estimates, the use of robotics in electronics manufacturing now rivals that of the automotive industry. No wonder: Fabricated chips, components, and fully assembled electronics are high value, so they justify investments in automation technologies. Complicating matters is that volumes and therefore throughput must be high, and the products are also inherently delicate … with semiconductor wafers for some applications now only 140 µm thick. These application parameters demand precision handling with motion systems and robotics having exceptional reach, speed, force, and dexterity as well as cleanroom compliance.

Hastening the adoption of robotics in semiconductor manufacture are burgeoning classes of six-axis robots, selective compliance assembly robot arms (SCARAs), cartesian machinery, and collaborative robots featuring reconfigurable or modular hardware as well as unifying software to greatly simplify implementation.

These robots and their supplemental equipment must be designed, rated, and installed for cleanroom settings or else risk contaminating delicate wafers with impurities. Requirements are defined by ISO 14644-1:2015, which classifies cleanroom air cleanliness by particle concentration. So, there's especially heavy reliance on:

- Exacting integration, wrapping, delivery, and installation methods to prevent particulate from hitchhiking into the cleanroom
- pecialty coatings that won't flake or otherwise degrade
- Stainless steel enclosures and other elements wherever feasible
- Specialty inert and non-gassing lubricants for mechanical components
- Vacuum elements within the robotic body to direct any particulate to a segregated exhaust area
- Specialty sealing of all robot joints

The latter is especially important for high-speed robots that satisfy the need for high semiconductor throughput but shed more particles than slower-moving equipment.

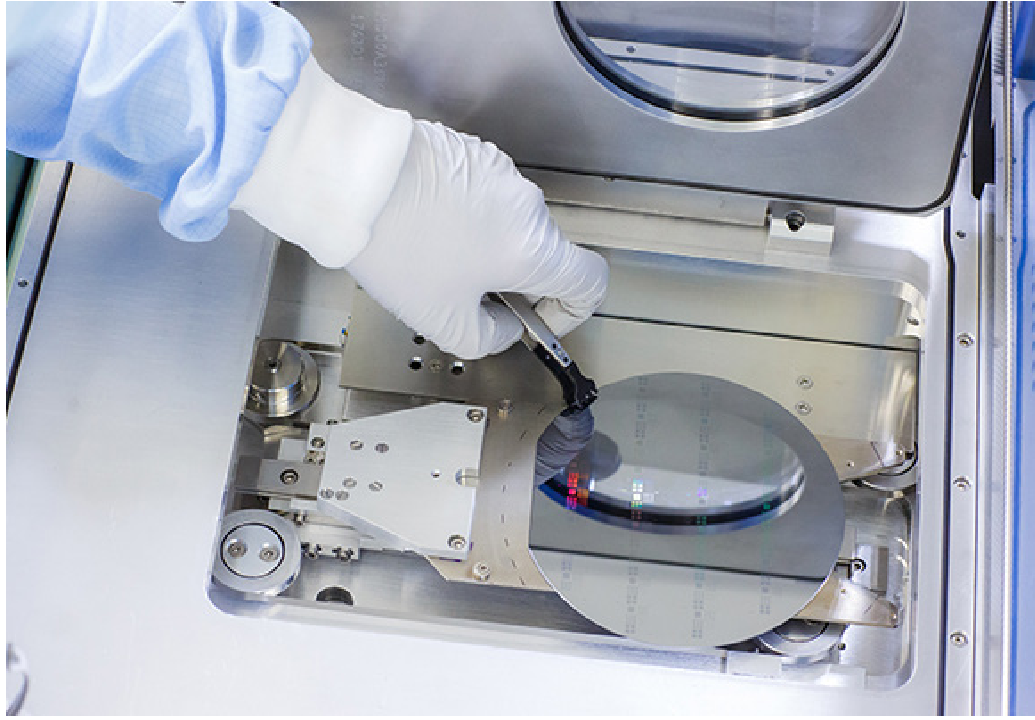


Figure 1: Here, a delicate wafer is placed into an atomic layer deposition machine located within a cleanroom. (Image source: Dreamstime)

Summary of where each robotic type excels

Though application overlaps abound, six-axis robots are most strongly associated with electronic device assembly. SCARAs maneuver electronic components through 360° to execute pick-and-place wafer handling and processing tasks faster and often more precisely than other options. Cartesian robots in contrast are often associated with semiconductor testing and packaging tasks as well as the processing of large-format electronic products. On the other hand, collaborative robots (cobots) are used to bridge highly protected cleanroom zones to sections of cleanrooms that can be traversed by plant personnel. Cobots are also seeing increased use in soldering and other tasks once the near-exclusive domain of manual operations.

Figure 2: The use of robotics and other automation for the production of micro-electronics extends beyond the cleanroom. (Image source: Dreamstime)

Though beyond the scope of this article, the parallel-kinematics design known as delta robots is also seeing increased adoption — especially for electronic products assembly. Whether operating alone, ganged in pairs, or installed to complement SCARAs in a workcell, delta robots in semiconductor manufacture provide exceptionally quick and dynamic picking and packing capabilities. Read more about these applications in the digikey.com How Delta Robotics Optimize and Streamline Electronics Manufacturing Processes article on delta robots in the semiconductor industry. In fact, the kinematics of deltas impart accuracy and repeatability for suitability in the assembly of photovoltaic electronics.

Robotics rely on end effectors for productivity

Advanced cleanroom-rated robotic end-of-arm tooling (EoAT or *end effectors*) such as grippers are core to semiconductor production. Here, EOATs must have high dynamics and the ability to execute tracing, placing, and assembling with exacting precision. In some cases, EoAT force feedback or machine vision boosts parts-handling accuracy by imparting adaptive capabilities — so pick-and-place routines are quickly executed even if there's some variability in workpiece positions, for example. Such sensor and feedback advancements can sometimes render the complicated electronics-handling fixtures of legacy solutions unnecessary.

Consider how flexible workcells served by six-axis robots often execute two or more tasks such as general workpiece handling, conveyor and other machine tending, machining, assembly, and packaging. Similarly, the application of encapsulation, vibration damping, shielding, adhesion, and sealing materials is often executed within one six-axis robotic workcell. Here, robotic end effectors complemented by automated tool changers impart multitasking capabilities so every workcell is maximally useful; EoAT changeovers are typically fast to support the semiconductor industry's high throughput requirements. For example, a robot might employ one EoAT to pick and place items into a fixture. Then (after a quick EoAT changeover) it might apply adhesive and press together mating housing halves of an end product. A third EoAT might load finished items onto an outbound conveyor or into a case.

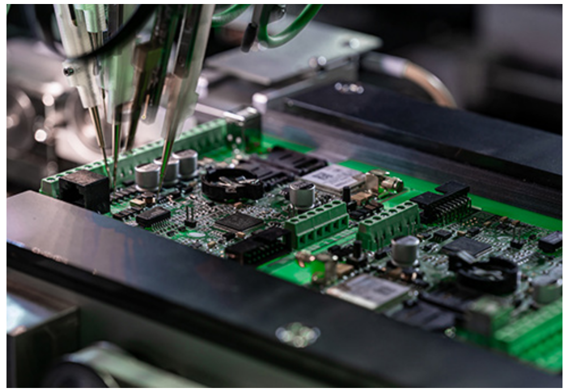


Figure 3: Shown here is the automated soldering of chip components onto a PCB. (Image source: Dreamstime)

Figure 4: Small-component EGK grippers are lubricated with H1 grease and sport cleanroom certification. (Image source: SCHUNK Intec Inc.)

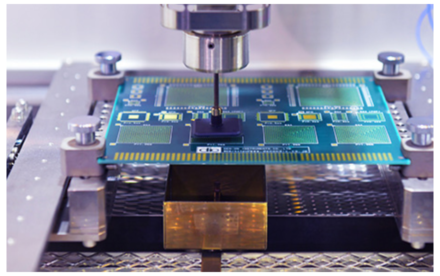


Figure 5: Electronics contract manufacturing makes copious use of robotics for board testing. (Image source: Dreamstime)

SCARA robotics in electronics manufacturing

For decades, SCARAs have remained the gold standard for semiconductor wafer processing, handling, and assembly tasks including:

- Deposition and etching
- Thermal processing
- Reticle processing
- Circuit board assembly
- Testing and metrology

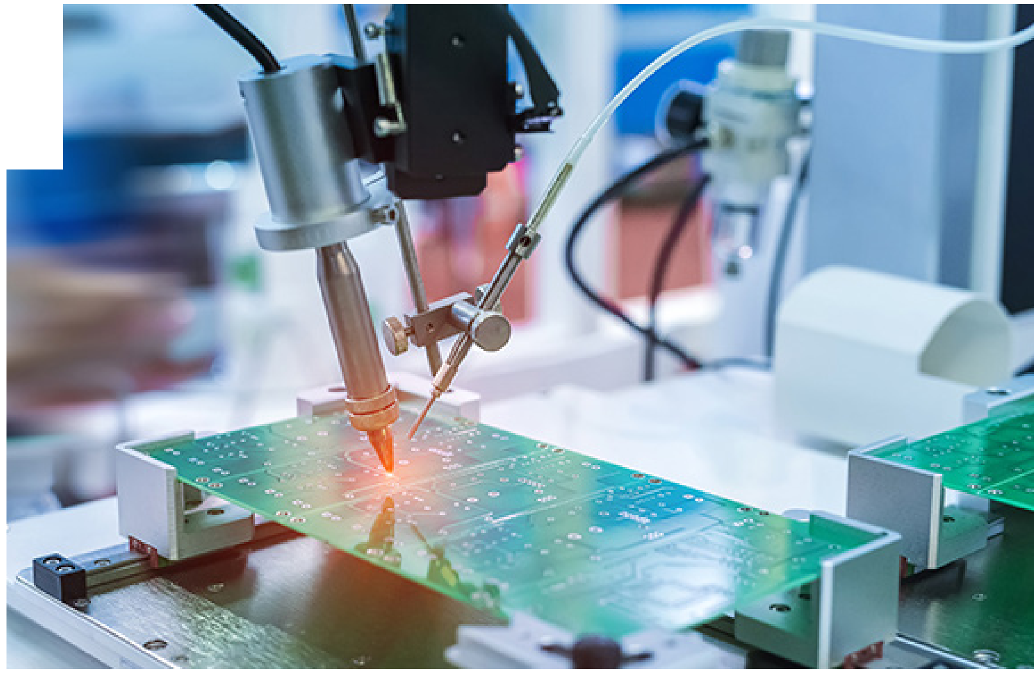


Figure 6: Robotic end effectors can take the form of soldering iron tips to automate the assembly of subcomponents onto PCBs. (Image source: Dreamstime)

After all, SCARAs offer high speeds throughout their cylindrically shaped 360° reach — often capable of executing pick-and-place tasks far faster (and sometimes more precisely) than comparable six-axis and cartesian solutions. More specifically, some industry-typical SCARAs deliver repeatability to within ±20 μm on linear degrees of freedom (DOFs) and ±0.01° on the angular axis — as well as direct-drive options for smooth transport of thin and relatively brittle wafers. While payloads can be limited to 10 kg or lighter for many SCARAs, that's rarely an issue in semiconductor applications — though is certainly a consideration for the related field of solar-panel production.

SCARAs pair well with conveyors used in semiconductor processing stations as well as wafer carousels (also called rotary tables) designed to facilitate the addition of components or features to multiple circuit boards at a time.

Six-axis robotics in electronics manufacturing

Industrial-grade articulated robots feature multiple rotary joints to manipulate objects through two to 10 DOFs. The most common articulated-robot format is the six-axis robot. Semiconductor processes necessitating cleanroom settings benefit from six-axis robots that are suitably rated as well as compact to

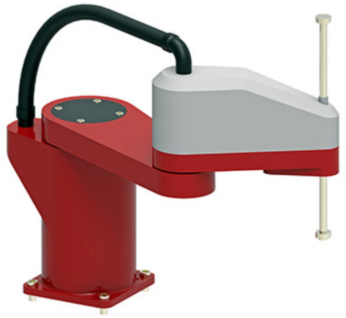


Figure 7: SCARA robots execute pick-and-place wafer handling and processing tasks quickly and precisely. (Image source: Dreamstime)

consume less power and less of the premium cleanroom real estate. Variations abound to deliver the speed and accuracy needed for high-throughput handling and assembly. The servomotors to drive the robots' joints are similar to those found in other robot types, but six-axis robots are far more likely to pair these motors with strain-wave or cycloidal gearing.

Like SCARAs, six-axis robots also pair well with conveyors used in semiconductor processing stations.

The main strength of six-axis robots is their dexterity and large working volume for a given linkage-set size — whether installed on a floor base or inverted from a ceiling. To illustrate, a six-axis arm that's 600 mm tall when folded might reach 650 mm in all directions with the ability to quickly and concurrently sweep each joint 120° to 360° for nimble movement of electronic payloads of a few grams to several kilograms or more. Absolute encoders at each joint and Ethernet-based networking provide motion feedback and connectivity for PLC, PC, or dedicated robot controls and adaptive software to both command and improve processes over time. These controls include the integration of sophisticated end effectors — for example, grippers to safely handle small and fragile electronics components.

Six-axis robots excel at machine tending and the packaging of electronics products. Beyond the assembly of the boards themselves, the robots can fasten electronics into end products' metal or plastic housings and make the necessary electrical connections as well. Some six-axis robots can also execute finished electronics products kitting, case packing, and palletizing.

Cartesian robotics in electronics manufacturing

Cartesian robots — those based on modular stacks of linear axes — help operations satisfy the semiconductor industry's need to maintain cleanroom conditions for many processes. Nearly unlimited scalability means travel can cover anything from a few centimeters to more than 30 meters. Cartesian robot repeatability can stay within ±10 μm on linear DOFs with comparable angular repeatability from end effectors as well as rotary-to-linear and direct-drive options for especially smooth transport of wafers. Speeds to six meters per second are common.

Cartesian machinery typically executes dedicated automation tasks, as its kinematics tend to be less flexible and reconfigurable than that of other robotic types. However, accuracy is exceptional … especially when controls use feedback and generate commands for millisecond responsiveness. Such motion is key for automated board manufacturing; trimming and surface polishing; and extensive assembly routines.

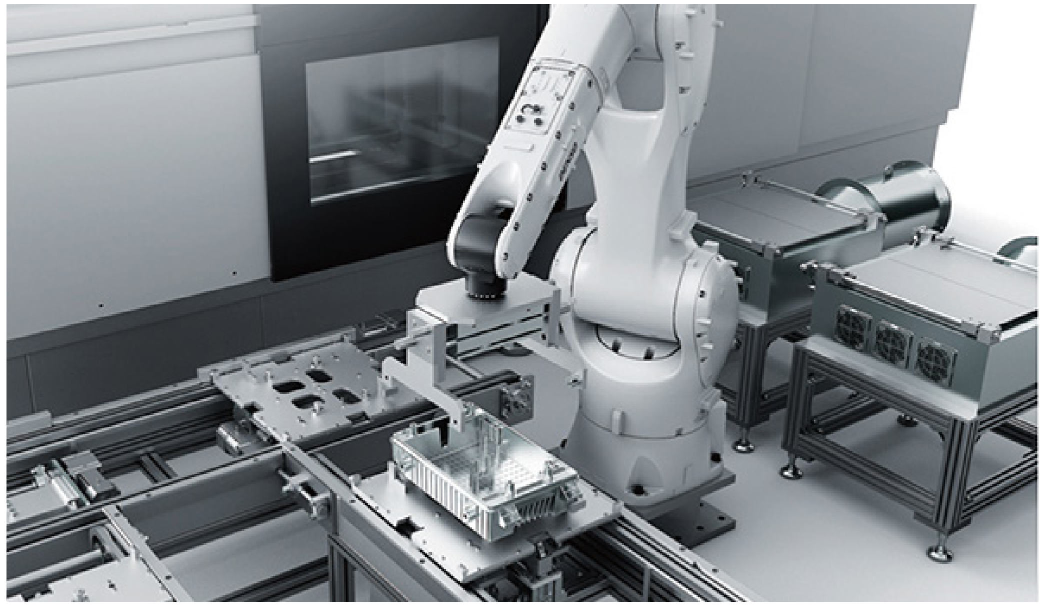


Figure 8: This six-axis articulated robot is available in ISO 5 (class 100) cleanroom models. (Image source: Denso Robotics)

Cartesian robotics stations are also the top choice for large-format electronics such as flat-panel displays and solar panels.

Specific cartesian robotics application example

Consider cartesian robotics in maximally automated printed circuit board (PCB) manufacture and assembly. Cartesian robotics either maneuver end effectors over the boards or take the form of cartesian tables that move PCBs through the reach of fixed processing equipment. For example, such tables might move boards through lithography equipment to print copper circuits onto a nonconductive silicon substrate. Then after the initial PCB print process, copper not part of the design circuitry is chemically etched off. Nonconductive solder masks isolate adjacent traces and components.

In many PCB assembly operations, cartesian robotics accept electronic subcomponents on reel tapes or box tapes fed into the workcell. (The robotics' pick-and-place head is designed to grasp and place a variety of these subcomponents.) The robotics verify each subcomponent value and polarity and then set and solder the subcomponents via through-hole or surface-mount technology (SMT) attachments. Through-hole subcomponent leads insert into board holes, get trimmed and clinched, and then get soldered to the board backside for top mechanical strength (though necessitating more complicated assembly routines). In contrast, SMT subcomponents accept maximally automated high-volume set and solder routines … so they now dominate many board designs. That said, through-hole mounting is still most common for attaching large capacitors, transformers, and connectors to boards.

For SMT components, solder paste is pre-applied to the PCB before component assembly. Reflow soldering then uses hot air to melt the solder paste to form the SMT component connections. Wave soldering is more common for through-hole components; this involves passing the board across a standing wave formed on the surface of a pan of molten solder. Such machines are costly and best suited to very high-volume manufacturing.

Typical motors and drives for cartesian robotics

Cartesian robotics use many of the same types of servomotors, precision gearing, and electromechanical drives as other robotics solutions. One caveat is that the stepper motors in some cartesian designs that transport semiconductors during production shouldn't be confused with so-called step-and-repeat cameras — sometimes simply called steppers. The latter are essential to photolithography processes during chipmaking.

Figure 9: Cartesian robots execute fully automated semiconductor manufacturing tasks. Note the linear motors that provide high-precision direct driving on the critical axis. (Image source: Dreamstime)

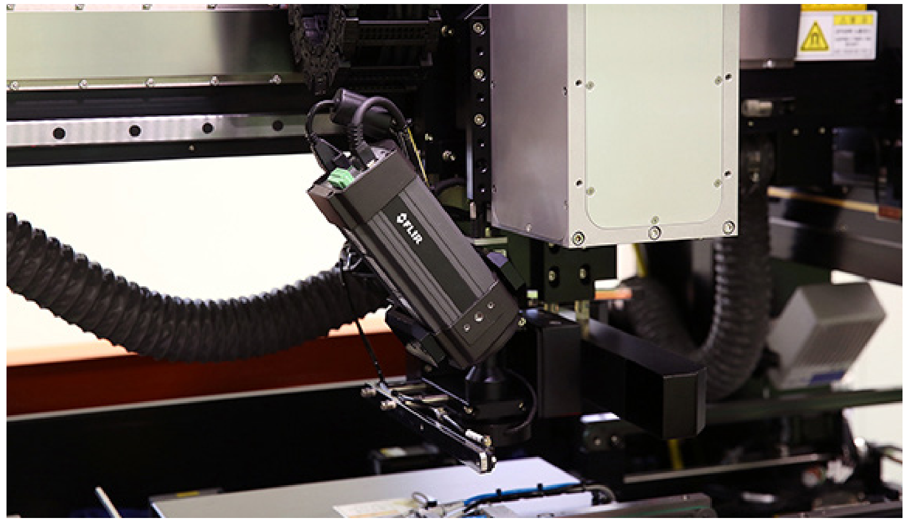
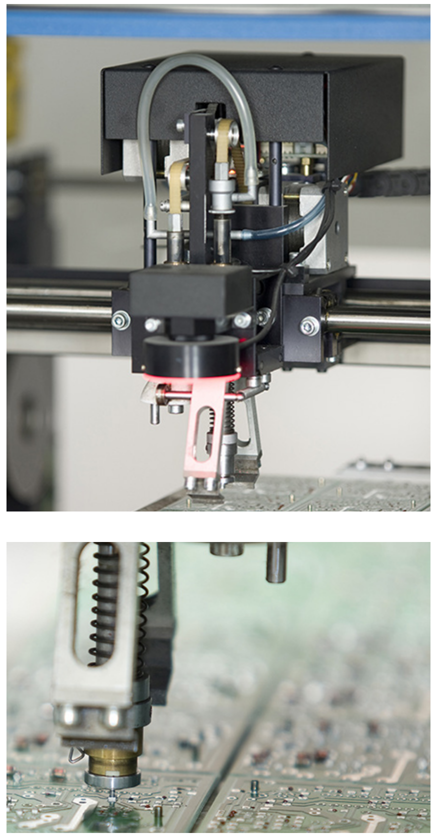


Figure 10: Cartesian robotics can be fitted with imaging equipment (such as this thermal-imaging camera) for thermography of PCBs produced with laser-assisted bonding techniques. (Image source: Teledyne FLIR)



Figures 11a and 11b: Shown here are tool heads for affixing surface-mount technology (SMT) subcomponents to a board. (Image source: Dreamstime)

Just as SCARA and especially six-axis robotics have made increased use of direct-drive torque motors, cartesian robotics have (in designs to serve the semiconductor industry) made increased use of linear motors in recent years. A variety of industry-standard and proprietary motor coils, miniature end positioners, piezo-based adjustment modules, vacuum and cleanroom-rated subsystems, linear bearings, controls, and other innovations complement these direct drives to help cartesian systems output ultra-fine ultra-fast motions.

Collaborative robotics in electronics manufacturing

Collaborative robots (cobots) have proliferated in the semiconductor industry over the last decade. For more reasons about this, see the DigiKey.com blog, Easy Automation with Omron TM Collaborative Robots. In semiconductor manufacture, cobots from Omron and other makers can prevent the extremely costly contamination of wafers by bridging protect wafer workzones and those serviced by cleanroom personnel. Semiconductor-production grade cobot installations also prevent particulate and lubricant outgassing contamination while complementing manual operations for placing and soldering.

Cobots in the semiconductor and electronics industry must have above-average speed capabilities complemented by advanced dynamics and controls to prevent the jarring of thin and therefore delicate wafers. Otherwise, tiny cracks can form. Of course, breakage is far less likely with properly specified cobots than human labor.

Automated soldering with cobots is also appropriate where components are being assembled onto especially thin boards and the effects of silicon thermal expansion are a concern. Where cobots are destined to perform this and other assembly tasks, it's often logical to integrate thermography or other board-inspection equipment onto the EoAT. That speeds error-proofing tasks for higher yields and quality assurance … often at relatively low cost.

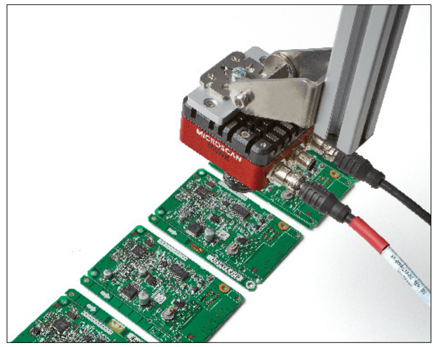


Figure 12: Machine-vision feedback often informs cartesian system responses. Massive onboard processing power, advanced algorithms, and an FPGA let HAWK smart cameras (including the model shown here) achieve real-time trigger response for code reading, verification, inspection, and guidance for 4,000 to 14,000 parts per minute. In fact, this camera is an intermediate solution between complex PC-based cameras and basic industrial smart cameras. (Image source: Omron Automation and Safety)

Figure 14: KUKA collaborative robots (cobots) are core to the design of this Infineon ISO3 wafer-processing cleanroom. (Image source: KUKA)

Figure 15: KUKA cobots in this Infineon cleanroom were expertly integrated, networked, and programmed by mechatronic and automation specialists. (Image source: KUKA)

Conclusion

Industrial robotics can provide affordable and flexible automation of semiconductor and electronics production. Technical challenges are the need to satisfy cleanroom ratings, high throughput, and careful handling of exceedingly expensive workpieces. Even so, today's robotic hardware as well as robotic simulation software and programming have simplified the sizing and selection of cleanroom robotic solutions.

Complicating matters is how increasingly fine details on increasingly miniaturized electronics necessitate roboticized assembly processes that follow suit. Robotics have risen to this challenge with motors, mechanical linkages, controls, and networks that allow evermore advanced capabilities. Complementary technologies such as machine vision and real-time industrial networking have also imparted new capabilities in robotics for manipulating, processing, and assembling high-volume semiconductor production.

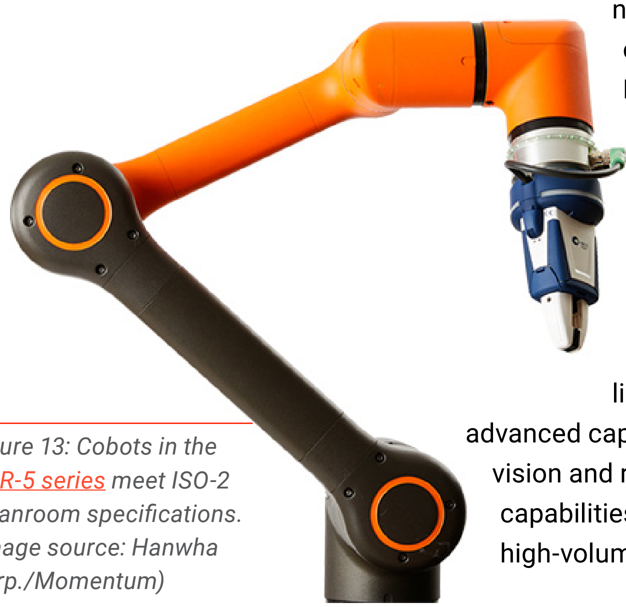


Figure 13: Cobots in the HCR-5 series meet ISO-2 cleanroom specifications. (Image source: Hanwha Corp./Momentum)

How delta robotics optimize and streamline electronics manufacturing processes

By Jody Muelaner

Delta robots are relatively small robots employed in handling food items for packaging, pharmaceuticals for casing, and electronics for assembly. The robots' precision and high speed make them ideally suited to these applications. Their parallel kinematics enables this fast and accurate motion while giving them a spiderlike appearance that's quite different from that of articulated-arm robots.

Delta robots are usually (though not always) ceiling mounted to tend moving assembly and packaging lines from above. They have a much smaller working volume than an articulated arm, and very limited ability to access confined spaces. That said, their stiffness and repeatability are assets in high-precision processing of delicate workpieces — including semiconductors being assembled.

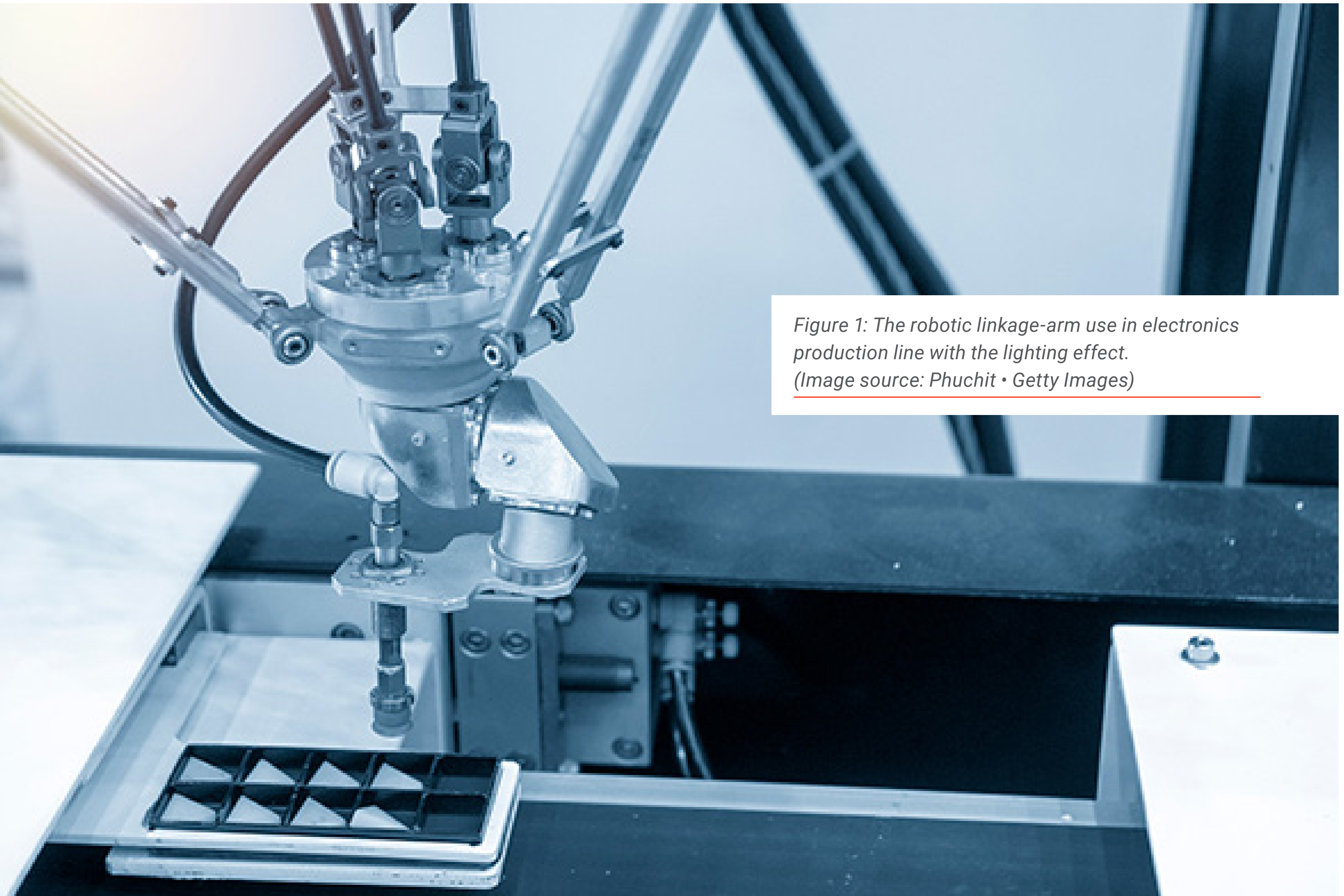


Figure 1: The robotic linkage-arm use in electronics production line with the lighting effect. (Image source: Phuchit • Getty Images)

Delta robots in context

Industrial robots are broadly categorized as mobile robots, serial manipulators, or parallel manipulators.

Mobile robots include autonomous ground vehicles (AGVs) and automated forklifts that are primarily programmed to move materials around factories and warehouses.

Robots classified as serial manipulators have a chain of kinematic linkages connecting a fixed base to an end effector; these robotics include articulated arms and cartesian robots. Because the rigidity and positional accuracy of each linkage is dependent on the previous linkage, serial manipulators are decreasingly accurate and rigid the further the linkage is from the base. Though there are exceptions, this morphology tends to limit the accuracy of six-axis robots to a few millimeters … and after rapidly moving to a new position and stopping, such robots' end effectors will oscillate for some time before settling.

Figure 2: A delta robot is a type of parallel manipulator with three parallelograms all connected to a single rigid body at the end effector end. The base of each parallelogram is actuated in a single degree of freedom relative to the robot's base. Delta robots are typically ceiling mounted to tend conveyors or workpieces from above. (Image source: Wikimedia Commons)

One type of serial manipulator use in many of the same applications as delta robots is the selective compliance articulated robot arm or *SCARA* robot. They're mechanically quite simple with two revolute joints aligned so that their axes are parallel to each other and a third linear axis. The two revolute joints provide X-Y positioning in a single plane while the third linear axis provides motion in the Z direction. While they can lack the precision of delta robots, SCARAs are relatively low cost and can execute tasks quite rapidly — even in confined spaces.

In contrast with serial manipulators, robots classified as parallel manipulators (including delta robots) have multiple kinematic linkages connecting the end effector to the base. Such morphology makes for a much stronger, stiffer, and lighter structure than serial robot types. Their lightweight yet rigid structure lets delta robots quickly accelerate to deliver very short cycle times. Another type of parallel manipulator is the Stewart platform or hexapod; these deliver maximal stiffness, precision, and speed — often to correct for vibrations in real time in precision optics applications.

Typically each parallelogram on a delta robot is actuated by a rotary electric motor via linear actuation. (Low-cost delta robots from the Igus Drylin series use a less common linear-drive configuration.) The coupling of

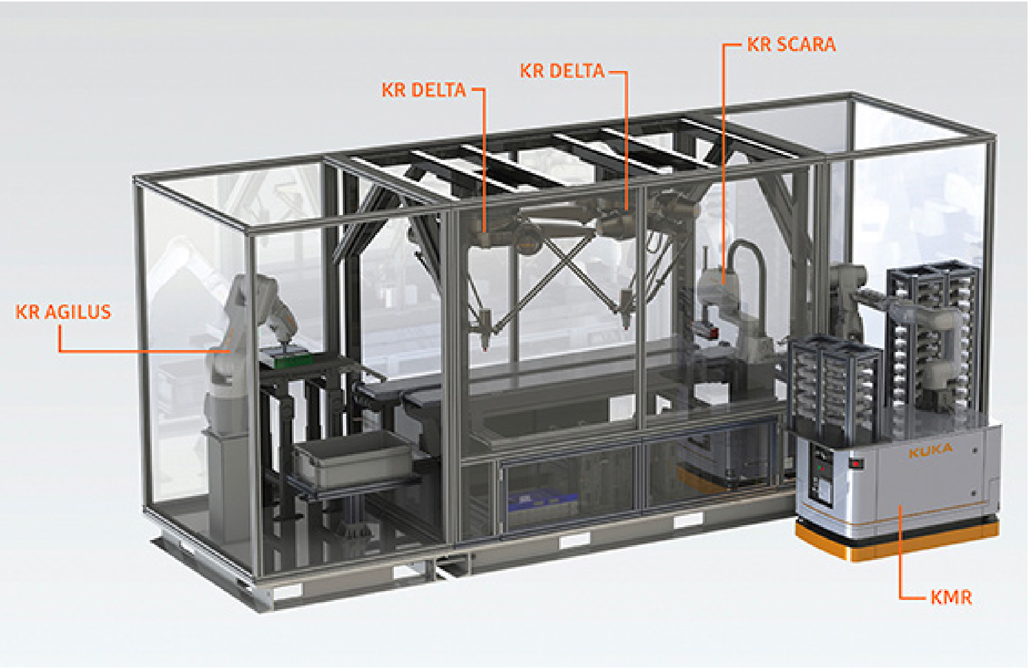


Figure 3: Shown here is a vision-laden work cell that employs delta robots, SCARA robots, and mobile robots. The delta robot is stainless steel and IP-67 rated. (Image source: KUKA)

Figure 4: This servomotor-driven delta robot moves to 200 cycles per minute in three degrees of freedom (DOFs) plus a rotational axis. A controller can command these robots' axes with 2-msec response time to synchronize with conveyors and other tasks. In fact, another delta-robot is the Quattro; it has four instead of three parallelograms connecting the base to the end effector to deliver high stiffness and positioning accuracy at high speeds. (Image source: Omron Automation)

parallelograms constrains the end effector to only translational motion. That imparts the same degrees of motion as a three-axis cartesian machine but with a much stiffer and lighter structure. An added advantage of this configuration is that the mass of the drive motors is located in the (typically ceiling-mounted) base, so all the robot's moving parts are passive lightweight structural elements. Some delta robots have additional rotary axes mounted in series at the end effector to provide four, five, or six-axis motion.

Overview of delta robot applications

Delta robots are widely used in pick-and-place applications for electronics assembly as well as food and pharmaceutical packaging. When a delta robot operates over one or more conveyors or mobile assembly platforms, items are conveyed or otherwise transported into the robot's working volume. Then a vision system identifies parts' exact locations and orientations to guide the robot on where and how to grasp or otherwise operate on the part.

So, the delta robot may pick up an item and then move it to its required location. Next, it might set the item down in the target place and orientation. For example, a delta robot may pick electronic components randomly orientated on a conveyor belt and assemble them onto a circuit board presented to the work cell via a second conveyor belt.

Multiple delta robots often work simultaneously along a line with two parallel continuously moving conveyor belts for on-the-fly pick-and-place. Centralized control systems coordinate the systems of such installations — with heavy reliance on machine vision to inform robot control routines. Each individual pick and place operation can take just a fraction of a second to complete.

With several delta robots operating at the same time, very rapid assembly and packaging is possible.

Delta uses specific to electronics manufacturing

Electronics manufacturing relies on delta robots for the transport and handling of printed circuit boards (PCBs) and components, PCB assembly, and device assembly.

PCBs are layered with nonconductive substrates and copper layers. Circuit layouts are typically printed on the board with lithography; then the rest of the copper layer is chemically etched away. Nonconductive solder masks are then applied to prevent solder bridging between closely positioned components and copper traces. PCB assembly involves placing and then soldering through-hole or surface mount technology (SMT) components. Older PCBs only used through-hole components, but this is now uncommon. Through-hole components have leads inserted through holes in the board and are soldered on the opposite side for greater mechanical strength, but this extra process makes them more difficult to assemble. No wonder SMT components now

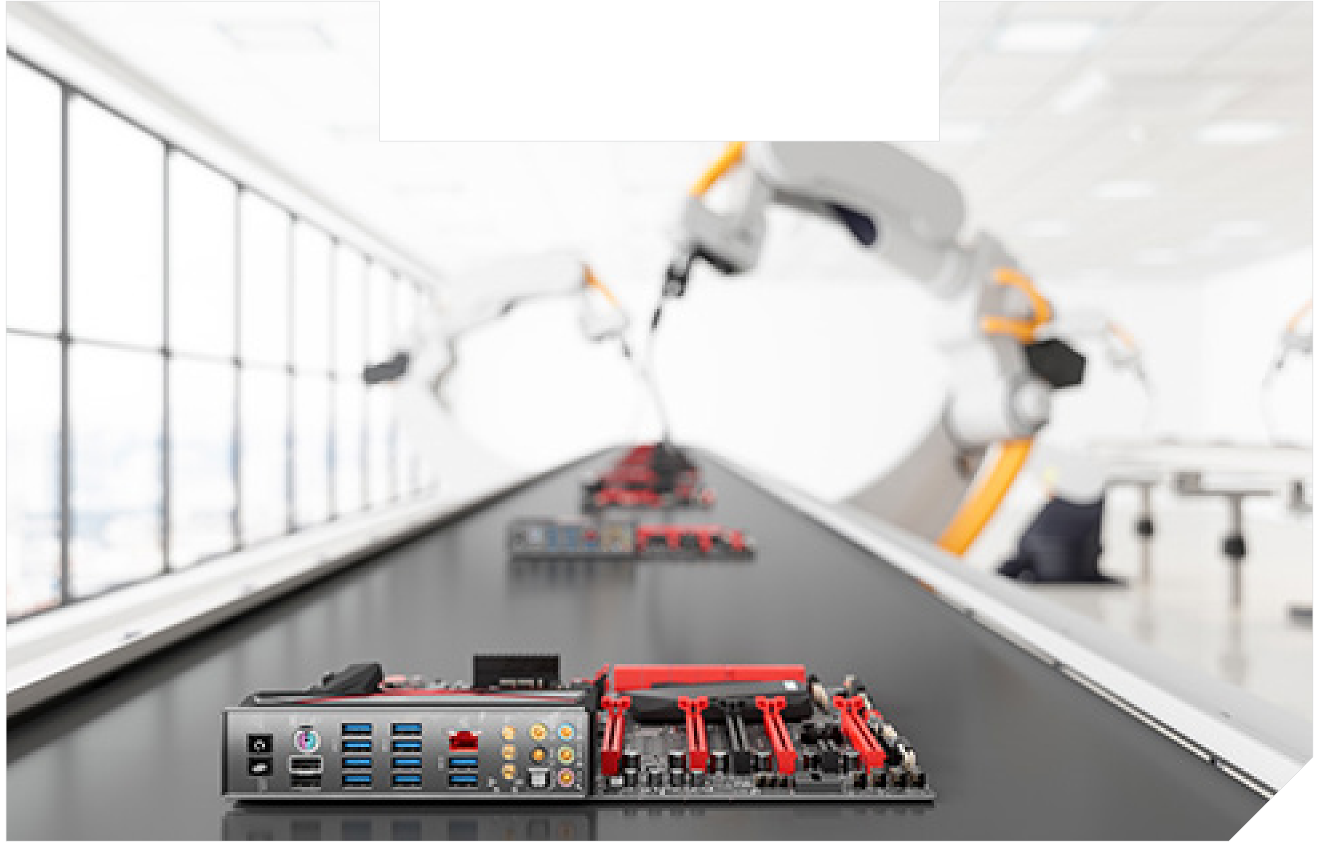


Figure 5: Electronics boards ride a conveyor through an assembly work cell. (Image source: Getty Images)

Figure 6: Some delta robots maneuver through five axes to orient objects of all types. The IRB 365 shown here can sort, feed, pick, reorient, and place 1-kg products at 120 picks per minute — satisfying the requirements of production facilities needing high throughput and efficiency. Commanded by a compact delta-robot controller called the OmniCore, the system offers performance motion control, digital connectivity, and more than a thousand programmed functions. (Image source: ABB)

dominate for smaller components; they're much better suited to highly automated volume manufacturing. That said, some through-hole mounting is often still required for larger components such as capacitors, transformers, and connectors.

For both kinds of PCB component attachment, machine vision complementing a delta robot can check the component variation and orientation before installation on the board. For high throughput, the robotic pick-and-place head may be designed to process several components at a time. A robotic end effector may also apply solder paste, and yet another may apply heat to electrically connect the installed components. Otherwise, components may be attached by a wave-soldering technique … though machines for this are expensive and best suited to very high-volume manufacturing. Even costlier is how components too large for insertion machines are often manually assembled onto semiconductor boards. Solder may also need to be manually applied in difficult-to-reach locations between components.

For the latter, delta robots can replace manual operations to place larger components and solder between components.

Delta robots can also be far less costly and far easier to configure than cartesian-type pick-and-place machines. After all, the latter are large and heavy — similar to CNC machine tools. Cartesian systems are difficult to move, and after being moved can require costly and time-consuming recalibration. In contrast, delta robots are small and light enough to relocate fairly frequently. After setup in the new location, they simply run a simple self-calibration routine and then resume operation.

Delta robot options abound. Codian Robotics specializes in only delta robots, in contrast with most industrial robot manufacturers that primarily produce articulated-arm robots. The supplier's delta robots offer payloads of 1.5 to 125 kg to execute the assembly of tiny electronic parts to many designs far larger. A Mitsubishi Electric partnership pairs Codian delta robots with Mitsubishi controllers.

ABB's delta robots are produced under the FlexPicker brand. The current model is the IRB 360, a delta robot with two auxiliary rotary axes in series at the end effector for five-axis motion. These robots are optimized for pick and place operations.

Fanuc produces delta robots in two ranges. The M-series includes small robots used for assembly of small parts (most commonly electronics) as well as larger robots. M-series robots are available in three, four, and five-axis configurations. The DR-3iB series robots are larger four-axis robots designed for picking and packing operations, with motion speeds of up to 5.5 m/sec and payloads up to 8 kg.

Conclusion

Delta robots provide affordable and flexible automation for electronics manufacturing. They often provide higher speed and more flexibility than other robotics and automated pick-and-place machines.

How to optimize intra logistics to streamline and speed industry 4.0 supply chains – part one of two

By Jeff Shepard
Contributed By DigiKey's
North American Editors

Figure 1: Intra logistics can integrate information about material, people, and machines to optimize Industry 4.0 operations. (Image source: Getty Images)

Intra logistics (internal logistics) uses autonomous mobile robots (AMRs) and automated guided vehicles (AGVs) to efficiently move materials around Industry 4.0 warehouses and production facilities. In this article, the issues related to how AMRs and AGVs are used on a system level for implementing intra logistics and quickly and safely moving materials as needed are discussed. Part 2 of this series focuses on use cases and how AMRs and AGVs employ sensors to identify and track items, how ML and AI support material identification, movement and delivery of materials throughout warehouse and production facilities.

Moving materials rapidly from the receiving dock to the shipping dock in a warehouse or from location to location in a manufacturing facility — called intra logistics (for internal logistics) — is a critical aspect of streamlining and speeding up supply chain operations in Industry 4.0. There's more to intra logistics than raw speed; it must be done efficiently, accurately, and with reduced waste for maximum benefits. Autonomous mobile robots (AMRs) and automated guided vehicles (AGVs) can be critical to improved intra logistics.

AMRs and AGVs look similar but operate differently. While traditional AGVs are preprogrammed to perform limited functions for the lowest costs, new models of AGVs are available with sensors like AMRs, blurring the distinction between the two. As a result of safety concerns, traditional AGVs operate in areas separate from people, but newer models include sensors for collision avoidance and can ensure higher levels of safety.

This article begins with a review of intra logistics and how it can be used to speed up supply chains. It then compares the operation and uses of AGVs and AMRs and briefly considers the differences between the two in terms of navigation and obstacle avoidance capabilities, flexibility, safety, deployment challenges, maintenance, and cost of ownership. At the same time, it looks at the blurring distinction between AMRs and AVGs and closes with a look at how the use of digital twins may enhance future intra logistics operations. The second article in this series will dive deeper into the wide range of sensor technologies AMRs and AGVs need. DigiKey offers a full range of automation products for intra logistics in both cases.

Intra logistics defined

Intra logistics is deployed using cyber-physical systems designed to optimize internal distribution and production processes. To be fully effective, an intra logistics system must also be integrated with the larger supply chain through the Internet and local operational processes.

In warehouses, the system includes knowing where all the material is in the facility, what is needed to fulfill outstanding orders, what may be missing to complete orders, and where incoming material is in the broader supply chain.

In factories, intra logistics includes knowing what material is needed for specific manufacturing processes and supporting maximum scheduling efficiency by coordinating information about what's currently in the facility and when additional materials will arrive, combined with machine and operator availability.

When fully integrated, information about material availability, people, their skills and locations, plus machinery and its availability, reduces costs by minimizing inventory, increasing flexibility for mass customization, and improving quality (Figure 1).

Intra logistics impacts process engineering, systems design, project management, material requirements planning, and numerous other functions.

The automated movement of material throughout the facility is key to maximizing the benefits of intra logistics.

Material handling options

AMRs and AGVs are designed to move material from place to place, enhancing the efficiency, accuracy, productivity, and safety of intra logistics operations. These systems can be differentiated based on their load-carrying configurations. There are several configurations of AMRs and AGVs suited for specific intra logistics functions:

- Carts are also called under load or under ride vehicles and move beneath the item to be moved, lift it vertically, and carry it to its destination. These vehicles can be designed to lift and transport 1 ton or more.
- Tow tractors or tugs connect with one or more automated or unautomated carts loaded with material and take them from place to place. Most are rated for about 1 ton, but models are available rated for 20-ton loads. In addition, models are available that can operate autonomously or be manually driven by an operator.
- Robotic forklifts are available in several configurations, including pallet movers, counterbalanced fork trucks, and narrow aisle vehicles. Depending on the design, they can handle several tons and lift the load over 10 meters high.
- Load carriers are automated mobile platforms that can pick up materials from the end of a conveyor line, from robotic loading stations and other automated systems. Their load capacities tend to be lower than the other types of AMRs and AGVs.

AGV vs. AMR, what's the difference?

AGVs and AMRs can have similar configurations, but they don't have the same capabilities. The basic differences include:

- AGVs navigate using external tracks made with magnetic strips, tapes/paint on the floor, or wires in the floor to move from place to place; they cannot go anywhere without those external tracks.
- AMRs use a combination of internal sensors, wirelessly connected external sensors, artificial intelligence (AI), and machine learning (ML) to plan the most efficient route and avoid obstacles dynamically.

AGVs were developed before the introduction of Industry 4.0 warehouses and factories and have recently evolved somewhat to accommodate Industry 4.0 applications, so the differences are not as clear-cut as they once were. Similarities and differences include:

Navigation and obstacle avoidance. Navigation is the biggest differentiator. AGVs can only travel on predefined paths, while AMRs can travel variable routes throughout a predefined area or environment. Since they move autonomously, AMRs have extensive obstacle avoidance capabilities, including identifying new obstacles like a pallet placed in a previously clear aisle and sensing and avoiding personnel in their paths. Early models of AGVs had limited obstacle avoidance capabilities, and the areas where they were used were designed to be devoid of people. Newer AGVs include a larger variety of sensors, making them safer for use around people. However, while AVGs can identify obstacles, they can't navigate around them like AMRs can. Instead, AVGs stop until the obstacle is removed. Some models can automatically resume their travel if an obstacle is moved out of the way.

Flexibility. AMRs can provide more flexibility and can be reprogrammed for deployment into new environments without physical modifications. When an AGV is introduced into a new environment, the guide tracks must be installed or modified to support the needed travel routes. AGVs are also limited to a single task involving the movement of material from one predetermined point to another and can be disrupted by changes in the environment, like the addition of new equipment that requires changes to the travel route.

Safety. Because of their greater ability to avoid obstacles, AMRs are generally considered safer than AGVs. But it's not a simple question. Both can be equipped with emergency stop switches and sensors to identify obstacles and avoid hitting them — including people. AMRs are designed for use around people and include numerous safety measures. However, AGVs travel predetermined routes, and personnel know in advance where they will be and can more easily avoid contact with them. Both technologies support high levels of safety.

Deployment challenges. AGVs and AMRs require specific infrastructure to support their deployments. In general, AMR deployments can be completed faster and are less disruptive compared to AGVs. AGVs require the installation of guide tracks to support point-to-point navigation. AMRs depend on various sensors installed throughout the facility and help provide detailed situational awareness and navigation support. AMRs are suitable for use in more complex environments and applications. For example, an AMR can be programmed to work collaboratively with a human order picker in a "follow-me" application. Those differences generally make AMRs more suitable for use in Industry 4.0 environments where changes are expected and must be efficiently supported (Figure 2).

Maintenance. This is a mixed situation. AGVs are simpler machines with fewer sensors and can require less maintenance than AMRs. However, the support infrastructure needed by AGVs can be subject to damage requiring additional maintenance. In the

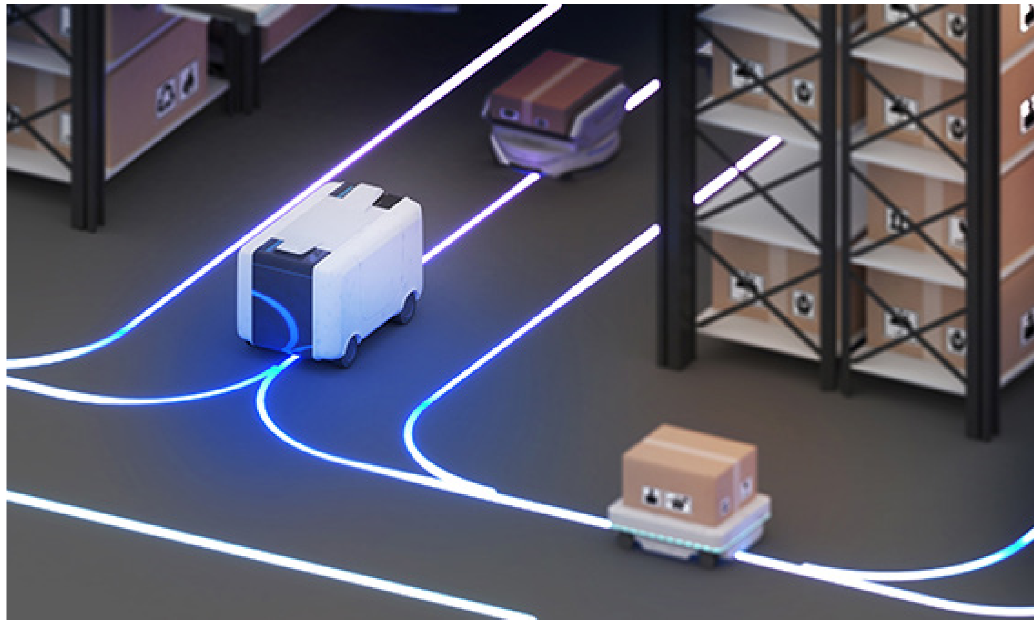


Figure 2: AGVs travel fixed routes making them less suitable for many Industry 4.0 applications. (Image source: Getty Images)

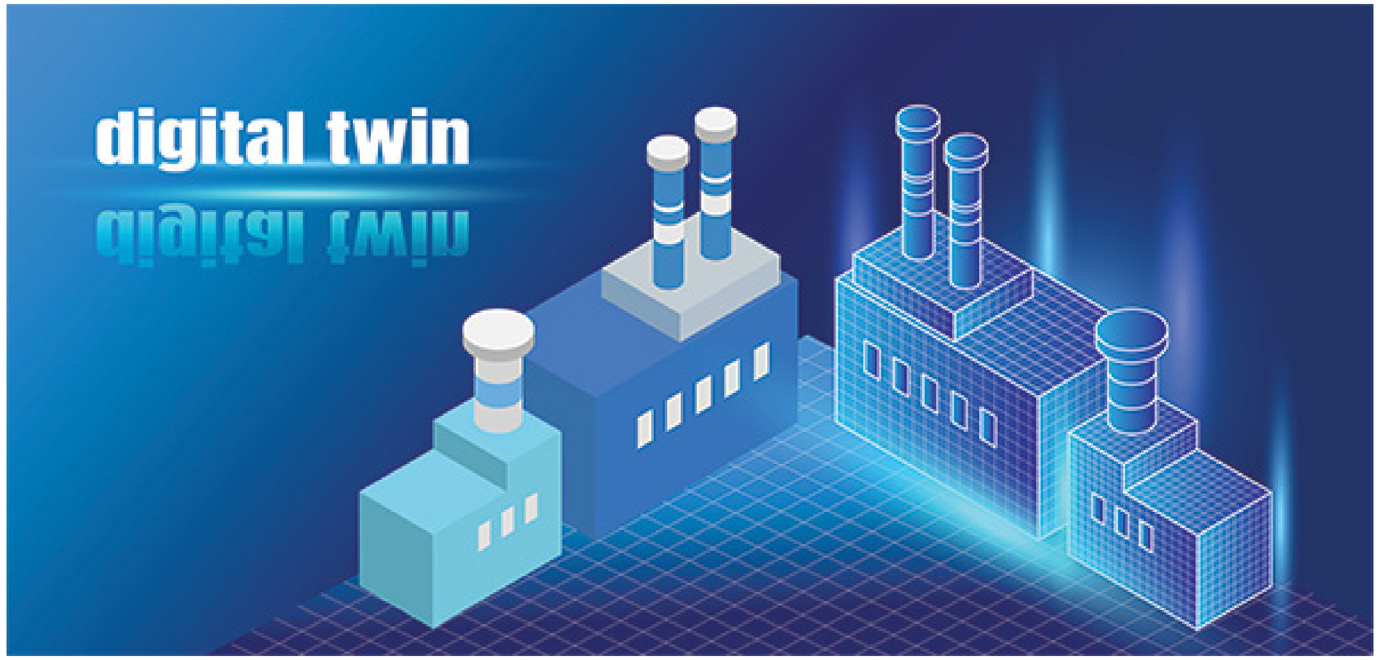


Figure 3: A digital twin (left) can provide real-time simulations to support higher productivity in Industry 4.0 factories. (Image source: Getty Images)

case of AMRs, the suite of sensors can require maintenance, and software updates are periodically needed. The requirement that AGVs travel in areas separated from people often means that they travel longer distances to reach a destination compared with AMRs. Longer travel distances increase wear on AGVs, potentially increasing maintenance costs. So, the question of which needs more maintenance — AGVs or AMRs — is application dependent.

Cost. AGVs are simpler machines and cost less than AMRs. Installation cost differences are more complex to define since AGVs require the installation of guide tracks, while AMRs need a suite of external sensors and wireless connectivity. Operating costs are higher for AGVs since their guide tracks require more maintenance than the infrastructure needed to support AMRs. Finally, AMRs can usually be deployed faster, reducing the costs associated with downtime in the facility and making them more suitable for use in Industry 4.0 applications.

Digital twins, digital threads, and intra logistics

Digital twins and digital threads can be valuable tools for intra logistics deployments. Digital twins are detailed virtual models of complex cyber-physical systems like those used for intra logistics. Digital twins are created using data from various sources, including sensors in the facility, computer-aided design (CAD) models of the facility, feedback from sensors on equipment operating in the facility, and so on. They are used to provide real-time simulations of the warehouse or factory operation to help optimize processes and pinpoint potential problems before they arise (Figure 3). A digital thread accompanies the digital twin and includes the complete history of all activities in the digital twin throughout its operational lifetime.

Digital twins and digital threads in intra logistics are in the early stages of development. Predictable operations are important to efficient intra logistics systems.

AMRs, AGVs, and robots operate with high levels of predictability and repeatability, and their use in Industry 4.0 can simplify the use of digital twin technology. Including them in the digital twin supports fleet optimization and management in the facility and enables preventative maintenance with minimal impact on operational efficiencies.

Digital twins are supported by large quantities of real-time data, including environmental conditions as well as functional and operational data about the state of machines and processes. The digital twin uses that data to simulate the actual systems and predict the condition of complete machines and individual components like the battery packs in AGVs and AMRs to optimize their performance.

The closer the digital twin simulates the real world, the greater the benefits. An infra logistics system typically integrates automated systems with people. Including human activities in the digital twin can further enhance the accuracy of the simulations and the benefits of intra logistics. The combination of intra logistics, digital twins, and digital threads with artificial intelligence and machine learning are expected to be important elements supporting the emergence of fully automated Industry 4.0 factories and warehouses.

Summary

Intra logistics is the movement of materials within an industrial facility like a warehouse or factory. AGVs and AMRs are important tools used to automate and speed the flow of materials. While both have advantages and disadvantages, AMRs are more suited for use in Industry 4.0 applications. When combined with digital twins, AI, and ML, intra logistics can support the development of fully automated factories and warehouses.

How to optimize intra logistics to streamline and speed industry 4.0 supply chains – part two of two

By Jeff Shepard
Contributed By DigiKey's
North American Editors

Part 1 of this series on intra logistics discussed issues related to how autonomous mobile robots (AMRs) and automated guided vehicles (AGVs) are used on a system level for implementing intra logistics and quickly and safely moving materials as needed. This article focuses on use cases and how AMRs and AGVs employ sensors to identify and track items, how machine learning (ML) and artificial intelligence (AI) support material identification, movement and delivery of materials throughout warehouse and production facilities.

Intra logistics (internal logistics) uses autonomous mobile robots (AMRs) and automated guided vehicles (AGVs) to efficiently move materials around Industry 4.0 warehouses and production facilities. To streamline and speed supply chains, intra logistics systems need to know the current location of material, the intended destination of material, and the safest, most efficient path for the material to reach the destination. This streamlined navigation requires a diversity of sensors.

In intra logistics solutions, AGVs and AMRs use sensors to increase their situational awareness. Arrays of sensors provide safety for nearby personnel, protection of other equipment, and efficient navigation and localization. Depending on application requirements, sensor technologies for AMRs can include contact sensors like limit switches built into bumpers, 2D and 3D light detection and ranging (LiDAR), ultrasonics, 2D and stereo cameras, radar, encoders, inertial measurement units (IMUs), and photocells. For AGVs, sensors can include magnetic, inductive, or optical line sensors, as well as limit switches built into bumpers, 2D LiDAR, and encoders.

The first article of this series covers issues related to how AMRs and AGVs are used at a system level for implementing intra logistics and efficiently moving materials as needed.

This article is focused on sensor fusion and how AMRs and AGVs employ combinations of sensors plus AI and ML for localization, navigation, and operational safety. It begins with a brief review of common sensors found in AGVs, examines robot pose and simultaneous location and mapping (SLAM) algorithms using sensor fusion, considers how SLAM estimates can be improved with scan-to-map matching and scan-to-scan matching techniques, and closes with a look at how sensor fusion contributes to safe operation for AMRs and AGVs. DigiKey supports designers with a wide range of sensors and switches for robotics and other industrial applications in all these cases.

A range of sensors and sensor fusion, AI, ML, and wireless connectivity are needed to support autonomous operation and safety in AMRs. While the performance demands for AGVs are lower, they still rely on multiple sensors to support safe and efficient operation. There are two overarching categories of sensors:

- Proprioceptive sensors measure values internal to the robot like wheel speed, loading, battery charge, and so on.
- Exteroceptive sensors provide information about the robot's environment like distance measurements, landmark locations, and obstacle identification such as people entering the robot's path.

Sensor fusion in AGVs and AMRs relies on combinations of proprioceptive and exteroceptive sensors. Examples of sensors in AMRs include (Figure 1):

- Laser scanner for object detection with 20+ meter (m) range
- IMU with a 6-axis gyroscope and accelerometer, and sometimes including a magnetometer
- Encoders with millimeter (mm) resolution on the wheels
- Contact sensor like a microswitch in the bumper to immediately stop motion if an unexpected object is contacted
- Two forward-looking 3D cameras with a 4 m range
- Downward-looking sensor to detect the edge of a platform (called cliff detection)
- Communications modules to provide connectivity and can optionally offer Bluetooth angle of arrival (AoA) and angle of departure (AoD) sensing for real-time location services (RTLS) or 5G Transmission Points/Reception Points (TRP) to plot a grid with centimeter-level accuracy
- 2D LiDAR to calculate the proximity of obstacles ahead of the vehicle
- Wide angle 3D depth vision system suitable for object identification and localization
- High-performance compute processor on board for sensor fusion, AI, and ML

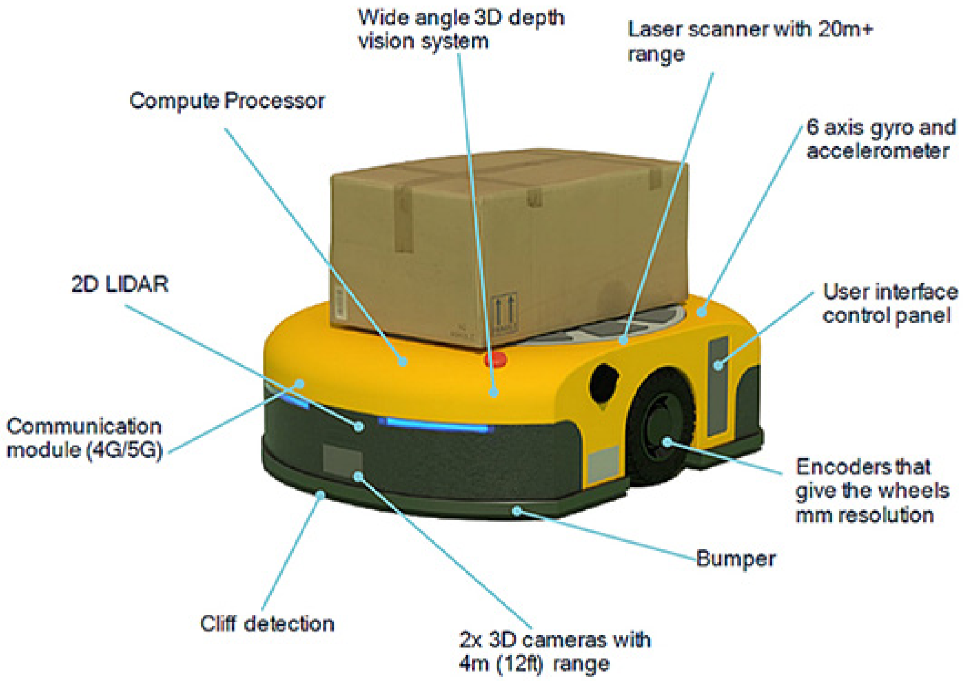


Figure 1: Exemplary AMR showing the diversity and positions of the embedded sensors. (Image Source: Qualcomm)

Robot pose and sensor fusion

AMR navigation is a complex process. One of the first steps is for the AMR to know where it is and what direction it's facing. That combination of data is called the robot's pose. The concept of pose can also be applied to the arms and end effectors of multi-axis stationary robots. Sensor fusion combines inputs from the IMU, encoders, and other sensors to determine the pose. The pose algorithm estimates the (x, y) position of the robot and the orientation angle θ, with respect to the coordinate axes. The function q = (x, y, θ) defines the robot's pose. For AMRs, pose information has a variety of uses, including:

- The pose of an intruder, like a person entering close to the robot, relative to an external reference frame or relative to the robot
- The estimated pose of the robot after moving at a given velocity for a predetermined time
- Calculating the velocity profile needed for the robot to move from its current pose to a second pose

Pose is a predefined function in several robot software development environments. For example, the robot_pose_ekf package is included in the Robot Operating System (ROS), an open-source development platform. Robot_pose_ekf can be used to estimate the 3D pose of a robot based on (partial) pose measurements from various sensors. It uses an extended Kalman filter with a 6D model (3D position and 3D orientation) to combine measurements from the encoder for wheel odometry, a camera for visual odometry, and the IMU. Since the various sensors operate with different rates and latencies, robot_pose_ekf does not require all sensor data to be continuously or simultaneously available. Each sensor is used to provide a pose estimate with a covariance. Robot_pose-ekf identifies the available sensor information at any point in time and adjusts accordingly.

Sensor fusion and SLAM

Many environments where AMRs operate include variable obstacles that can move from time to time. Although a basic map of the facility is useful, more is needed. When moving around an industrial facility, AMRs need more than pose information; they also employ SLAM to ensure efficient operation. SLAM adds real-time environment mapping to support navigation. Two basic approaches to SLAM are:

- Visual SLAM that pairs a camera with an IMU
- LiDAR SLAM that combines a laser sensor like 2D or 3D LiDAR with an IMU

LiDAR SLAM can be more accurate than visual SLAM, but it is generally more expensive to implement. Alternatively, 5G can be used to provide localization information to enhance visual SLAM estimates. The use of private 5G networks in warehouses and factories can augment embedded sensors for SLAM. Some AMRs implement indoor precise positioning using 5G transmission points/reception points (TRP) to plot a grid for centimeter-level accuracy on x-, y-, and z-axes.

Successful navigation relies on an AMR's ability to adapt to changing environmental

elements. Navigation combines visual SLAM and/or LiDAR SLAM, overlay technologies like 5G TRP, and ML to detect changes in the environment and provide constant location updates. Sensor fusion supports SLAM in several ways:

- Continuous updates of the spatial and semantic model of the environment based on inputs from various sensors using AI and ML
- Identification of obstacles, thus enabling path planning algorithms to make the needed adjustments and find the most efficient path through the environment
- Implementation of the path plan, requiring real-time control to alter the planned path, including the speed and direction of the AMR, as the environment changes

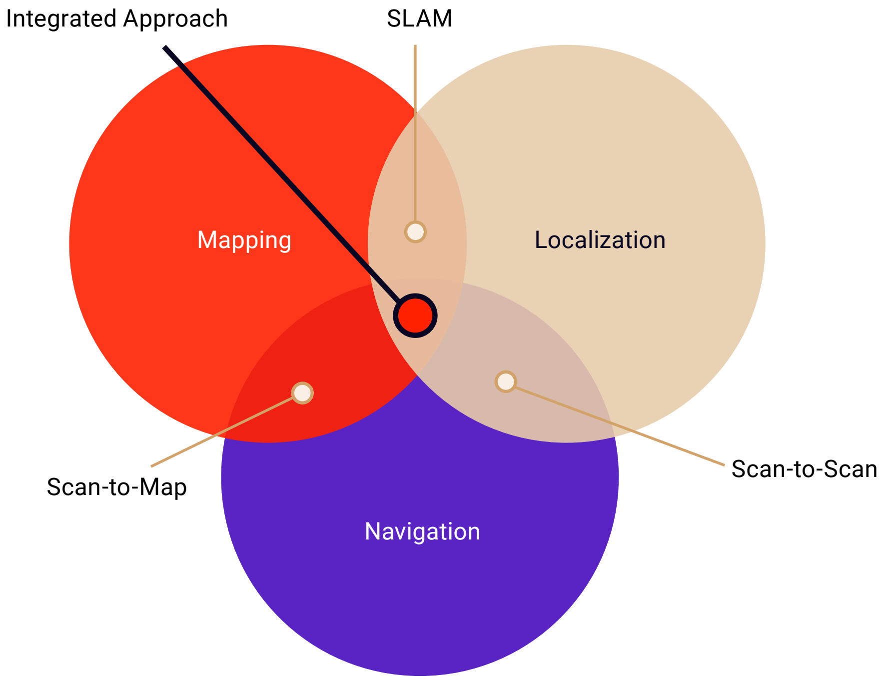


Figure 2: Scan-to-map and scan-to-scan matching algorithms can be used to complement and improve the performance of SLAM systems. (Image source: Aethon)

When SLAM is not enough

SLAM is a vital tool for efficient AMR navigation, but SLAM alone is insufficient. Like pose algorithms, SLAM is implemented with an extended Kalman filter that provides estimated values. SLAM estimated values extend the pose data, adding linear and rotational velocities and linear accelerations among others. SLAM estimation is a two-step process; the initial step involves compiling predictions using internal sensor analytics based on physical laws of motion. The remaining step in SLAM estimation calls for external sensor readings to refine initial estimates. This two-step process helps eliminate and correct small errors that may compile over time and create significant errors.

SLAM depends on the availability of sensor inputs. In some instances, relatively low-cost 2D LiDAR may not work, such as if there are no objects in the direct line of sight of the sensor. In those instances, 3D stereo cameras or 3D LiDAR can improve system performance. However, 3D stereo cameras or 3D LiDAR are more expensive and require more compute power for implementation.

Another alternative is to use a navigation system that integrates SLAM with scan-to-map matching and scan-to-scan matching techniques that can be implemented using only 2D LiDAR sensors (Figure 2):

- Scan-to-map matching uses LiDAR range data to estimate the AMR's position by matching the range measurements to a stored map. The efficacy of this method relies on the accuracy of the map. It does not experience drift over time, but in repetitive environments, it can result in errors that are difficult to identify, cause discontinuous changes in perceived position, and be challenging to eliminate.
- Scan-to-scan matching uses sequential LiDAR range data to estimate the position of an AMR between scans. This method provides updated location and pose information for the AMR independent of any existing map and can be useful during map creation. However, it's an incremental algorithm that can be subject to drift over time with no ability to identify the inaccuracies the drift introduces.

Safety needs sensor fusion

Safety is a key concern for AGVs and AMRs, and several standards must be considered. For example, American National Standards Institute / Industrial Truck Standards Development Foundation (ANSI/ITSDF) B56.5 – 2019, Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles, the ANSI / Robotic Industrial Association (RIA) R15.08-1-2020 – Standard for Industrial Mobile Robots – Safety Requirements, several International Standards Organization (ISO) standards, and others.

Safe operation of AGVs and AMRs requires sensor fusion that combines safety-certified 2D LiDAR sensors (sometimes called safety laser scanners) with encoders on the wheels. The 2D LiDAR simultaneously supports two detection distances, can have a 270° sensing angle, and coordinates with the vehicle speed reported by the encoders. When an object is detected in the farther detection zone (up to 20 m away, depending on the sensor), the vehicle can be slowed as needed. If the object enters the closer detection zone in the line of travel, the vehicle stops moving.

Safety laser scanners are often used in sets of 4, with one placed on each corner of the vehicle. They can operate as a single unit and communicate directly with the safety controller on the vehicle. Scanners are available and certified for use in Safety Category 3, Performance Level d (PLd), and Safety Integrity Level 2 (SIL2) applications and are housed in an IP65 enclosure suitable for most outdoor as well as indoor applications (Figure 3). The scanners include an input for incremental encoder information from the wheels to support sensor fusion.

Figure 3: 2D lidar sensors like this can be combined with encoders on the wheels in a sensor fusion system that provides safe operation of AMRs and AGVs. (Image source: Idec)

Conclusion

Intra logistics supports faster and more efficient supply chains in Industry 4.0 warehouses and factories. AMRs and AGVs are important tools for intra logistics to move material from place to place in a timely and safe manner. Sensor fusion is necessary to support AMR and AGV functions including determining pose, calculating SLAM data, improving navigational performance using scan-to-map matching and scan-to-scan matching, and ensuring safety for personnel and objects throughout the facility.