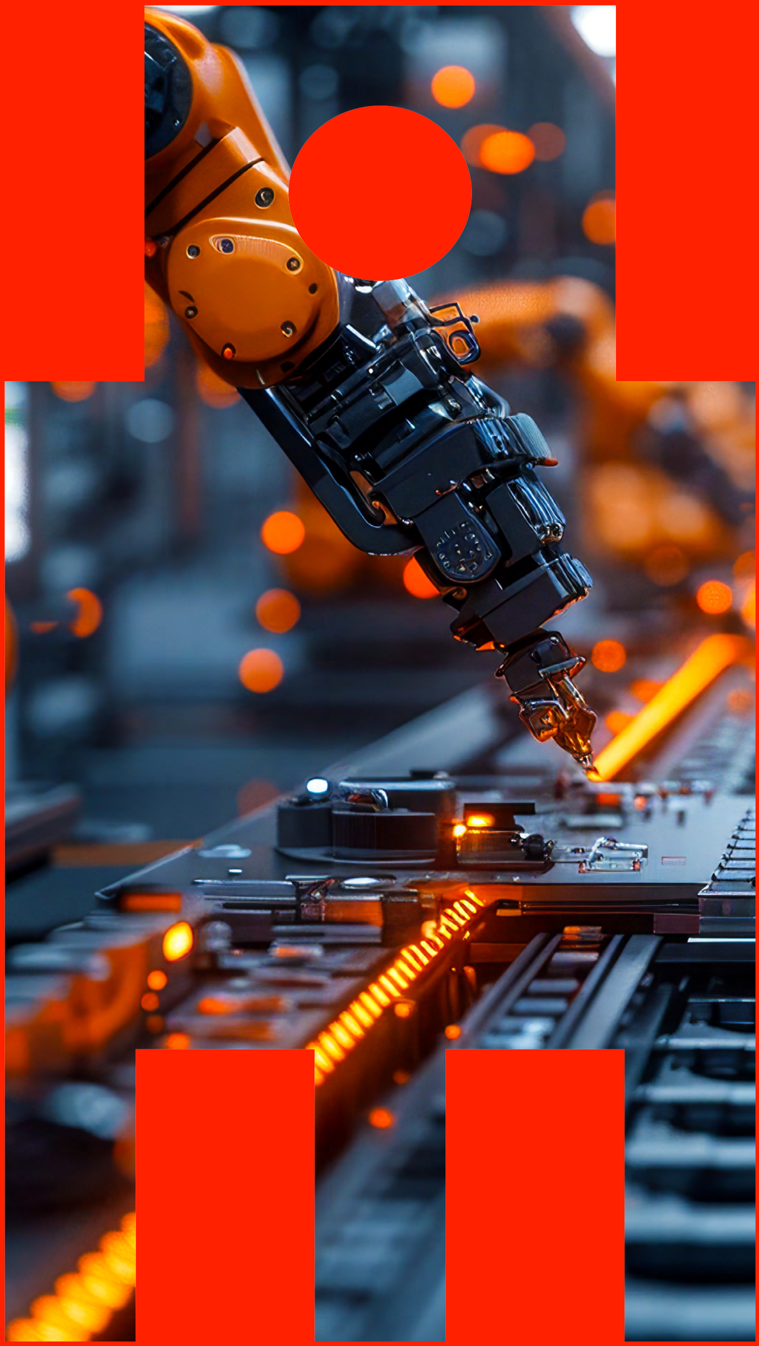
We get technical



Industrial robots and their human counterparts

How sensor fusion enables AMRs to maneuver around factory floors efficiently

How delta robotics optimize and streamline electronics manufacturing processes

Use compact industrial robots to make any shop more productive

DigiKey




contents

Editor's note

Today's manufacturing landscape is filled with obstacles and difficult choices. While facing the biggest workforce shortage in our lifetime, manufacturers also have to compete against low-cost labor markets all while trying to meet an ever-rising customer demand. One way to combat this is through automation. The benefits of adopting automation into their business model allows them to locate in more business-friendly environments. Industrial Robotics have been in the industry for decades, but new on the scene are Cobots (Collaborative Robotics). These new cobots are able to work side by side with their human counterparts. They provide humans with the ability to focus on more mentally challenging tasks while the cobot handles the more tedious/menial tasks. This new partnership of man and machine means greater accuracy, more efficiency, less waste and higher throughput. In this magazine, we will discuss the various types of industrial robots, fundamentals of robots, AMRs, and much more.

Industrial robots and their human counterparts

By Eric Halvorson
Marketing Technology Manager, Automation & Control

The conversation around robots and their use in manufacturing has long been controversial. Many fear that the introduction of robots into the workplace will displace human jobs. In some respects, yes, robots will replace some jobs, but it's not that simple. Yes, robots will replace some lower-level jobs. These jobs are the more menial and tedious jobs. These are jobs such as quality control on a factory line. Some illness, and complacency. Robots and machines do not. But the question is what happens to those employees after their jobs are made obsolete? This is where the employee benefits. Now, those same employees who were being underutilized in the past can move into better quality jobs, including jobs that require problem solving or jobs that require more job fulfillment. These are higher quality jobs. Many of these jobs

People have off-days and are subject to fatigue, illness, and complacency. Robots and machines do not.

of us can recall the opening scene of "Laverne and Shirley" in Shotz Brewery. While their antics are funny and over the top, in today's manufacturing world, the demands for quality are quite high. The need to ensure those bottles are properly filled and meet customer expectations is more important than ever. With the use of robotics and machine vision, we can now inspect every bottle as it passes at break-neck speed. From ensuring the liquid is filled to the proper level and color accuracy to checking labeling applications and cap being seated correctly, all aspects of the product's quality are checked and made to meet specific tolerances. People have off-days and are subject to fatigue, are in concert with robotics. These are called collaborative robots or cobots for short.

As I said earlier, there is quite a bit of fear about the implementation of cobots in the workplace. Yes, some jobs will be made obsolete. But what many will experience is a shift in their job roles. There will be a need for robot designers, programmers, and maintenance workers. Others will need to be upskilled; basically, they will need to get an upgrade in their skillset. This means better pay, better benefits, and greater job satisfaction. There are also things that humans are inherently good at, where their robot counterparts are not, such as problem-solving skills, critical thinking, and creativity.

Cobots have come a long way over the past decade. With safety in mind, these robots work right alongside their human counterparts. These cobots are capable of handling the heavy lifting for humans, allowing them to focus on the more mental workload. For example, at Amazon, cobots are used to move product to pickers rather than the picker going to the shelf, pulling the product, and returning to their station. This saves the worker time, steps, and possibly a lot of heavy lifting. The cobot saves the worker's energy and reduces the wear and tear on their bodies daily.

But how do we ensure human safety around cobots? Great question. Today's safety standards for cobots are exceptionally stringent, as they should be. There are numerous safety features on cobots as defined by ISO/TS 15066, which provides guidelines for the design and implementation of collaborative workspaces.

This enables shop managers and manufacturers to safely incorporate cobots into overlapping workspaces between humans and their mechanical counterparts.

Some examples:

- Maximum Allowable Speed. This is set at the point of the EOAT (End-of-arm-tooling).

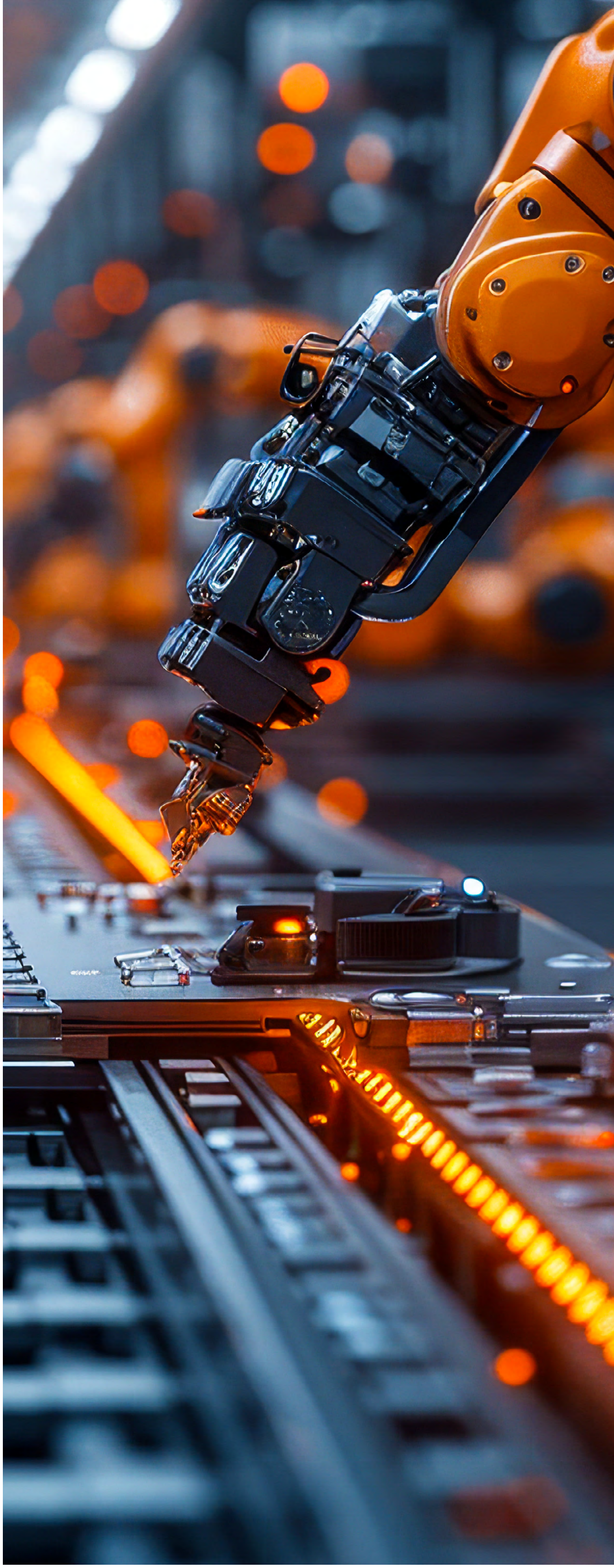
Cobots have come a long way over the past decade. With safety in mind, these robots work right alongside their human counterparts

These speeds are inline with human equivalent speeds.

- Speed and Separation Monitoring. Defines the minimum safety distance between the worker and the robot system to prevent contact between the robot and the human. This can be achieved utilizing safety scanners, light curtains, and operator presence mats.
- Power, Force, and Torque Limits. Cobots are designed to measure torque at every joint in case of excessive torques or forces, and monitors for sudden impacts, including soft obstructions.
- Redundant Checking Systems Diagnostics. If the robot detects an anomaly or error at any point, the robot will disable motor power instantly.
- Safety Rated Stop Modes. Cobots are required to act based on the level of risk. That could be a full emergency stop if a safety mishap has occurred, or it may be a protective stop if a human has entered its operating area.
- Ergonomic Design. In six axis robots, there are a number of potential pinch points. By designing those joints ergonomically, the worker can avoid injury should their hand, fingers, or even loose clothing get trapped in a joint.

With the installation of any robot in a production setting, great care must be taken to ensure a truly safe workspace. This is particularly true in an overlapping workspace that will be shared by humans and their robot counterparts. Consulting a professional installer or integrator will help you to do a full risk assessment and ensure you meet all applicable safety codes and regulations with regards to cobots.

Cobots have the ability to reduce worker fatigue, increase production rates, and increase quality, all while reducing waste. In truth, they can be a force multiplier for your production force. In today's world where we all face labor shortages, increased competition, and high consumer demand, cobots can be an equalizer while creating higher quality jobs.



What are the key factors used to classify industrial robots?

By Jeff Shepard
Contributed By DigiKey's North American Editors

Millions of industrial robots are active in Industry 4.0 factories around the world. They are used to increase production rates, improve quality, reduce costs, and support more flexible and sustainable operations. Because of the importance of industrial robots, the International Organization for Standardization (ISO) developed standard 8373:2021, Robotics Vocabulary, to define terms used in robotics and provide a common language for discussing the many types of robots and their applications.

The International Federation of Robots (IFR) used key terms defined in ISO 8373:2021 to identify six robot classifications based on their mechanical structure, including:

- Articulated
- Cartesian
- Cylindrical
- Parallel/Delta
- Polar
- SCARA

This article reviews ISO 8373:2021, looking at the four key terms that define a robot, focusing on the need for reprogrammability and the types and numbers of robot joints used by the IFR to develop robot classifications. It then digs into the details and nuances of each robot classification and presents exemplary robots from several makers. Along the way, it also looks at systems called robots that don't meet all the ISO requirements.

ISO 8373:2021 defines an industrial robot as an "automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or fixed to a mobile platform for use in automation applications in an industrial environment."

Reprogrammability is a crucial differentiator. Some industrial machines may have manipulators and move in multiple axes that can handle specific tasks like picking up bottles on a beverage filling line and placing them into a box. But it's not a robot if it's dedicated to that single purpose and not reprogrammable. "Reprogrammable" is defined in ISO 8373 as "designed so that the programmed motions or auxiliary functions may be changed without physical alterations."

Types and numbers of robot joints

ISO 8373 defines two types of robot joints:

- Prismatic joint, or sliding joint, is an assembly between two links that enables one to have a linear motion relative to the other.
- Rotary joint, or revolute joint, is an assembly connecting two links that enables one to rotate relative to the other about a fixed axis.

The IFR has used these and other ISO 8373 definitions to identify six industrial robot classifications based on their mechanical structure or topology. In addition, different robot topologies have different numbers of axes and, therefore, different numbers of joints.

The number of axes is a key characteristic of industrial robots. The number of axes and their types determines the robot's range of motion. Each axis represents an independent motion or degree of freedom. More degrees of freedom result in a robot being able to move through larger and more complex spaces. Some robot types have a fixed number of degrees of freedom, while others can have different numbers of degrees of freedom.

End effectors, also called end-of-arm tooling (EOAT) or "multipurpose manipulators" in ISO 8373, are another important element in most robots. There's a wide range of end effectors, including grippers, dedicated process tools like screwdrivers, paint sprayers, or welders, and sensors, including cameras. They can be pneumatic, electric, or hydraulic. Some end effectors can rotate, giving the robot another degree of freedom.

The following sections begin with the IFR definition for each robot topology and then examine their capabilities and applications.

Articulated robots have three or more rotary joints. This is a large class of robots. Articulated robots can have ten or more axes, with six being the most common. Six-axis robots can move in x, y, and z planes and pitch, yaw, and roll rotations, enabling them to mimic the movement of a human arm.

They are also available with a wide range of payload capacities from under 1 kg to over 200 kg. The reach capabilities of these robots also vary widely from under 1 meter to multiple meters. For example, the KR 10 R1100-2 from KUKA is a six-axis articulated robot with a maximum reach of 1,101 mm, a maximum payload of 10.9 kg, and a pose repeatability of ±0.02 mm (Figure 1). It also features high-speed movements, short cycle times, and an integrated energy supply system.

Articulated robots can be permanently mounted on the floor, wall, or ceiling. They can also be mounted on tracks on the floor or overhead, on top of an autonomous mobile robot or other movable platform, and moved between workstations.

They are used for various tasks, including material handling, welding, painting, and inspection. Articulated robots are the most common topology for implementing collaborative robots (cobots) designed to work with humans. While a conventional robot operates in a safety cage with safety barriers, a cobot is designed for close interaction with people. For example, the LXMRL12S0000 cobot from Schneider Electric has a maximum reach of 1,327 mm, a maximum payload of 12 kg, and a pose repeatability of ±0.03 mm. Cobots often feature collision protection, rounded edges, force limits, and lighter weight for enhanced safety.

Figure 1: Six-axis articulated robot with a pose repeatability of ±0.02 mm. (Image source: DigiKey)

Cartesian robot (sometimes called a rectangular robot, linear robot, or gantry robot) has a manipulator with three prismatic joints whose axes form a Cartesian coordinate system.

Modified Cartesian robots are available with two prismatic joints. Still, they don't meet the ISO 8373 requirement that they must be "programmable in three or more axes" and so aren't technically robots.

There's more than one way to configure three prismatic joints and, therefore, more than one way to configure a Cartesian robot. In a basic Cartesian topology, all three joints are at right angles, with one moving in the x-axis, attached to a second one moving in the y-axis, that's attached to a third one moving in the z-axis.

Although often used as a synonym for a Cartesian robot, the gantry topology is not identical. Like a basic Cartesian, gantry robots support linear motions in three-dimensional space. But gantry robots are configured with two base x-axis rails, a supported y-axis rail spanning the two x axes, and a cantilevered z-axis attached to the y-axis. For example, the DLE-RG-0012-AC-800-800-500, from Igus, is a gantry robot with an 800 mm x 800 mm x 500 mm work area that can carry up to 5 kg and move at up to 1.0 m/s with a repeatability of ±0.5 mm (Figure 2).

Cylindrical robot has a manipulator with at least one rotary joint and at least one prismatic joint, whose axes form a cylindrical coordinate system.

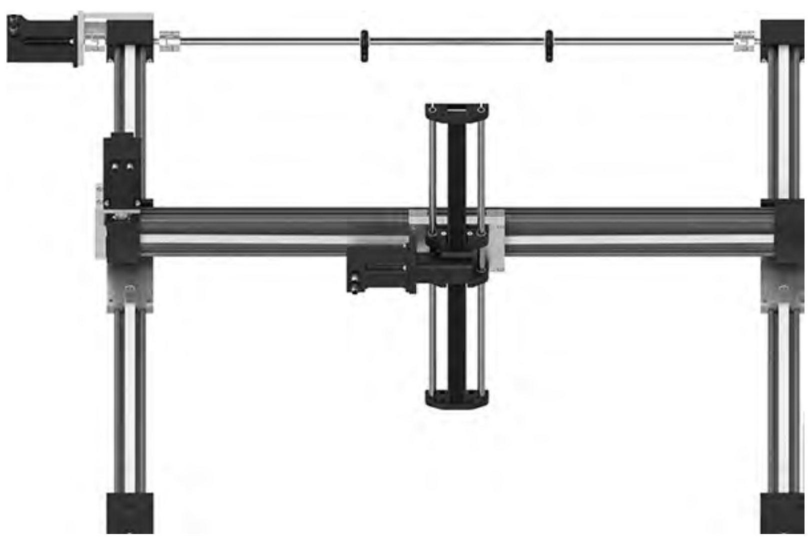


Figure 2: Gantry robot with an 800 mm x 800 mm x 500 mm workspace. (Image source: Igus)

Cylindrical robots are relatively simple and compact, and their limited range of motion makes them easy to program. They are less common than their more complex cousins. Still, they are especially suited for applications like grinding processes, palletizing, welding (especially spot welding), and material handling, for example, loading and unloading semiconductor wafers into cassettes in an integrated circuit fabrication operation (Figure 3).

Cylindrical robots typically move at speeds of 1 to 10 m/s, and they can be designed to carry heavy loads. Applications for cylindrical robots can be found in automotive, pharmaceutical, food and beverage, aerospace, electronics, and other industries.

Figure 3: This cylindrical robot has one rotary and prismatic joint. (Image source: Association for Advancing Automation)

Parallel/Delta robot is a manipulator whose arms have links that form a closed loop structure.

While other robots, like cylindrical or Cartesian topologies, are named after their motion, the delta robot is named for its upside-down triangular shape. Delta robots have 2 to 6 axes, with 2- and 3-axis designs being the most common. Like 2-axis Cartesian robots, 2-axis delta robots don't technically meet the requirements of ISO 8373 to be called robots.

Delta robots are designed for speed rather than strength. They are mounted above the work area and perform functions like pick-and-place, sorting, disassembly, and packaging. They are often found above a conveyor, moving parts down a production line. The gripper is connected to long, slender mechanical linkages. These linkages lead to three or four large motors at the robot's base. The other end of the linkages is attached to a tooling plate where the EOAT attaches.

The RBTX-IGUS-0047 from Igus is an example of a 3-axis delta robot. It has a working space diameter of 660 mm and can handle a maximum load of 5 kg. When handling a load of 0.5 kg, it can perform 30 picks per minute move with a maximum speed of 0.7 m/s and an acceleration of 2 m/s2. It has a repeatability of ±0.5 mm (Figure 4).

Figure 4: Three-axis delta robot and controller (left). (Image source: DigiKey)

Polar robot (spherical robot) is a manipulator with two rotary joints and one prismatic joint, whose axes form a polar coordinate system.

One of the rotary joints enables a polar robot to rotate around the vertical axis that extends up from the base. The second rotary joint is at right angles to the first rotary joint and enables the robot arm to swing up and down. Finally, the prismatic joint enables the robot arm to extend or retract from the vertical axis.

Polar robots, while simple in construction, have drawbacks that limit their use compared with other topologies like articulated, Cartesian, and SCARA robots:

- The spherical coordinate system makes programming more complex.
- They typically have a more limited payload capacity than other types of robots.
- They are slower than other robots.

The main benefits of polar robots include a large workspace and high precision. They are used for machine tool tending, assembly operations, material handling in automotive assembly lines, and gas and arc welding.

SCARA robot (from "selectively compliant arm for robotic assemblies") is a manipulator with two parallel rotary joints to provide compliance in a selected plane.

A basic SCARA robot has three degrees of freedom, the third from a rotating end effector. SCARA robots are also available with an additional rotary joint for a total of four degrees of freedom, enabling more complex motions.

SCARA robots are often used in pick-and-place or assembly applications where high speed and high accuracy are needed. For example, Dobot's M1-PRO is a 4-axis SCARA robot with a working radius of 400 mm, a maximum payload of 1.5 kg, and a repeatability of ±0.02 mm. It has sensor-free collision detection and drag-to-teach programming, making it suitable for use as a cobot as well as a standalone robot (Figure 5).

Figure 5: Four-axis SCARA robot with a repeatability of ±0.02 mm. (Image source: DigiKey)

Conclusion

All industrial robots meet the ISO 8373 requirement to be automatically controlled with a reprogrammable, multipurpose manipulator. However, not every design has a defined number of axes for a specified topology. Delta and Cartesian robots are available with fewer than the defined number of axes, while some SCARA robots have more axes than defined by IFR.

What are the important considerations when assessing cobot safety?

By Jeff Shepard
Contributed By DigiKey's North American Editors

Collaborative robots (cobots) are designed to work with humans and support flexible production in Industry 4.0 factories. Compared with traditional industrial robots, cobots are simpler, easier to set up, and don't require safely isolated workspaces. Because they are designed to work with people, cobots are built differently than other industrial robots, including features like collision detection systems, force feedback, elastic actuators, and low-inertia servo motors.

Since they are different by design, specific safety standards have been developed for cobots. The International Organization for Standardization Technical Specification (ISO/TS) 15066 specifies safety requirements for industrial cobots and their work environments. It supplements the requirements and guidance on cobot operation in ISO 10218-1 and ISO 10218-2.

This article briefly reviews the requirements of ISO/TS 15066 and how they fit in with ISO 10218-1 and 10218-2. It then considers the complexities of collaboration, including how the collaborative workspace is defined. It examines factors related to robot safety, like safety features built into cobots, and what external safety functions are needed, along with exemplary devices like proximity sensors, light curtains, and safety contact mats. It closes with a brief review of a few applications specific to cobot safety considerations.

There are several key safety standards for industrial robots and cobots. ISO/TS 15066 details safety requirements for industrial cobot systems and the work environment and was written to build on and supplement the limited requirements in previous standards like the ISO 10218 series. ISO 10218-1 focuses on general robots and robotic devices, while ISO 10218-2 focuses on robot systems and integration. American National Standards Institute/Robotics Industry Association (ANSI/RIA) R15.06 is a national adoption of ISO 10218-1 and ISO 10218-2.

Complexities of collaboration

Before getting into the details of cobot safety, it's helpful to define collaboration. Collaboration in robotics is complex and includes three factors:

- A cobot is a "robot designed for direct interaction with a human within a defined collaborative workspace," according to ANSI/RIA R15.06.
- A collaborative operation is a "state in which a purposely designed robot system and an operator work within a collaborative workspace," according to ISO/TS 15066.
- Finally, a collaborative workspace is the "workspace within the safeguarded space where the robot and a human can perform tasks simultaneously during production operation," according to ANSI/RIA R15.06.

It comes down to the definition of the collaborative workspace "within the safeguarded space." The safeguarded space includes a layer of safety protection in addition to the standard safety functions included in the cobot.

Common protective features integrated into cobots include contact detection systems based on torque measurements at every joint that monitor for unexpected impacts, obstructions, or excessive forces or torque. There should also be automatic braking systems and manual brake releases for moving the arm without power.

Unexpected contact with the person by the cobot is a particular concern. The standards dictate that contact should be prevented anywhere on a person's head. In addition, the standard splits the body into 29 specific areas and details limitations for two types of contact:

- Transient contact is a moving, dynamic event where the cobot hits a person. Limitations are based on location, inertia, and relative speed.
- Quasi-static contact occurs when a body part is trapped between the cobot and a surface. Limitations are based on pressure and force related to crushing and clamping effects.

The specification provides guidance, not absolute limits, based on application considerations. It also states that the guidance is informative and reflects current best practices since collaboration between people and robots is a new field, and research is ongoing.

Continuum of collaboration

There is no single collaborative application. People and cobots can interact and collaborate in a continuum of ways. Collaborative applications range from co-existence, where a robot stops under power when a person enters the collaborative workspace, to an interactive activity with the person touching the cobot while in operation (Figure 1).

A risk assessment is required to identify the safety needs of individual collaborative applications. It includes identifying, evaluating, and reducing the hazards and risks associated with the application. ISO 10218 includes a list of safety features that can be appropriate in various circumstances but no definitive requirements. ISO/TS 15066 brings additional details to cobot risk assessments. In each case, the goal of the risk assessment is to identify external safety devices and systems needed to ensure the safe implementation of collaborative applications.

For a deeper dive into risk assessment and robots, see the article "Safely and Efficiently Integrating AMRs into Industry 4.0 Operations for Maximum Benefit."

Protection and efficiency

While cobots are designed for safe operation, additional protection layers can improve collaborative applications' efficiency. Without additional safety, when a person enters the collaborative workspace, ISO/TS 15066 mandates a maximum speed of 0.25 meters per second (m/s) per axis. For most cobots, that's very slow.

For example, the LXMRL12S0000 Lexium cobot from Schneider Electric has a maximum payload of 12 kilograms (kg), an operating radius (working range) of 1327 millimeters (mm), positioning

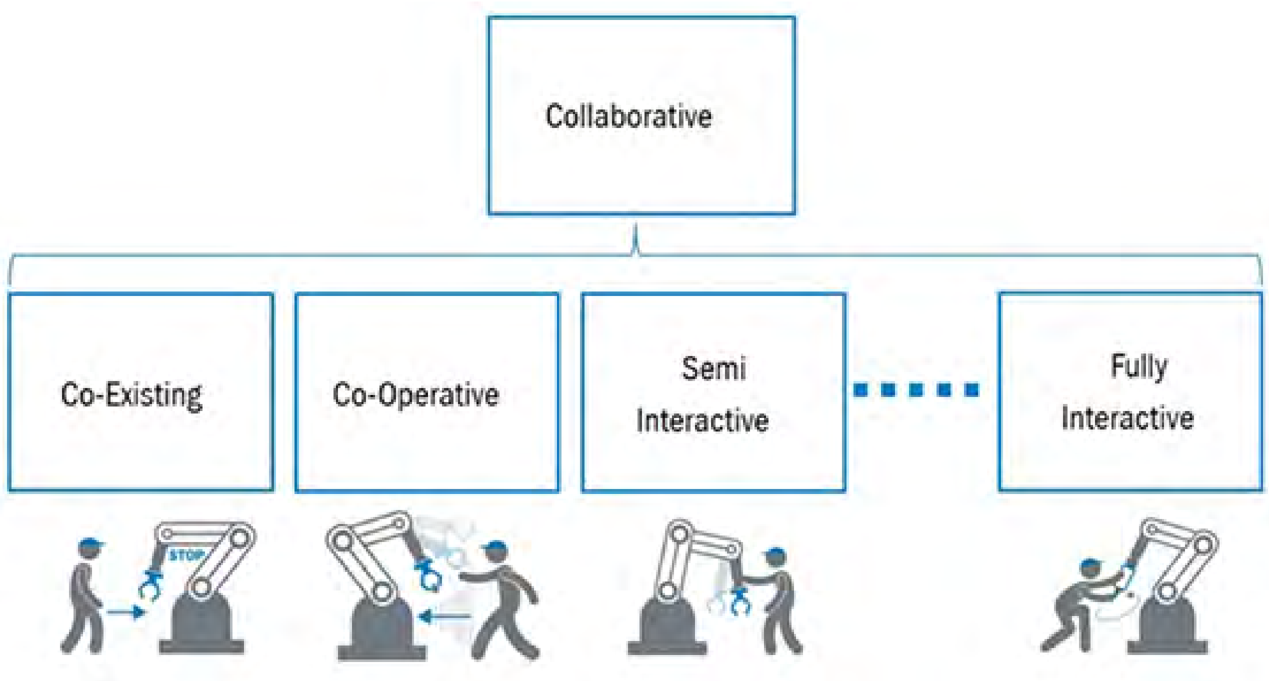


Figure 1: Human and robot collaboration includes a broad range of possible levels of interaction. (Image source: SICK)

accuracy of ±0.03 mm, and a maximum speed of the tool end of 3 meters per second (m/s), 12 times faster than the maximum allowed by ISO/TS 15066 when a person is in the collaborative workspace (Figure 2).

Figure 2: This cobot can move 12 times faster than the maximum allowed by ISO/TS 15066 when a person is in the collaborative workspace. (Image source: Schneider Electric)

In many applications, the cobot can be operating alone for long periods. So, sensing the presence or absence of people in the collaborative workspace can enable much faster operation and higher efficiency when no one is present. Common devices for sensing the presence of people include safety scanners, light curtains, and safety contact floor mats. Each technology offers a different set of benefits, and they are often used in combination.

Safety scanners

Safety scanners monitor a designated area to detect the presence of people. They can determine how far away a person is and implement various warning zones in addition to the active safety zone.

Omron's model OS32C-SP1-4M is a good example of a safety laser scanner designed for use with cobots. It has a safety radius of up to 4 meters (m) and can support multiple warning zones up to 15 m. It includes 70 standard sets of safety zone and warning zone combinations to support complicated collaborative workspaces. In addition, the minimum object resolution can be set to 30, 40, 50, or 70 mm, and the response time can range from 80 milliseconds (ms) up to 680 ms, further increasing application flexibility (Figure 3).

Figure 3: This safety scanner has a safety radius of up to 4 m and can support multiple warning zones up to 15 m. (Image source: DigiKey)

Light curtains

Light curtains can measure the presence of people and can be designed to detect objects of various sizes, like fingers or hands. Unlike safety scanners, light curtains don't measure distance. They send a series of light beams between linear emitter and receiver arrays and can sense when an object breaks one or more beams.

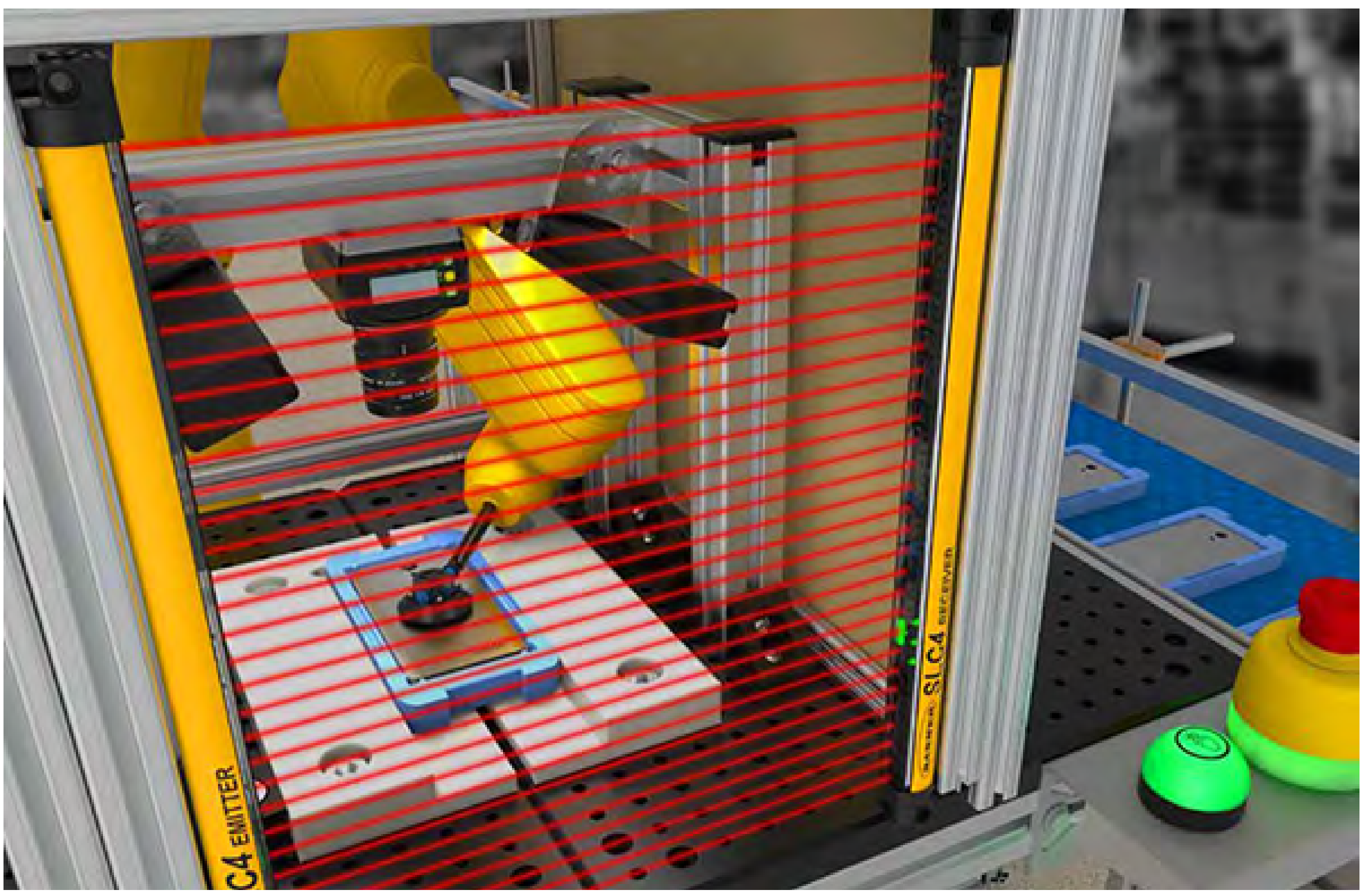
In terms of safety ratings, there are two primary light curtain classifications: Type 2 and Type 4. They have similar outward appearances but are designed to provide different levels of safety. Type 4 monitors the safeguarded space that defines a collaborative workspace. Type 2 light curtains are designed for lower-risk applications.

Light curtains guard perimeters and are available with several levels of resolution, like 14 millimeters (mm) for finger detection and 24 mm for hand detection. The model, SLC4P24-160P44 from Banner Engineering, is a Type 4 light curtain kit with an emitter and receiver array and has a resolution of 24 mm to protect people and machines like cobots (Figure 4). The emitters have a row of synchronized modulated infrared light-emitting diodes. Receivers have a corresponding row of synchronized photodetectors. The emitters have a 2-meter range, and these light curtains can be installed in lengths from 160 to 320 mm in 80 mm increments.

Safety laser scanners and light curtains provide non-contact means for enhancing the safety of collaborative workspaces. However, they can be difficult to use in optically challenging environments like areas with highly reflective surfaces that can send unwanted light interference, and they can trip because of leaking oil or grease or excessive dust or humidity.

Some of these optical sensors include sensitivity adjustments that can help mitigate certain types of interference. Those sensitivity adjustments can also increase response times and other performance compromises. Another solution is to use a safety contact mat together with optical sensing devices.

Figure 4: This Type 4 light curtain has a resolution of 24 mm. (Image source: Banner Engineering)



Safety contact mats

Safety contact mats have two conductive plates separated by a rasterized insulating layer and can be used alone or in combination with other types of sensors. If a person steps on the mat, the top conductive plate is depressed and contacts the lower plate, triggering an alert signal (Figure 5). The exterior of the mats is a polyurethane material that's slip-resistant and impervious to water, dirt, and oil. The SENTIR mat model 1602-5533 from ASO Safety Solutions can connect up to 10 mats in series to a single monitoring unit for a maximum coverage of 10 m^2.

Safety is in the details

There is no single formula that guarantees safety. Every collaborative application is different and needs to be handled based on its unique characteristics and needs. A key factor is: where does the application lie on the continuum of collaboration (see Figure 1)? The closer the interaction between the cobot and people, the more safeguarding is needed.

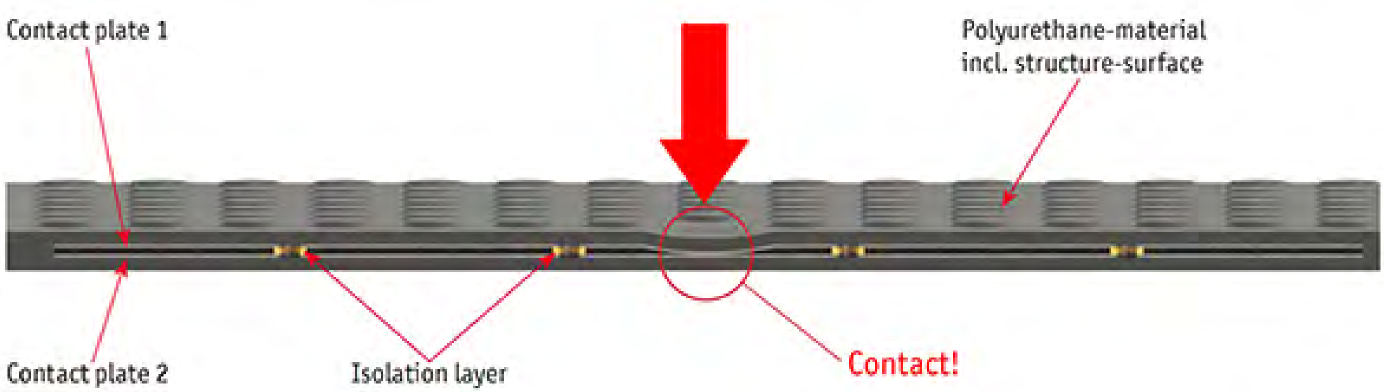
There are more details to consider. Some of them include:

- Each location needs to undergo a detailed risk assessment to see if the cobot has been moved from workstation to workstation. Even if they appear to be the same, small variations can make a difference in safety.
- If other machines are in the collaborative workspace, do they need to be linked to the shutdown system or the safety slowdown for the cobot?
- This article has focused on safety-related hardware, but for networked systems that are increasingly common, cybersecurity is an important consideration to prevent interference with cobot operation or the safety systems.

Conclusion

Cobot safety is complex. It begins with defining the collaborative workspace within the safeguarded space and requires a risk assessment of the collaborative operation. Standards like ISO/TS 15066 and the ISO 10218 series are important and provide recommendations and guidelines. Cobots include basic safety features like collision detection systems, force feedback, elastic actuators, and low-inertia servo motors. Depending on the specifics of the collaborative application, additional safety devices like proximity sensors, light curtains, and safety contact mats may be needed.

Figure 5: When stepped on, the safety mat's top and bottom conductive layers make contact, triggering an alert signal. (Image source: ASO Safety Solutions)



Safely and efficiently integrating AMRs into industry 4.0 operations for maximum benefit

By Jeff Shepard
Contributed By DigiKey's North American Editors

In response to the surging use of autonomous mobile robots (AMRs), also called industrial mobile robots, in Industry 4.0 operations, the Association for Advancing Automation (A3), together with the American National Standards Institute (ANSI), recently released the second increment of its safety standard for AMRs: ANSI/A3 R15.08-2, which details the requirements for integrating, configuring, and customizing an AMR or fleet of AMRs into a site. An essential requirement is the performance of a risk assessment per ANSI/ISO 12100 or ANSI B11.0. The new standard complements the previously released R15.08-1 that focused on the safe design and integration of AMRs.

The R15.08 series of standards builds on the earlier ANSI/ Industrial Truck Standards Development Foundation (ITSDF) B56.5 safety standard for automated guided industrial vehicles (AGVs). The newer standard recognizes three classes of AMRs based on the inclusion of specific functions and features.

This article briefly compares AMRs and AGVs and ANSI/ITSDF B56.5 and International Standards Organization (ISO) 3691-4 versus ANSI/A3 R15.08. It then reviews the risk assessment strategies outlined in ANSI/International Standards Organization (ISO) 12100 and ANSI B11.0, how they relate to AMRs, and how they are integrated into R15.08-2. Next, it reviews the three classes of AMRs defined in R15.08-2 before closing with a presentation of practical considerations for AMR integration, including how to implement mapping and commissioning, how to manage fleets of AMRs, and how to navigate new opportunities for virtual commissioning using simulation and digital twins using examples from Omron Automation and Siemens.

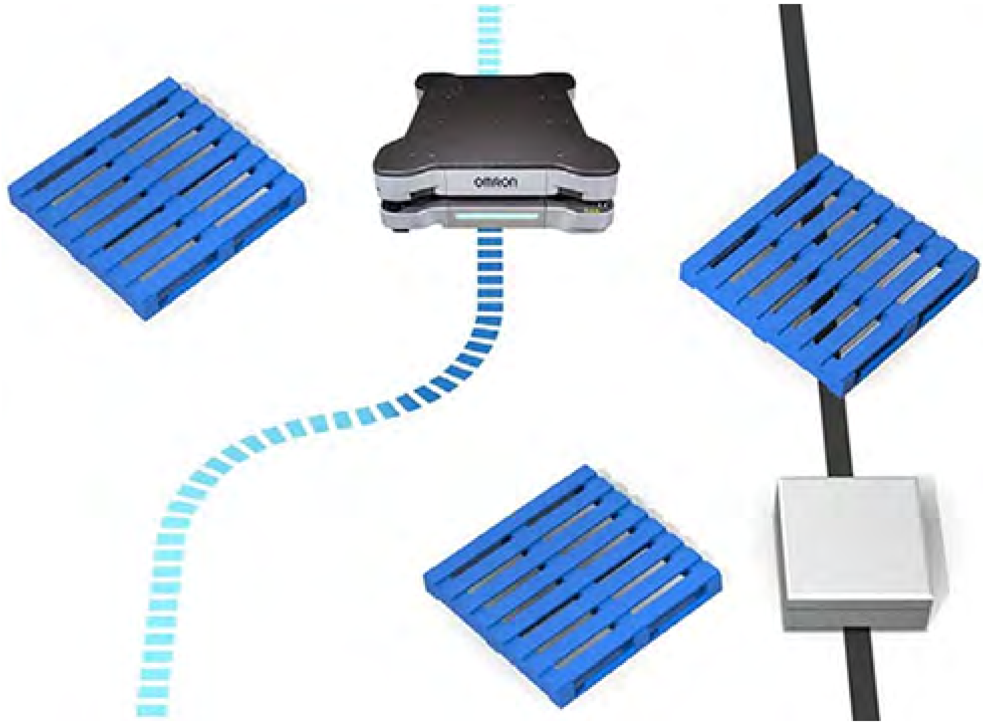


Figure 1: AMRs (left) navigate around obstacles while AGVs (right) stop when they arrive at an obstacle. (Image source: Omron)

AGVs can travel only along a predetermined and marked path. They have no independent navigation capabilities. They stop if they arrive at an obstacle and wait for it to be removed before proceeding along the fixed path. AMRs include independent navigation systems and can change paths and move around obstacles (Figure 1). Because of these differences, AGVs are better suited for relatively stable and unchanging environments, while AMRs support more flexible and scalable deployments like those needed in Industry 4.0 operations.

Standard evolution

Some AMR standards have evolved from previously developed standards for AGVs and stationary robots. For example, EN 1525:1997 was developed for AGVs and was subsequently applied to AMRs without modification. The newer ISO 3691-4 standard covers AGVs and has sections dedicated to AMRs.

ANSI/ITSDF B56.5 is a Safety Standard for Guided Industrial Vehicles, unmanned guided industrial vehicles, and the automated functions of manned industrial vehicles; it does not cover AMRs. The newer ANSI/ RIA R15.08 is a safety standard for the use of AMRs in industrial environments. It's based on and expanded from the R15.06 standard for safely using stationary robotic arms.

Another important standard is EN ISO 13849, which defines the safety performance levels (PLs) for various types of equipment. There are five levels, from PLa to PLe, with increasingly stringent requirements. AGV and AMR makers must reach PLd safety that ensures continuous safe operation in the event of a single fault, i.e., by using redundant systems.

ANSI/A3 R15.08-2 requires a risk assessment for integrating and deploying AMRs. The risk assessments defined by ISO 12100 and ANSI B11.0-2010 are very similar, though not identical. ISO 12100 targets original equipment manufacturers, whereas ANSI B11.0 focuses more on machinery and end-user safety. The basics of risk assessment are similar for both standards.

Risk assessment

A risk assessment is a highly structured analysis to arrive at an acceptable level of risk. It recognizes that no system or environment is perfect; inherent risks can be managed but not eliminated. It begins by determining the limits of the machine's operation and identifies hazards that can arise if the machine operates near or outside of those limits.

Next is risk estimation, which looks at the likely severity of harm from each hazard and the probability of its occurrence. A very severe hazard with a low likelihood of occurrence may receive a similar ranking as a hazard with a less severe outcome that's more likely to occur. All identified risks are evaluated and ranked to prioritize risk reduction efforts. Risk assessment can be an iterative process, identifying the most severe risks and reducing their probability of occurrence and/or the severity of their outcome until an acceptable level of residual risk has been achieved (Figure 2).

AMR classes

R15.08 recognizes three types of AMRs:

Type A: AMR platform only. In contrast with AGVs, type A AMRs can function as independent systems without requiring environmental changes. They can include optional features like a battery management system, the ability to independently locate a charger and recharge its battery, the ability to integrate with centralized fleet management software, etc. Type A AMRs are most often used to move materials around a factory or warehouse.

Type B: A type A AMR with the addition of a passive or active attachment that is not a manipulator (Figure 3). Typical attachments include conveyors, roller tables, fixed or removable totes, lifting devices, vision systems, weighing stations, etc. Type B AMRs can be used for more complex logistics tasks. Vision systems can be used for product inspections and identification, weighing (or estimating the number of) parts, and so on.

Figure 2: Key components of a risk assessment include risk analysis, evaluation, and reduction. (Image source: SICK)

Figure 3: Type B AMR with a roller table attachment. This also shows typical navigation and safety systems common to all three types of AMRs. (Image source: Omron)

Type C: A type A AMR with the addition of a manipulator. The manipulator can be a robotic arm with three or more axes of movement. Type C AMRs can be designed to function as collaborative robots (cobots) working alongside humans. They can also be machine attendants, perform pick and place operations, complete complex inspection tasks, do harvesting and weeding in agricultural settings, etc. Some designs can move from place to place and perform different tasks at each station.

Commissioning, mapping, and following the lights

All three types of AMRs are designed to simplify deployment. Compared with AGVs that require extensive infrastructure installation, no construction is necessary for AMR deployment, and programming needs can be minimal. Basic commissioning is a four-step process (Figure 4):

- The AMR is delivered with all the needed software installed; the first task is to install and charge the battery.
- Mapping is critical and can be manually or automatically implemented. For manual mapping, a technician controls the AMR and takes it around the facility so it can learn about the environment. Laser-guided AMRs can automatically scan up to 1,000 square feet per minute to create maps capturing all the features in the immediate area and wirelessly send the resulting map to a central computer. In both cases, maps can be customized with virtual routes and forbidden lines for safe operations and can be shared across fleets of AMRs.
- Setting goals includes the identification of pick-up and drop-off locations.
- Task assignment is the final step and includes scheduling and coordination of the various AMRs in the fleet and integration with Enterprise Resource Planning (ERP), the Manufacturing Execution System (MES), and the Warehouse Management System (WMS).

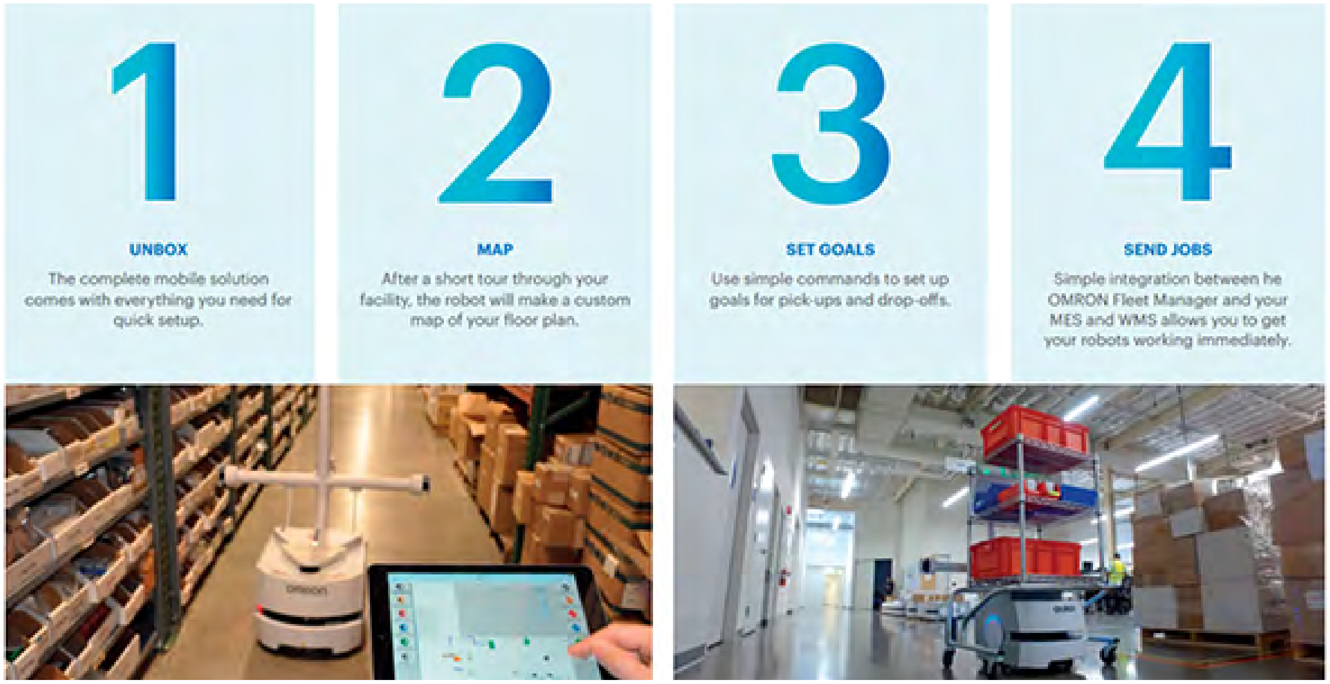


Figure 4: AMRs are delivered with complete software installed and can be quickly commissioned and integrated into a production environment. (Image source: Omron)

In addition to mapping a facility using laser scanning, some Omron AMRs use a camera to detect and plot the location of overhead lights. It creates and overlays a "light map" with the standard "floor map."

Laser localization can tolerate changing environments on the floor up to a point. Suppose over 80% of the features change, for example, on a shipping dock where pallets or rolling carts constantly change location. In that case, laser localization is less useful, and adding the light map increases the reliability of navigation. Using the light map also enables AMRs to more easily navigate across wide-open areas in large facilities.

Managing robot fleets

Effective management of robot fleets can multiply the benefits of using AMRs. It can support centralized control and coordinated operation of mixed types of AMRs and provide the data and analytics needed to maximize operational efficiencies. Some common features of AMR fleet management systems include:

Optimized task assignments are based on the capabilities of each robot in the fleet, their current locations, and anticipation of where their next assignment will be located.

Traffic management includes scheduling pick-up and drop-off locations and times for maximum efficiency and notifying robots of destination changes or new obstacles, enabling them to recalculate their path for maximum efficiency and safety.

Charge management tracks the battery charge level of each robot in the fleet, enabling proactive charging and maximum uptime.

Coordinated software updates across the fleet to ensure the latest version is available for each type of robot.

Enterprise integration connects the fleet management software to ERP, MES, and WMS systems so jobs can be allocated and scheduled automatically to the fleet in real-time.

Virtual commissioning

A combination of digital twins and simulation software enables virtual commissioning. In this case, a digital twin is a virtual representation of an AMR. Digital twins can be used to virtually validate the performance of individual AMRs and fleets of AMRs. Virtual commissioning uses robotics simulation software to combine the digital twins of AMRs with a digital twin of the surrounding environment (Figure 5).

AMR virtual commissioning can also be used to integrate and coordinate the operation of robots from several manufacturers. During the virtual commissioning process, engineers can quickly and efficiently create multiple scenarios to verify the proper functioning of the entire system, not just isolated AMRs.

Virtual safety testing and debugging can also be implemented with digital twins and simulation. Virtual AMRs can be subjected to anomalous situations to test various contingencies and ensure the proper functioning of safety protocols.

Figure 5: AMR digital twins can be virtually inserted into a simulated factory environment for virtual commissioning. (Image source: Siemens)

The ability to implement virtual debugging can speed up the deployment of AMR fleets. Debugging fleets of *physical* AMRs after deployment is challenging and time-consuming. It involves work stoppages and negatively impacts the productivity of the facility. There are no work stoppages with *virtual* debugging, and users are assured that the AMRs will perform as expected in the real world.

Conclusion

AMR deployments are becoming increasingly prevalent in a wide range of Industry 4.0 installations. The standards landscape for AMRs is evolving to address requirements for safely and efficiently integrating, configuring, and customizing an AMR or AMR fleet into a site. A risk assessment performance is a key requirement within the new standards in accordance with ANSI and ISO standards. The tools for AMR commissioning are also evolving with the emergence of virtual commissioning using digital twins and simulation.

This was the first of a two-part series and focused on the implications of the recently released R15.08-2 standard regarding safety, risk assessment, and commissioning of AMRs. The second article is written in anticipation of R15.08-3, which is currently under development and will address the topic of sensor fusion in AMRs.

How sensor fusion enables AMRs to maneuver around factory floors efficiently

By Jeff Shepard
Contributed By DigiKey's North American Editors

With increasing instances of people and autonomous mobile robots (AMRs), also called industrial mobile robots (IMRs), working in the same area, multiple inherent safety risks must be addressed. The safe and efficient operation of AMRs is too important to rely on a single sensor technology.

Multi-sensor fusion, or simply "sensor fusion," combines technologies like laser range finding (LIDAR), cameras, ultrasonic sensors, lasers obstacle sensors, and radio frequency identification (RFID) to support a range of AMR functions, including navigation, path planning, collision avoidance, inventory management, and logistics support. Senor fusion also encompasses alerting nearby people to the presence of the AMR.

To address the need for the safe and efficient operation of AMRs, the American National Standards Institute (ANSI) and the Association for Advancing Automation (A3), formerly the Robotic Industries Association (RIA), are developing the ANSI/A3 R15.08 series of standards. R15.08-1 and R15.08-2 have been released, focusing on basic safety requirements and integrating AMRs into a site. R15.08-3 is currently under development and will expand the safety requirements for AMRs, including more detailed recommendations for using sensor fusion.

In anticipation of R15.08-3, this article reviews some of today's best practices related to safety and sensor fusion in AMRs, beginning with a brief overview of functional safety requirements currently used with AMRs, including generic industrial safety standards like IEC 61508, ISO 13849 and IEC 62061, and the safety requirements for sensing human presence like IEC 61496 and IEC 62998. It then presents a typical AMR design detailing the numerous sensor technologies, presents representative devices, and looks at how they support functions like navigation, path planning, localization, collision avoidance, and inventory management/logistics support.

Good, better, best

AMR designers have a range of safety standards to consider, starting with general-purpose functional safety standards like IEC 61508, ISO 13849, and IEC 62061. There are also more specific safety standards related to sensing human presence, such as IEC 61496, IEC 62998, and the ANSI/A3 R15.08 series of standards.

IEC 61496 offers guidance for several sensor types. It refers to IEC 62061, which specifies requirements and makes recommendations for the design, integration, and validation of electrosensitive protective equipment (ESPE) for machines, including safety integrity levels (SILs), and ISO 13849 that covers safety of machinery and safety-related parts of control systems including safety performance levels (PLs) (Table 1).

Requirement	**Type**			
	1	**2**	**3**	**4**
Safety performance in accordance with IEC 62061 and/or ISO 13849-1	N/A	SIL 1 and/ or PL c	SIL 2 and/ or PL d	SIL 3 and/ or PL e
SIL = safety integrity level; PL = performance level				

Table 1: Safety requirements for ESPE by type specified in IEC 61496. (Table source: Analog Devices)

IEC 62998 is newer and can often be a better choice since it includes guidance on implementing sensor fusion, using artificial intelligence (AI) in safety systems, and using sensors mounted on moving platforms outside the coverage of IEC 61496.

R15.08 Part 3, when it's released, may make the R15.08 series the best since it will add safety requirements for users of AMR systems and AMR applications. Likely topics may include sensor fusion and more extensive AMR stability testing and validation.

Sensor fusion functions

Mapping the facility is an essential aspect of AMR commissioning. But it's not a one-and-done activity. It's also part of an ongoing process called simultaneous localization and mapping (SLAM), sometimes called synchronized localization and mapping. It is the process of continuously updating the map of an area for any changes while keeping track of the robot's location.

Sensor fusion is needed to support SLAM and enable the safe operation of AMRs. Not all sensors work equally well under all operating circumstances, and different sensor technologies produce various data types. AI can be used in sensor fusion systems to combine information about the local operating environment (is it hazy or smoky, humid, how bright is the ambient light, etc.) and enable a more meaningful result by combining the outputs of different sensor technologies.

Sensor elements can be categorized by function as well as technology. Examples of sensor fusion functions in AMRs include (Figure 1):

- Distance sensors like encoders on wheels and inertial measurement units using gyroscopes and accelerometers help measure the movement and determine the range between reference positions.
- Image sensors like three-dimensional (3D) cameras and 3D LiDAR are used to identify and track nearby objects.
- Communications links, compute processors, and logistics sensors like barcode scanners and radio frequency identification (RFID) devices link the AMR to facility-wide management systems and integrate information from external sensors into the AMR's sensor fusion system for improved performance.
- Proximity sensors like laser scanners and two-dimensional (2D) LiDAR detect and track objects near the AMR, including people's movement.

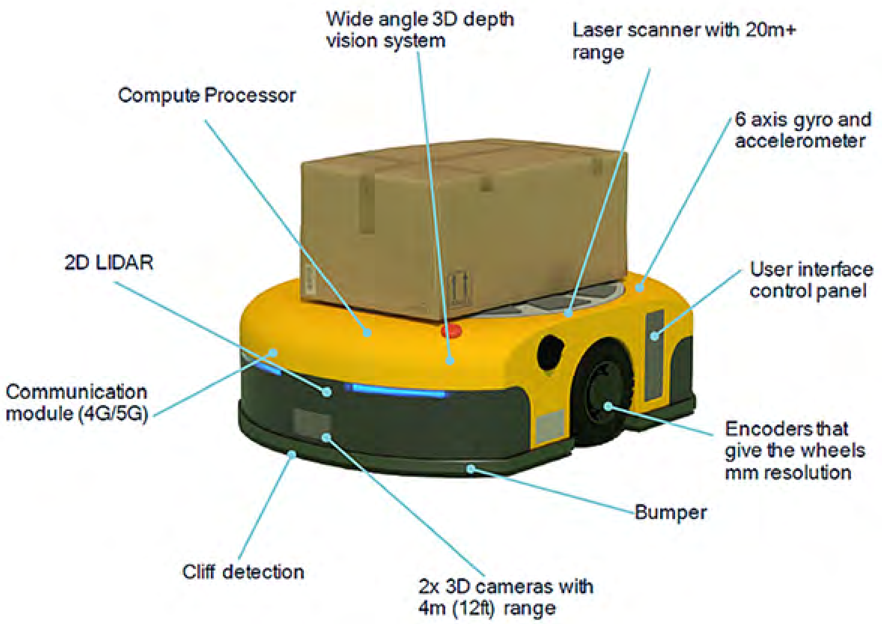


Figure 1: Examples of common sensor types and related system elements used in AMR sensor fusion designs. (Image source: Qualcomm)

2D LiDAR, 3D LiDAR, and ultrasonics

2D and 3D LiDAR and ultrasonics are common sensor technologies that support SLAM and safety in AMRs. The differences between those technologies enable one sensor to compensate for the weaknesses of the others to improve performance and reliability.

2D LiDAR uses a single plane of laser illumination to identify objects based on X and Y coordinates. 3D LiDAR uses multiple laser beams to create a highly detailed 3D representation of the surroundings called a point cloud. Both types of LiDAR are relatively immune to ambient light conditions but require that objects to be detected have a minimum threshold of reflectivity of the wavelength emitted by the laser. In general, 3D LiDAR can detect low-reflectivity objects with more reliability than 2D LiDAR.

The [HPS-3D160](#) 3D LiDAR sensor from [Seeed Technology](#) integrates high-power 850 nm infrared vertical-cavity surface-emitting laser (VCSEL) emitters and high-photosensitive CMOS.

Figure 2: This 2D LiDAR sensor has an aperture angle of 270 degrees. (Image source: SICK)

The embedded high-performance processor includes filtering and compensation algorithms and can support multiple simultaneous LiDAR operations. The unit has a range of up to 12 meters with centimeter accuracy.

When a 2D LiDAR solution is needed, designers can turn to the TIM781S-2174104 from [SICK](#). It features an aperture angle of 270 degrees with an angular resolution of 0.33 degrees and a scanning frequency of 15 Hz. It has a safety-related working range of 5 meters (Figure 2).

Ultrasonic sensors can accurately detect transmissive objects like glass and light-absorbing materials that LiDAR can't always see. Ultrasonic sensors are also less susceptible to interference from high dust, smoke, humidity, and other conditions that can disrupt LiDAR.

However, ultrasonic sensors are sensitive to interference from environmental noise, and their detection ranges can be more limited than LiDAR.

Ultrasonic sensors like the [TSPC-30S1-232](#) from [Senix](#) can complement LiDAR and other sensors for AMR SLAM and safety. It has an optimum range of 3 meters, compared to 5 meters for the 2D LiDAR and 12 meters for the 3D LiDAR detailed above. This temperature-compensated ultrasonic sensor is IP68-rated in an environmentally sealed stainless-steel enclosure (Figure 3).

Sensor fusion usually refers to using several discrete sensors. But in some cases, multiple sensors are co-packaged as a single unit.

Figure 3: Environmentally sealed ultrasonic sensor with an optimum range of 3 meters. (Image source: DigiKey)

Three sensors in one

Visual perception using a pair of cameras to produce stereoscopic images plus image processing based on AI and ML can enable the AMR to see the background as well as identify nearby objects. Sensors are available that include stereo depth cameras, a separate color camera, and an IMU in one unit.

Stereo depth cameras like the Intel RealSense D455 RealSense Depth Cameras use two cameras separated by a known baseline to sense depth and calculate the distance to an object. One key to precision is using a sturdy steel framework that ensures an exact separation distance between the cameras, even in demanding industrial environments. The accuracy of the depth perception algorithm is dependent on knowing the exact spacing between the two cameras.

For example, the model 82635DSD455MP depth camera has been optimized for AMRs and similar platforms and has extended the distance between the cameras to 95 mm (Figure 4). That enables the depth calculation algorithm to reduce the estimation error to less than 2% at 4 meters.

D455 depth cameras also include a separate color (RGB) camera. A global shutter for up to 90 frames per second on the RGB camera, matched to the depth imager field of view (FOV), improves the correspondence between the color and depth images, enhancing the ability to understand the surroundings. D455 depth cameras integrate an IMU with six degrees of freedom that enables the depth calculation algorithm to include the rate of motion of the AMR and produce dynamic depth awareness estimates.

Figure 4: This module includes stereo depth cameras separated by 95 mm, a separate color camera, and an IMU. (Image source: DigiKey)

Lighting and sounding the way

Flashing lights and audible alerts for people near an AMR are important to AMR safety. The lights are usually in the form of a light tower or light strip on the sides of the AMR. They help the robot communicate its intended action(s) to people. They can also indicate status like battery charging, loading or unloading activities, intention to turn in a new direction (like the turn signals on a car), emergency conditions, and so on.

There are no standards for light colors, flashing speeds, or audible alarms. They can vary between AMR makers and are often developed to reflect the specific activities in the facility where the AMR operates. Light strips are available with and without built-in audible alert mechanisms. For example, the model TLF100PDLBGYRAQP from Banner Engineering includes a sealed audible element with 14 selectable tones and volume control (Figure 5).

Figure 5: This light bar annunciator includes a sealed audible element (top black circle). (Image source: DigiKey)

Logistics support

AMRs operate as part of larger operations and are often required to integrate with enterprise resource planning (ERP), manufacturing execution system (MES), or warehouse management system (WMS) software. The communications module on the AMR coupled with sensors like barcode and RFID readers enable AMRs to be tightly fused into enterprise systems.

When a barcode reader is needed, designers can turn to the V430-F000W12M-SRP from Omron, which can decode 1D and 2D barcodes on labels or Direct Part Mark (DPM) barcodes. It includes variable distance autofocus, a wide field of view lens, a 1.2-megapixel sensor, a built-in light, and high-speed processing.

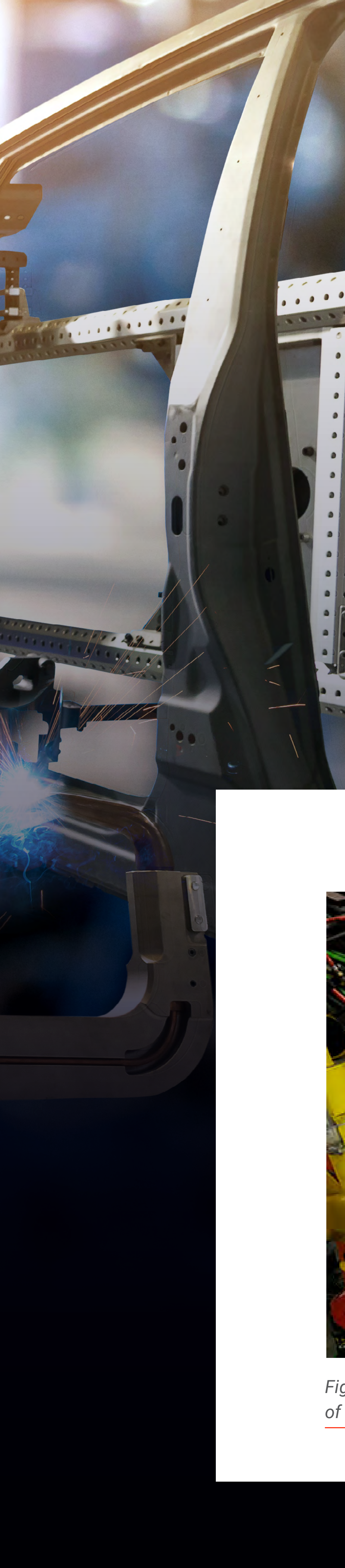
The DLP-RFID2 from DLP Design is a low-cost, compact module for reading from and writing to high-frequency (HF) RFID transponder tags. It can also read the unique identifiers (UDI) of up to 15 tags at once and can be configured to use an internal or external antenna. It has an operating temperature range of 0°C to +70°C, making it suitable for use in Industry 4.0 manufacturing and logistics facilities.

Conclusion

Sensor fusion is an important tool for supporting SLAM and safety in AMRs. In anticipation of R15.08-3, which may include references to sensor fusion and more extensive AMR stability testing and validation, this article reviewed some current standards and best practices for implementing sensor fusion in AMRs. This is the second article in a two-part series. Part one reviewed the safe and efficient integration of AMRs into industry 4.0 operations for maximum benefit.

Robotics in today's automotive manufacturing

By Jody Muelaner, Lisa Eitel



Industrial robots are essential to modern manufacturing — executing a vast array of functions while coordinating tasks with other forms of automation. In fact, the $1T automotive industry was the first industry with the means to make large-scale use of robotics … and advance the technologies associated with robotics as well. No wonder, as automobiles are highly sophisticated big-ticket items that can justify plant investments that may not yield ROI for years. Now, the vast majority of automotive manufacturing centers employ robotics. Only over the last two decades have the fields of packaging, semiconductor production, and the relatively new field of automated warehousing hastened their robotics adoption to rival the automotive industry.

Within robots themselves and in complementary industrial-automation equipment are electric motors, hydraulic systems, and fluid power systems; drives, controls, networking hardware, human-machine interfaces (HMIs), and software systems; and sensing, feedback, and safety components. These elements impart efficiency by executing preprogrammed routines that can readily adapt to changing real-time conditions. Increasingly, it's expected that robotic workcells also feature reconfigurability to produce new automobile offerings ... as consumer preferences have come to evolve more rapidly than ever.

Figure 1: The automotive industry, more than perhaps any other, has spurred the advancement of robotics technologies. (Image source: Getty Images)

Clarifying terminology used for automation and robotics

The Oxford English Dictionary defines robots as "machines capable of automatically carrying out complex series of movements, esp. programmable." Confusing matters is that this definition could describe everything from washing machines to CNC machine tools. Even the ISO 8373 definition of a robot as an "automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes" could describe a warehouse conveyor with vertical lift stations. However, such machines would never normally be classified as robots.

The practical differentiator to remember is that machines built for a single [read: very clearly defined] use in a fixed location aren't usually considered robots … at least not in industrial circles. For example, although a typical milling machine can run any number of complex programs to machine different parts, it's designed to cut metal using rotary blades mounted in its spindle … and it's likely to remain securely fixed in a single location for its entire service life.

Sometimes, even these definitions are contradicted. For example, automated machines such as CNC machine tools are increasingly flexible, with mill-turn centers performing the roles of both milling machines and lathes — and many such machines executing inspection and measurement tasks on parts with contact probes and laser scanners as well. Such machine tools may even be equipped to perform additive manufacturing. On the other hand, supposedly flexible industrial robots are often supplied as specialized models designed for a specific task such as paint spraying or welding … and may well spend their entire service life parked within one workcell on a production line.

Figure 2: In some cases, the distinction between robot and machine is based on how an automated design looks. Some classify articulated arms that resemble mechanized human arms as robots — and classify automated cartesian arrangements of linear slides (as the CT4 for small parts assembly and inspection) as machines. (Image source: IAI America Inc.)

The bottom line is that in the automotive industry today, automated systems classified as robots are indeed often expected to exhibit high flexibility — capable (with reconfiguration) of executing transport, sorting, assembly, welding, and painting tasks that may vary day to day. These industrial robotics are also expected to be relocatable to new areas in a plant — whether for redeployment as manufacturing systems and reconfigured or continually movable on seventh-axis linear tracks to service workcell arrays in a line.

Robot families for automotive production sites

Robots in automotive production sites are broadly classified by their mechanical structures — including their joint types, linkage arrangements, and degrees of freedom.

Serial manipulator robotics include most industrial robots. Designs in this design family have a linear chain of links with a base at one end and an end effector at the other end … with a single joint between each link in the chain. These include articulated robots, selective compliance articulated robot arm (SCARA) robots, collaborative six-axis robots, cartesian robots (essentially consisting of linear actuators), and (somewhat uncommon) cylindrical robots.

Figure 3: Collaborative robots are increasingly common in Tier-2 automotive supplier facilities that benefit from automated palletizing. (Image source: Dobot)

Parallel manipulator robotics excel where applications need high rigidity and operational speed. In contrast with articulated arms (suspended in 3D space via a single line of linkages), parallel manipulators are supported or suspended by arrays of linkages. Examples include delta and Stuart robots.

Mobile robotics are wheeled units that move materials and stock items around factories and warehouses. They may function as automated forklifts to retrieve, move, and place pallets on shelving or the factory floor. Examples include automated guided vehicles (AGVs) and autonomous mobile robots (AMRs).

Classic robot uses in automotive manufacturing

Classic robotic applications in automotive manufacturing facilities include welding, painting, assembly, and (for the transport of the 30,000-odd parts that go into the average car) material-handling tasks. Consider how some robot subtypes are put to use in these applications.

Six-axis articulated arm robots are serial manipulators in which every joint is a revolute joint. The most common configuration is the six-axis robot having degrees of freedom to position objects in any position and orientation within its working volume. These are very flexible robots suited to myriad industrial processes. In fact, six-axis articulated arm robots are what most people picture when thinking of an industrial robot.

In fact, large six-axis robots are often used in automobile frame welding and spot welding of body panels. In contrast with manual approaches, robots have the ability to precisely trace weld paths in 3D space without stopping while concurrently accommodating the changing parameters of the weld bead in response to environmental conditions.

Figure 4: High-performance barcode readers can quickly and reliably decode 1D and 2D barcodes. Some mount on robotic end effectors to support part picking of electronic and automotive parts as well as subassembly elements. (Image source: Omron Automation and Safety)

Figure 5: These six-axis robots are what most people picture when imagining an industrial robot. (Image source: Kuka)

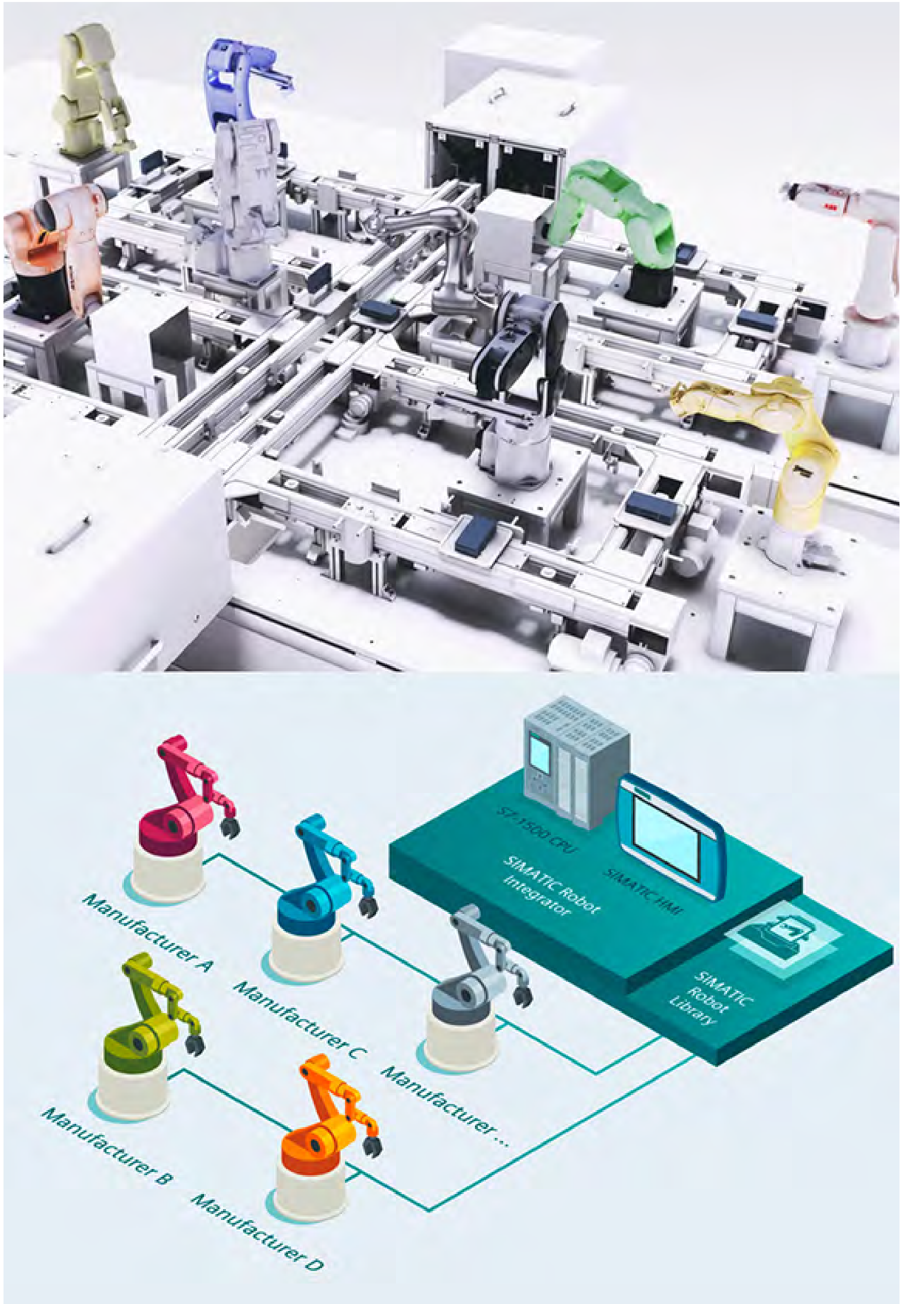


Figure 6: The SIMATIC Robot Integrator app simplifies the integration of robots into automated settings by accommodating the parameters of various suppliers' robots and various applications' geometries and mounting requirements; completing these installations are scalable high-performance SIMATIC S7 controllers having integrated I/O and various communication options for flexible design adaptations. (Image source: Siemens)

Elsewhere, six-axis articulated arm robots ride on seventh-axis systems to execute priming, painting, clearcoating, and other sealing processes on automobile panel bodies. Such arrangements deliver flawlessly consistent results that are in part so reliable because these processes are executed in well-isolated spray booths effectively kept uncontaminated by particles from the outside environment. Six-axis robots also follow programmatically optimized spray paths for perfect finishes even while minimizing overspray and paint and sealer waste. What's more, they eliminate the need to expose automobile-plant personnel to the harmful vapors associated with some spray-applied materials.

Selective Compliance Articulated Robot Arm (SCARA) robots have two revolute joints having parallel turning axes running in the vertical direction for X-Y positioning in a single plane of motion. Then a third linear axis allows motion in the Z (up and down) direction. SCARAs are relatively low-cost options that excel in confined spaces — even while delivering faster moves than equivalent cartesian robots. No wonder SCARA robots are used in production of automotive electronics and electrical systems — including those for climate control, mobile-device connectivity, audio/visual elements, entertainment, and navigation. Here, SCARAs are most commonly used to execute the precise material handling and assembly tasks to produce these systems.

Cartesian robots have, at minimum, three linear axes that are stacked to execute motion in the X, Y and Z directions. In fact, some cartesian robots employed by Tier-2 automotive suppliers take the form of CNC machine tools, 3D printers, and coordinate measurement machines (CMMs) to verify the quality and consistency of end products. If counting these machines in the tally, cartesian robots are easily the industry's most common form of industrial robot. As mentioned earlier though, cartesian machines are often only called *robots* when they are used for operations involving the manipulation of workpieces and not tools — in assembly, pick-and-place, and palletizing, for example.

Another cartesian robot variation used in the automotive industry is the automated gantry crane. These are indispensable for fastening and joining processes requiring access to the undercarriage of partially completed vehicle assemblages.

New and novel robot uses in automotive manufacturing

Cylindrical robots are compact and economical robots that give three-axis positioning with a revolute joint at the base and two linear axes for height and arm extensions. They are particularly well suited to machine tending, packing, and palletizing automobile subcomponents.

Collaborative six-axis robots (cobots) mentioned earlier feature the same basic linkage structure as larger industrial variations, but with extremely compact and integrated motor-based drives at each joint … typically in the form of a gearmotor or direct-drive option. In automotive settings, these are tasked with welding brackets, mounts, and geometrically complicated subframes. Benefits include high precision and repeatability.

Delta robots have three arms that are actuated via revolute joints from the base — often mounted to the ceiling for a suspended arrangement. Each arm has a parallelogram with universal joints mounted at its end, and these parallelograms all then connect to the end effector. This gives the delta robot three degrees of translational freedom with the end effector never rotating relative to the base. Delta robots can achieve extremely high accelerations, making them highly effective for pick-and-place operations in applications involving the sorting and other handling of small automotive fasteners and electrical components.

Stewart platforms (also called hexapods) consist of a triangular base and triangular end effector connected by six linear actuators in an octahedron. This imparts six degrees of freedom with an extremely rigid structure. However, the range of motion is relatively limited in comparison to the size of the structure. Stewart platforms are used for motion simulation; mobile precision machining; crane motion compensation; and high-speed vibration compensation in precision physics and optics test routines … including those to verify vehicle suspension designs.

Automated guided vehicles (AGVs) follow set routes marked by lines painted on the floor, wires on the floor, or other guidance beacons. AGVs typically have a degree of intelligence so they stop and start to avoid collisions with each other and with humans. They are highly suitable for material-transport tasks in automotive-production facilities.

Autonomous mobile robots (AMRs) don't require fixed routes and are able to make more sophisticated decisions

than AGVs. Particularly useful in the sprawling warehouses of automobile manufactures, these typically achieve free navigation using laser scanners and object recognition algorithms to sense their environment. When a potential collision is detected, instead of stopping and waiting like an AGV, AMRs can simply alter course and move around obstacles. This adaptability renders AMRs considerably more productive and flexible in automotive plant loading docks.

Conclusion

The automotive industry has spurred massive innovation in the field of robotics over the last 30 years, and that trend will continue with the burgeoning electric vehicles (EVs) market. The industry has also begun to benefit from new AI and machine vision adaptations to enhance robotic installations for uses of all types.

How delta robotics optimize and streamline electronics manufacturing processes

By Jody Muelaner

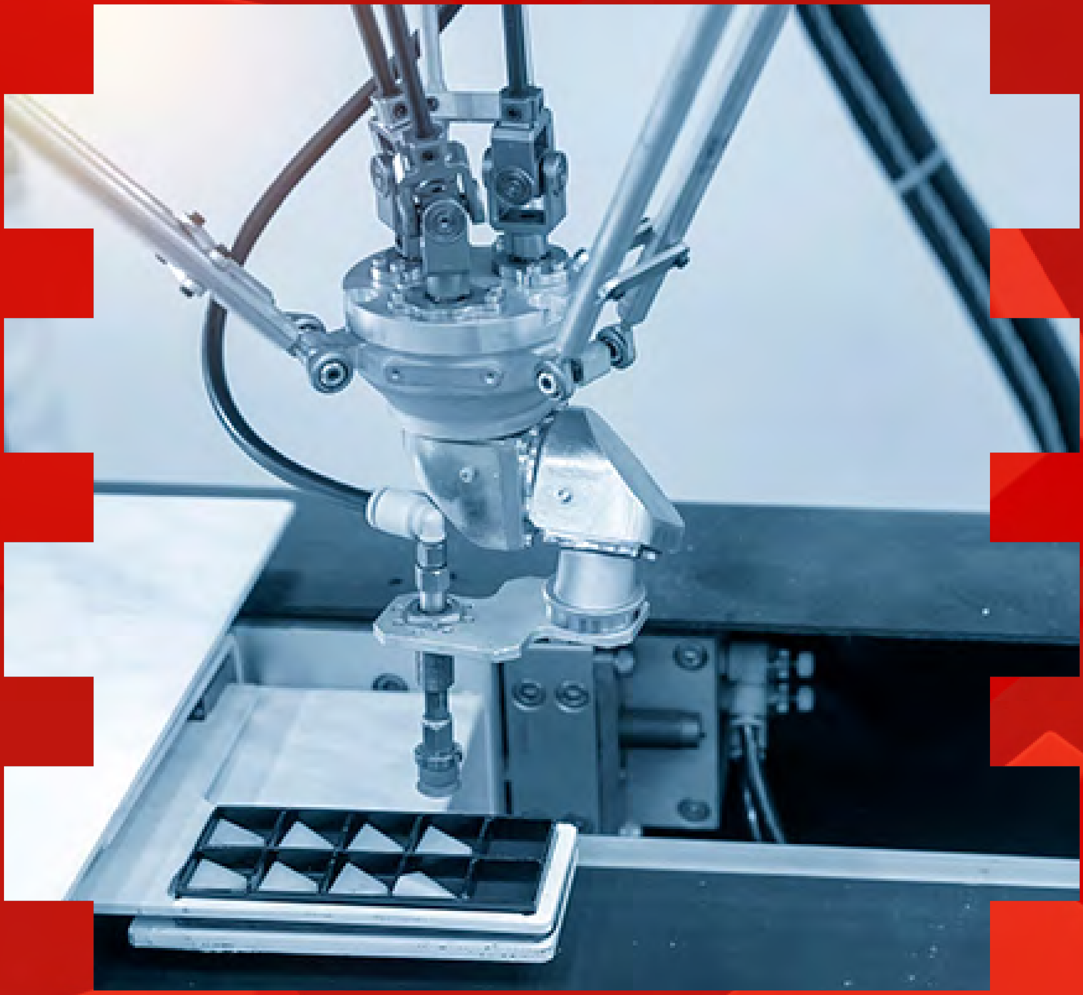


Figure 1: The robotic linkage-arm use in electronics production line with the lighting effect. - stock photo (Image source: Phuchit • Getty Images)

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 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)

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.

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 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.

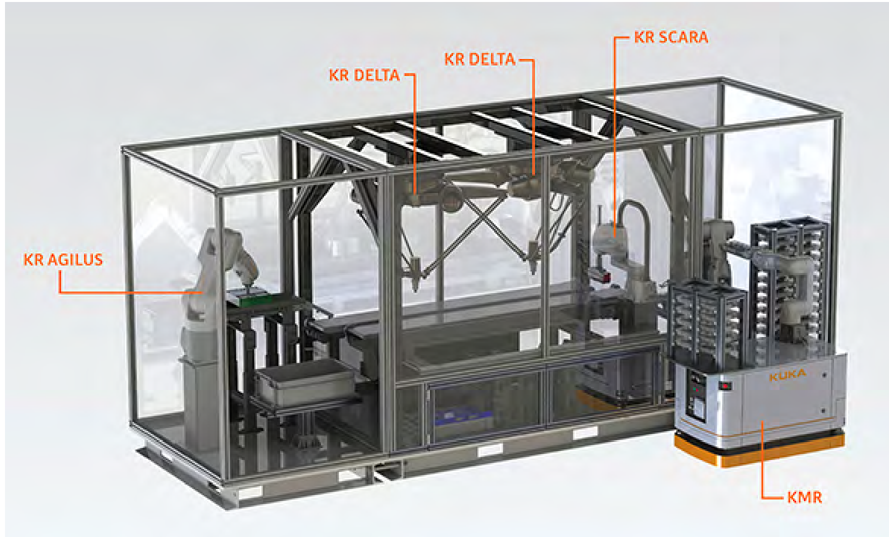


Figure 3: Shown here is a vision-laden work cell that employs delta robots, SCARA robots, and mobile robots. The delta robot is stainless steel and IP-67 rated. (Image source: KUKA)

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.

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)

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 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.

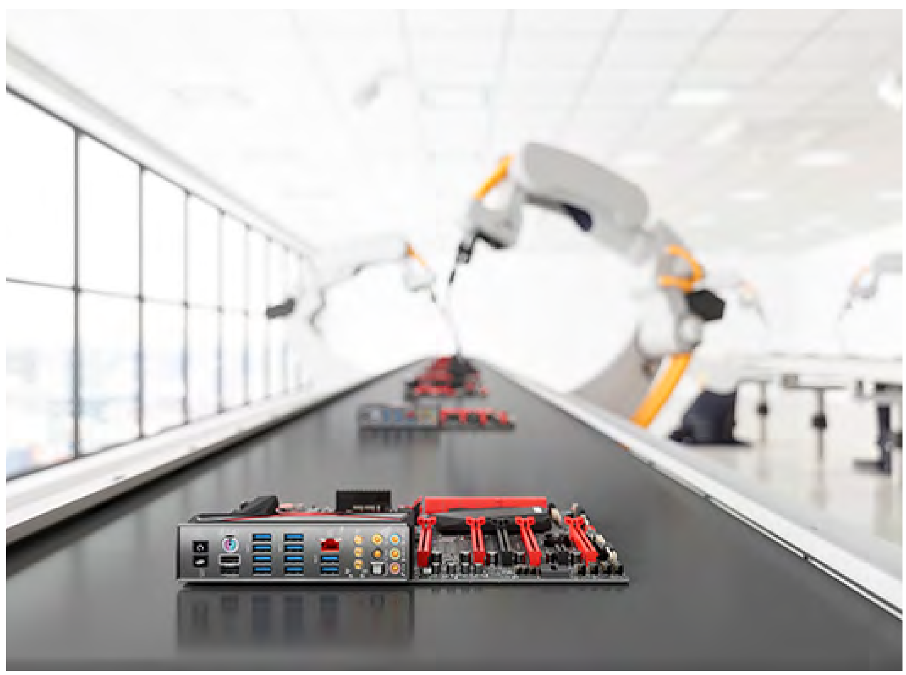


Figure 5: Electronics boards ride a conveyor through an assembly work cell. (Image source: Getty Images)

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.

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)

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 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.

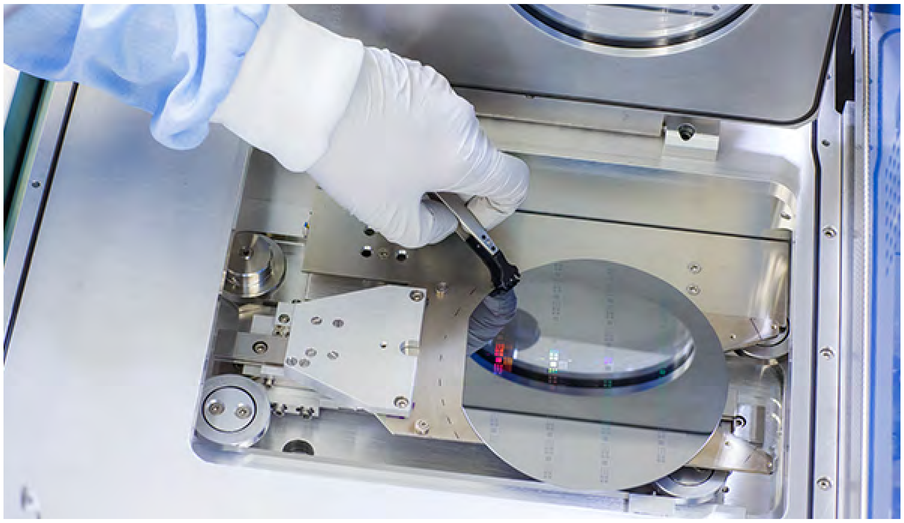


Figure 1: Here, a delicate wafer is placed into an atomic layer deposition machine located within a cleanroom. (Image source: Dreamstime)

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

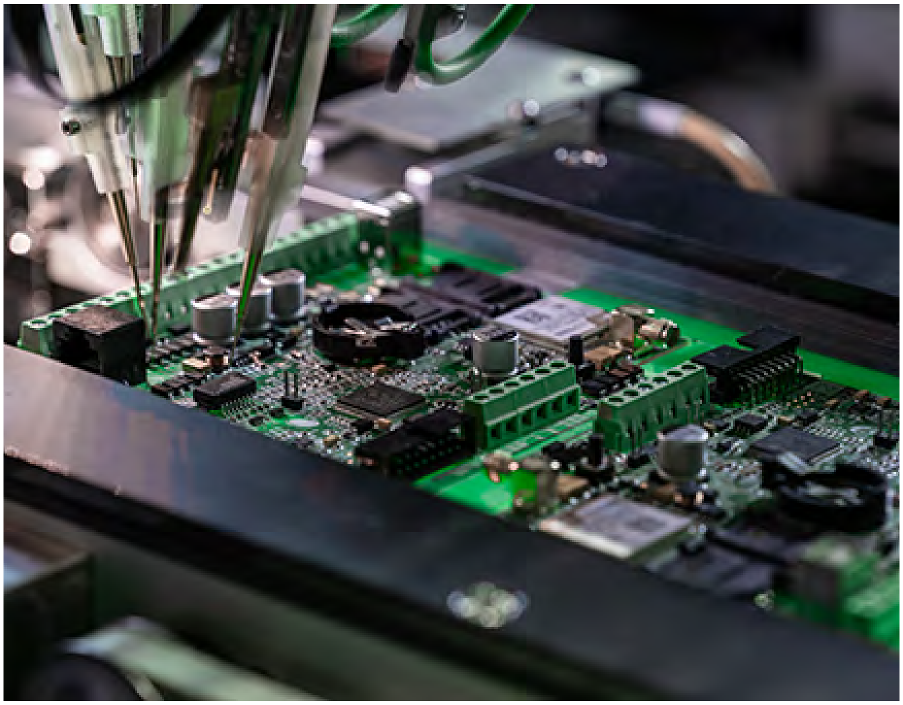


Figure 3: Shown here is the automated soldering of chip components onto a PCB. (Image source: Dreamstime)

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.

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.

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

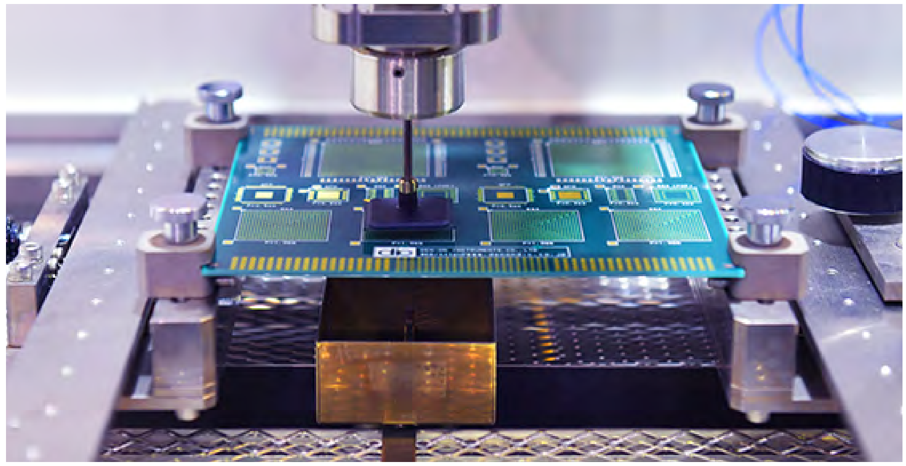


Figure 5: Electronics contract manufacturing makes copious use of robotics for board testing. (Image source: Dreamstime)

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

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.

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

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.

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

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 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.

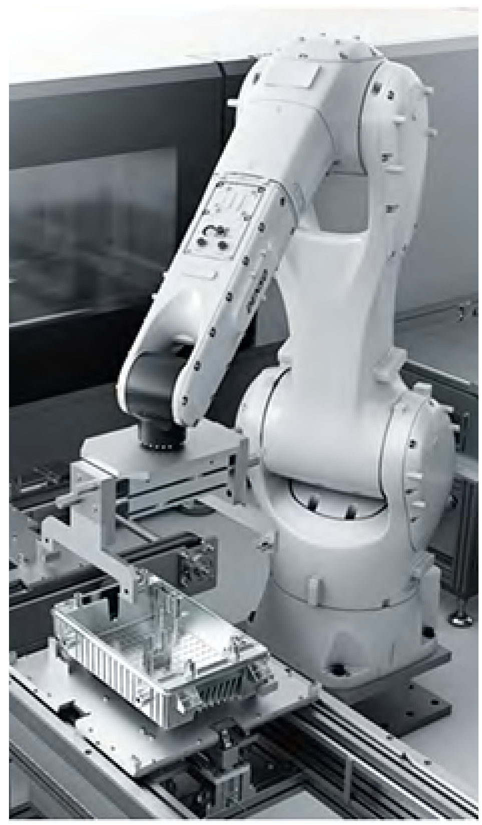


Figure 8: This six-axis articulated robot is available in ISO 5 (class 100) cleanroom models. (Image source: Denso Robotics)

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.

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)

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.

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.

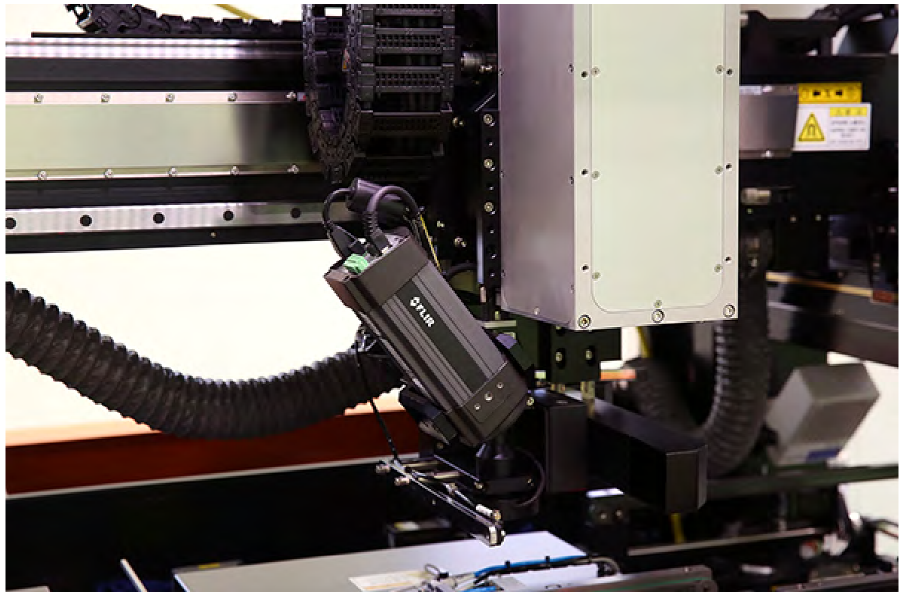
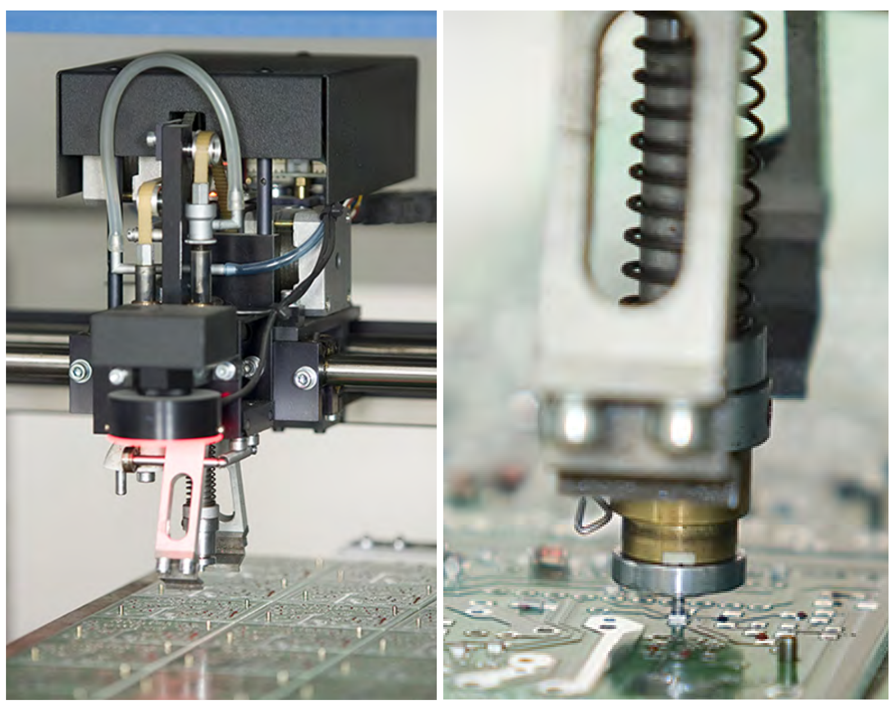


Figure 10: Cartesian robotics can be fitted with imaging equipment (such as this thermal-imaging camera) for thermography of PCBs produced with laser-assisted bonding techniques. (Image source: Teledyne FLIR)



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

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.

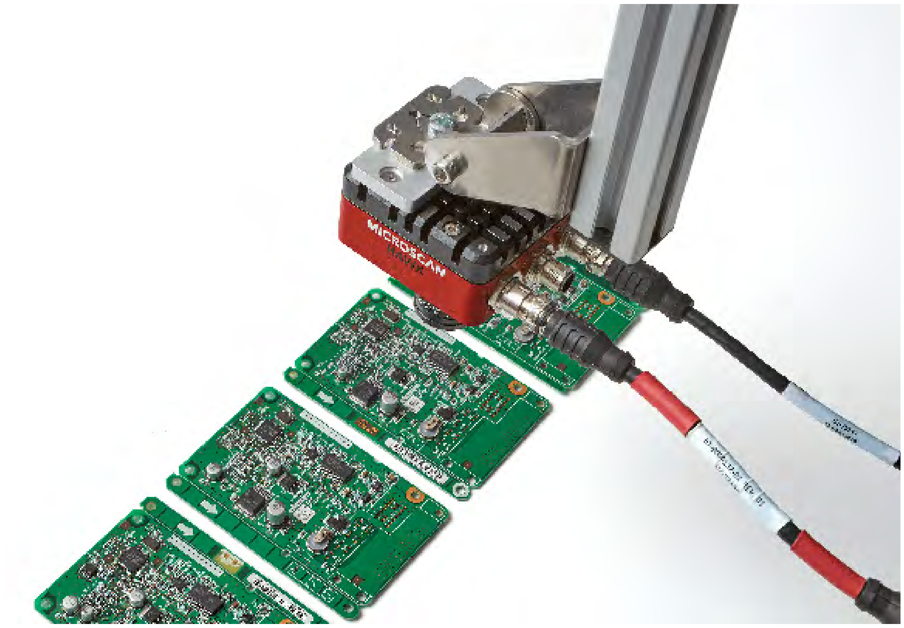


Figure 12: Machine-vision feedback often informs cartesian system responses. Massive onboard processing power, advanced algorithms, and an FPGA let HAWK smart cameras (including the model shown here) achieve real-time trigger response for code reading, verification, inspection, and guidance for 4,000 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)

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.

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.

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)

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

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.

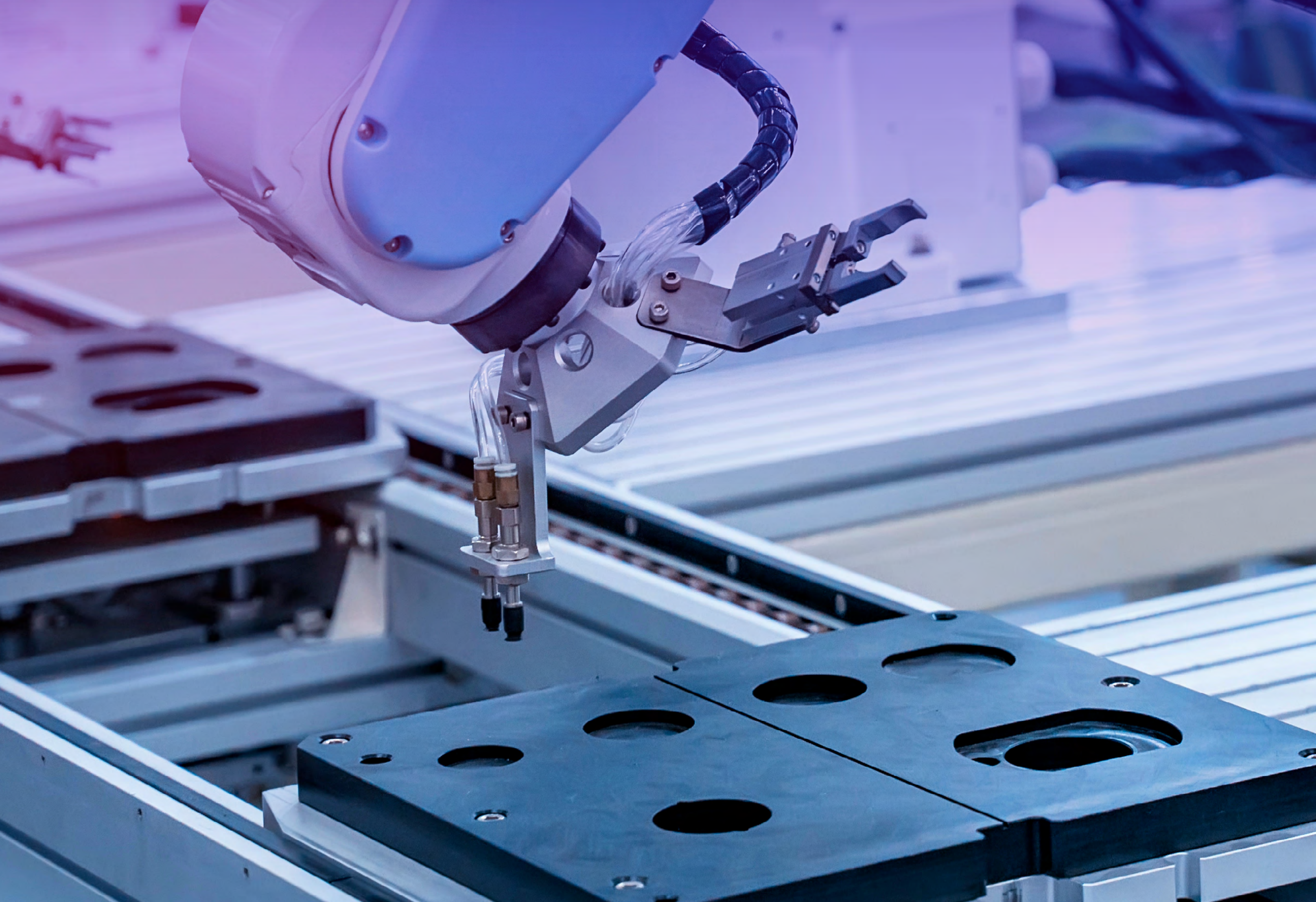
Conclusion

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.

Use compact industrial robots to make any shop more productive

By Richard A. Quinnell
Contributed By DigiKey's North American Editors



Major manufacturers have long used dedicated industrial robots to boost efficiency and throughput in their production lines, giving them cost advantages that smaller operations could not match. But industrial robots are no longer exclusive to large-scale production. Smaller, general purpose robots are now available to boost productivity for a wide range of operations, working alongside humans as partners in workspaces as small as two square feet.

This article looks at what has held robots back from large-scale deployment in smaller operations as co-worker robots and why that has changed. It then introduces example robots in the form of manipulator arms from KUKA Robotics Corp. and shows how they can be applied in both large and small facilities.

The rise of robotic co-workers

Several factors have historically limited industrial robotics to large scale operations. A principal factor was the difficulty in generating a return on investment (ROI). Early industrial robots required considerable design effort and were customized—unique to their task. As a result, they could only handle a narrowly defined range of operation. The resulting cost and inflexibility meant that the robot had to offer substantial efficiency and throughput improvements over manual methods and be utilized in a high-volume production line to justify its implementation. Small to mid-sized facilities could seldom meet such conditions.

To maximize benefit, most industrial robots for large-scale operation have also tended to be large and fast, working with materials and at speeds beyond human capabilities (Figure 1).

Figure 1: Traditional industrial robots tend to be large and fast-moving, requiring protective cages to ensure worker safety. (Image source: KUKA Robotics Corp.)

The momentum of the robot can be high enough to injure or even kill any worker struck while in the movement path. To keep workers safe, large industrial robots need to be isolated behind cages or other barriers with interlocks so that human entry into their operating space will shut them down.

The introduction of compact robotic manipulator arms, such as the AGILUS KR 3 R540 from KUKA Robotics, has given industrial facilities managers more options (Figure 2). These devices provide a generic, off-the-shelf platform offering considerable operational flexibility at a relatively modest cost. Coupled with suitable end-effector attachments such as grippers or tools mounted at the end of the robotic arm, these generic platforms greatly expand the range of activities for which a robotic system can be created to generate a suitable ROI. Further, these robotic arms can readily be programmed for different movements or repurposed with different end-effector mechanisms when their initial applications expire, extending their payback potential.

Another key feature of these compact industrial robotic arms is their ability to fit into compact workspaces and integrate with existing production efforts. Unlike their more massive cousins in large manufacturing facilities, compact robots can also serve as a partner to human operators rather than a replacement for them. Such compact collaborative robots—or cobots—are designed for physically close human collaboration without the need for protective cages or other such barriers to keep humans out of harm's way as the robots go through their paces. Compact robotic arms are less massive and move more slowly than traditional industrial robots, allowing compact robots to stop on contact, minimizing the potential for injury. Further, they often have proximity sensors built in to help avoid collisions entirely.

A growing number of vendors have begun producing compact industrial robotic arms targeting small to mid-

Figure 2: Manipulator arms, such as the AGILUS KR 3 R540 from KUKA Robotics, are bringing ROI for industrial robotics within reach of small to mid-size operations. (Image source: KUKA Robotics Corp.)

size operations. One representative example is the KUKA Robotics AGILUS family, which has three versions. The AGILUS KR 3 R540, mentioned earlier, is the smallest. It operates within a two foot square footprint and can handle loads of up to 3 kilograms (kg), making it suitable for numerous assembly and materials handling applications. The AGILUS KR 6 R900-2 handles up to 6 kg and the AGILUS KR 10 R1100-2 up to 10 kg. All three have the same overall form and behavior and are available in kits, complete with a controller unit and handheld operator unit for controlling, monitoring, and programming the robot's activity.

The mechanical design of the AGILUS devices gives insight into the flexibility of robotic arms in general (Figure 3).

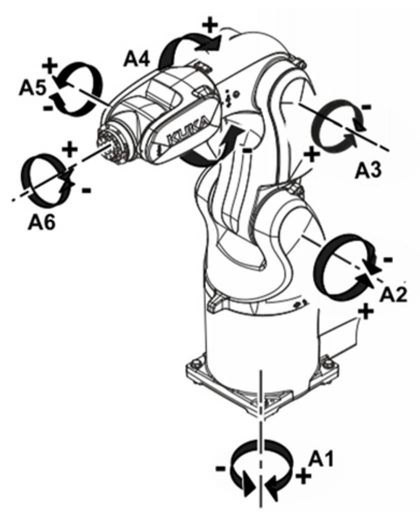


Figure 3: Six axes of motion provide flexibility in the mounting and reach of compact industrial robotic arms. (Image source: KUKA Robotics Corp.)

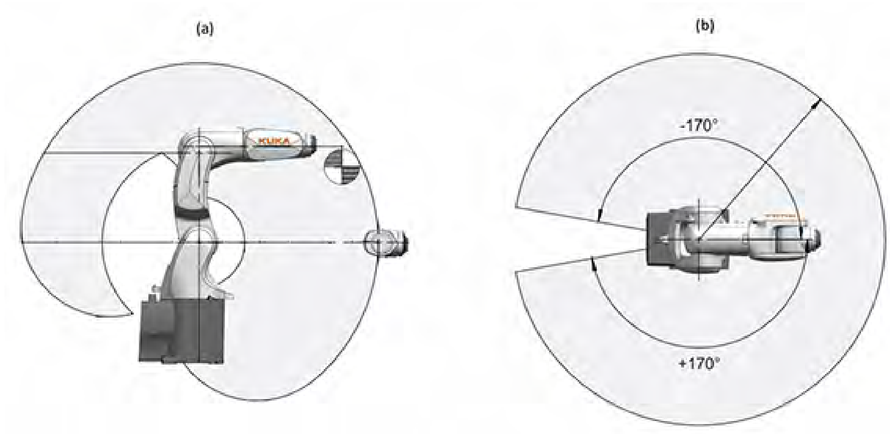


Figure 4: Robotic arms can position the center of their wrist within a vertical region (a) oriented nearly anywhere around the robot's location (b). (Image source: KUKA Robotics Corp., modified by DigiKey)

Like many robotic arms, the AGILUS devices have six movement axes: a rotating base (A1), a base arm (A2), a link arm (A3), an in-line wrist that can rotate (A4) and bend (A5), and a rotating mounting flange (A6) where end-effector devices are attached. Axes A2 to A5 work together to position the center of the wrist anywhere within the vertical operating profile, shown in Figure 4(a), while the rotating base can direct that vertical profile almost anywhere around the arm (Figure 4(b)). The center of mass for the end effector attachment can be offset from this position, as shown. The arm can be mounted on a floor, bench, cart, wall, or ceiling as desired without impeding operation.

Controlling a robot's movement with all these axes used to require sophisticated programming skills, but that has now been simplified. Robotic arms typically come with a controller computer and a user interface tablet that allows a user to move the robot using simple directional buttons to reach desired "waypoints." Logging a series of waypoints defines the complete sequence of motions the robot can follow automatically. Some robotic systems also allow the user to manually position the robot arm to desired waypoints instead of using the directional buttons.

Both approaches serve to "teach" the robot by example what movements it is to execute, which it will then be able to repeat upon command. The ability for the user to teach rather than code not only simplifies initial robot setup for a task, it allows for easy adaptation of movement as requirements evolve. The control tablet further allows the user to refine and correct movements as needed during production activity.

These types of robotic arms with simplified control programming provide an off-the-shelf foundation for industrial automation solutions, serving as the position manipulator for an end-effector mechanism appropriate for the task to be performed. Such end-effector mechanisms can range from simple grippers for pickup, position, and place operations, to machine tools such as screwdrivers and drills, to complex systems such as soldering irons and paint sprayers. The target application will dictate what end-effectors and system integration efforts are needed to create a full solution.

End-effector mechanisms designed for many common operations are available from robotic arm vendors as well as third-party system integrators. For picking up and manipulating objects, for instance, there are grippers with jaws, two or three fingers, and magnetic or vacuum pickup mechanisms available from a host of different vendors. Drills, screwdrivers, grinders, and blades for fabrication and assembly applications can also be found.

Complete application solutions are even becoming available as stock solutions from robotic arm vendors. KUKA Robotics, for example, offers a series of "ready2 use" systems for riveting, paint spraying, arc or spot welding, and micro-screw fastening applications, among others (Figure 5). These systems include end-effector system elements, controller elements, and system software along with the robotic arm as a pre-configured automation package.

Figure 5: Compact industrial robots that are complete system solutions for common applications are now available "off-the-shelf", such as this painting system from Dürr Group and KUKA Robotics. (Image source: Dürr AG)

The painting package, for instance, was developed in conjunction with mechanical and plant engineering firm Dürr Group and is based on the AGILUS KR 10. It includes the atomizer, pump, and color changer for high and low pressure, one or two component, water or solvent-based paint applications. The Dürr EcoAUC control unit regulates the painting process while the KUKA KR C4 controller handles robotic arm motion.

But users are not limited to such pre-configured systems when applying compact robot technology in their operations. Because of the robotic arm's installation and movement flexibility, ease of programming, and versatile end-effector attachment flange, a wide variety of custom applications are possible. The key is to identify repetitive tasks in an existing production process that the robot can assist with or take over from human operators.

Siemens, for instance, is using a small robotic arm in its electric motor production for the stator component. The stator is made of punched magnetic sheet steel with an aluminum bearing plate that needs machining to bring within tolerances. The robotic arm has taken over the repetitive task of taking workpieces out of a carrier, placing them in an automatic lathe for machining, removing the finished workpiece, cleaning it in an air blast, and placing it into a measuring station to check the tolerances.

The robot's controller works in conjunction with other pieces of equipment to scan the workpiece barcode for tracking purposes, and to move the measured workpiece either to a carrier for transport to the next processing station or to a holding station for a human operator to make adjustments or replacements as needed. The robot arm's safety features allow the human and robot to operate in the same workspace without protective fencing or other barriers that might impede workflow.

Tasks requiring repeatable precision are also suitable for robotic handling, even for small production runs. ALNEA, for instance, has set up a robotic arm to handle selective soldering in its SMT production line. Selective soldering is needed when components might be damaged by the heat involved in bulk wave or reflow soldering. Hand soldering an SMT device requires both a steady hand and careful timing to avoid solder bridges and heat damage.

In the ALNEA application, the robotic arm provides the steady hand while the end-effector soldering iron's control system ensures both the temperature and timing of the soldering operation are within set parameters (Figure 6). With the first units of a production run, the human operator sets the soldering parameters and trains the robot arm on the movement sequence. Operators then help position the pc board and components for robotic soldering during the rest of the production run. The company saw a 50% reduction in production time by using the robot for selective soldering.

The task to be automated may not even need to be a complete operation to prove economically beneficial. For example, the BMW Group has integrated a robotic arm into its existing workflow for the production of reinforced side members in automobiles simply to relieve the human operator from a repetitive task requiring precision that human operators found difficult to sustain throughout a work shift. The task was to position a number of metal reinforcement plates at points along the frame prior to inserting the frame into an automated welding station. However, the strain of repeatedly performing this otherwise simple task of positioning resulted in increased errors and reduced throughput as the day wore on.

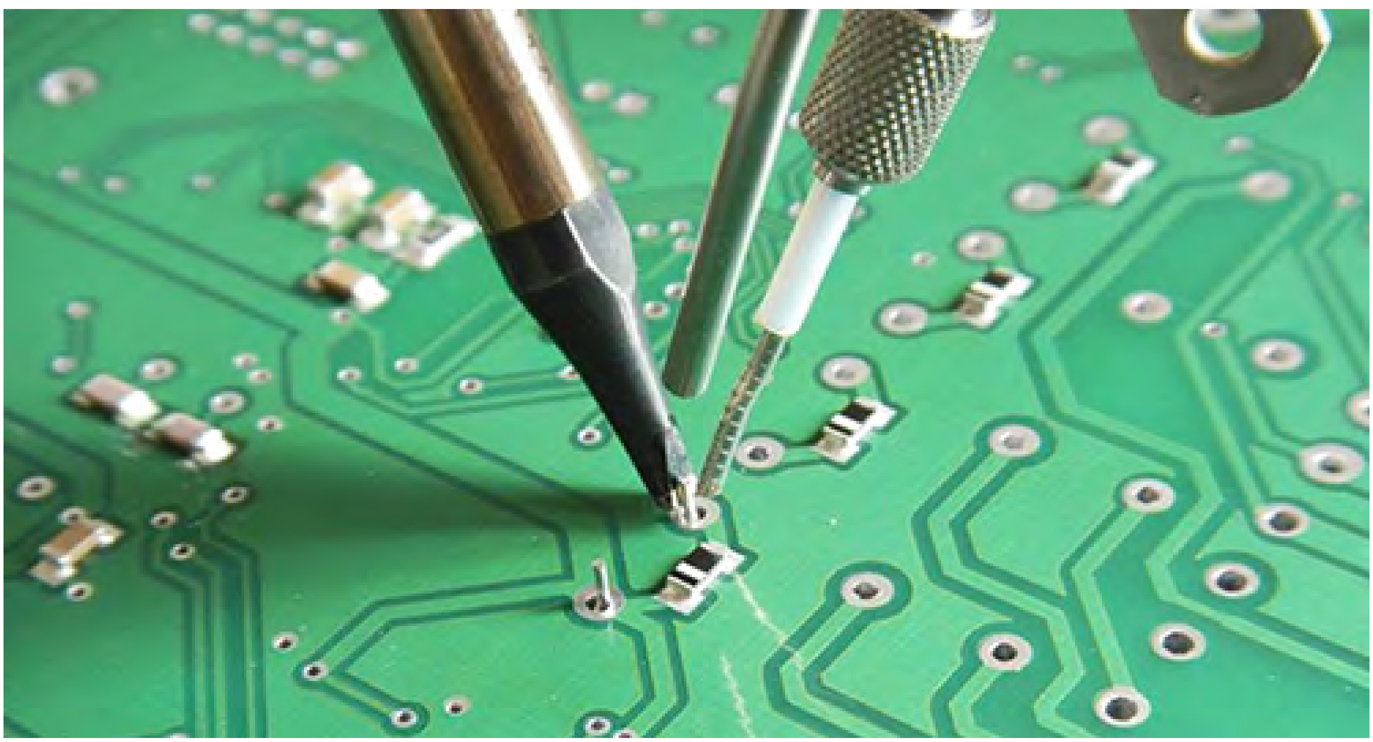


Figure 6: Robotic arms can provide the steady hand and precision positioning needed for applications such as selective soldering in pc board production. (Image source: KUKA Robotics Corp.)

BMW inserted the robotic arm into this operation specifically to take on the task of properly positioning the plates once the human operator had counted out the right number of plates and provided them to the robot. No other changes to the workflow were required. But by assuming the precision placement portion of the operator's task, the robot reduced fatigue-induced errors and ensured sustained production throughput throughout an entire shift. The robot's safety features allowed it to work alongside the human operator without a need to modify the workspace.

Conclusion

Industrial robots have traditionally been associated with large industrial facilities, mainly due to cost, complexity, and safety. However, an ever widening array of repetitive tasks, from simple positioning to painting complex shapes, are becoming economically feasible for compact industrial robots.

With their modest space requirements, simplified programming, falling costs, and ability to readily and safely integrate into an existing, human-centric workflow—without the need for physical barriers—such robots are able to gracefully join the workforce without disruption. Now, industrial automation is no longer just for large, high-volume operations with deep pockets: small shop operations can also incorporate a robotic hand.

Fundamentals of pneumatic grippers for industrial applications

By Jeff Shepard
Contributed By DigiKey's North American Editors

Figure 1: Shown here is a two-finger pneumatic gripper on the end of a robotic arm. The jaw fingers make physical contact with the object to be grasped and are what allow the gripper to hold and release objects. (Image source: Kazakov • Getty Images)

Pneumatic grippers are electromechanical devices used in industrial applications for grasping and lifting, holding, rotating, and placing objects into set locations. These grippers typically install on the furthest reaches of either workpiece-processing machines or six-axis, Cartesian, or selective compliance articulated robot arm (SCARA) robotic arms as end effectors to execute various material-handling tasks.

Complemented by the last several decades' worth of advancement in controls, sensors, and feedback connectivity, pneumatic gripper motions (primarily for grasping and releasing) typically coordinate with those of the machine axis or robotic arm to which they mount.

Pneumatic gripper operation

Pneumatic grippers are far and away the most common gripper type for industrial applications involving robotic pick-and-place, machine tools, workpiece machining, and assembly tasks. Though some pneumatic grippers take the form of bladder-type and suction-cup end effectors, pneumatic grippers with fingers or jaws are the most prevalent and those generally assumed when no other context is given.

Jaw pneumatic grippers rely on compressed air for their operation. Upon some command signal, valves allow air to travel through internal channels and activate mechanical linkages — which in turn open and close the gripper fingers. Supporting this primary set of subcomponents are pneumatic hoses, control subcomponents and wiring, mounting flanges for attachment to machines and robots, failsafe mechanisms, and a housing that encloses these components.

Though the released position (held by a mechanical compression spring) is usually the default, gripper designs that default to grasping are also available on the market. Where a closed (gripping) position is the default, a spring provides the gripping force … and allowing compressed air into the gripper serves to open the jaws. In fact, certain grippers rely on compressed air for both grasping and releasing force.

Figure 2: Parallel, three-finger, and angled grippers are the three most common gripper types in industrial applications. The three-finger pneumatic gripper shown here has fingers offset by 120° to gently stretch O-rings and mount them onto recipient shafts. (Image source: Schunk)

Video 1: In one common variation, the pneumatic gripper connects via a specialty hose to a compressed air system. The force of compressed air displaces a piston that in turn (through some gear, toggle, or slide linkage) causes the external jaws to actuate through their range of stroke. (Video source: Schunk)

Control of air into a pneumatic gripper is often reliant on preprogrammed grasp-release cycles … or (in more sophisticated applications) feedback from sensors that detect held objects.

Types of pneumatic grippers

Jaw and finger pneumatic grippers are classified by their:

- Kinematic arrangement, number of fingers, action, and type of mounting
- Physical size and maximum gripping force
- Jaw and housing construction — including level of ingress protection
- Connectivity to common industrial control networks

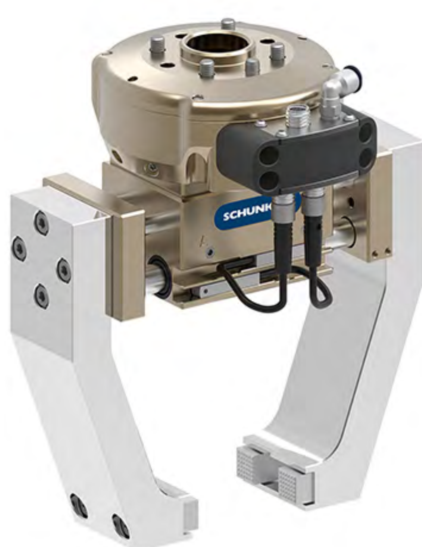


Figure 3: Two-finger parallel grippers in Schunk's PGN-plus series deliver long jaw strokes and include seals, dirt-resistant round linear guides, and high-strength aluminum-alloy housings to survive dirty industrial environments. (Image source: Schunk)

First commercially available in the 1970s, pneumatic two-finger grippers are the most widely applied today — accounting for more than half of all pneumatic gripper applications. The fingers in these designs slide or swing on pivot points to close like a gate or lobster claw around target objects. They can employ either parallel jaw action or angled finger action.

Pneumatic grippers with parallel jaw action: In parallel grippers, the two fingers slide inward and outward — in straight-line motion — on the same axis along tracks in the upper gripper body. Typically, the inward sliding action is what grasps the workpieces or other objects. However, applications abound in which the two fingers slide outward to secure hollow or open workpieces (such as O-rings or cylinders, for example) from their inner diameters. Benefits of these dead-simple grippers abound. The various subcomponents for such grippers are simpler to manufacture than others, making these grippers very cost-effective. In addition, there is one steady gripping force over the entire finger stroke — which simplifies the work associated with applications involving delicate or otherwise pressure-sensitive workpieces. Finally, parallel grippers can be designed to close and open quite wide — even to a couple feet or more.

Pneumatic grippers with angled finger action: In these grippers, the actuated ends of the fingers are pinned to a fixed pivot point. Upon application of pneumatic power, a piston action and mechanical wedge element cause the fingers to swing closed (or in other variations, open) like French doors. In the open position, the jaws wing outward beyond the gripper body or project straight out. In the closed (typically grasping) position, the tips of the gripper fingers tilt inward to close into a tapered grasping shape. One design caveat when using these grippers is that, unlike parallel-finger types, angled fingers have limited strokes and generate a gripping force that's variable along the actuation stroke. That said, angled finger grippers under direct piston action can have exceptionally high gripping force — up to 2,300 N or higher.

Higher finger Counts: three and four-finger grippers

Where two-finger pneumatic grippers are inappropriate to handle an operation's workpieces, three and four-finger grippers (and even five-finger grippers in specialty humanoid-type robotics applications) can provide better gripping support and stability. To be clear, though: all such grippers are far less common than two-finger grippers … and only three-finger grippers are common in industrial applications. Their higher level of applicability comes at a cost, but three-fingered grippers can grasp workpieces and other items with more complex or challenging geometry. So-called self-centering three-finger pneumatic grippers include a trio of fingers even spaced (120° apart on a machine chuck) that necessitate finger swap-outs for an operation change. These close inward to grip workpieces at a center point. In contrast, so-called adaptive three-finger pneumatic grippers set two fingers together and the third to oppose them like a thumb. Most common on mobile robotics, such grippers can pick up objects in several ways to accommodate variations on a given workpiece geometry.

Internal gripping and double acting

Though the majority of pneumatic grippers are used for grasping or cradling parts around their exterior (contacting outer object surfaces) internal gripping operations are essential to many assembly applications. Here, the gripper fingers open to grasp objects with hollow geometries from within. In some cases, grippers can be tasked with both external and internal gripping operations — though must be designed to have both capabilities.

Jaw and finger pneumatic grippers can take the form of single and double-action grip types as well. In single-acting grippers, the force of compressed air generates the gripping motion and force. Once the supply is shut off, the fingers return to and stay in their original position thanks to the action of a simple compression spring. In contrast, double-acting grippers require compressed air actuation for both the grip and release motions. In fact, double-acting grippers may be capable of both internal and external gripping as described above.

Common pneumatic-gripper applications

Pneumatic grippers are widely used in industrial settings — especially for automated workcells, assembly and production lines, machine tending associated with advanced manufacturing, hazardous plant areas, and logistics as well as automated warehousing operations. A small but growing array of commercial, recreational, and consumer robotics applications (including mobility bionics) also make use of pneumatic grippers.

Consider pneumatic grippers for material handling in food and beverage processing and packaging equipment. Here, the clean operation of pneumatics


Figure 3: Two-finger parallel grippers in Schunk's PGN-plus series deliver long jaw strokes and include seals, dirt-resistant round linear guides, and high-strength aluminum-alloy housings to survive dirty industrial environments. (Image source: Schunk)

is an asset — and pneumatically actuated finger grippers complement the use of other air-powered bladder and suction gripper types to handle everything from boxes and wine bottles to eggs and bags of candy. In contrast, grippers in machine-tool applications are typically designed for just one workpiece type — and in some cases, are even tasked with holding those workpieces as machining or other processes are performed. Where pneumatic grippers are involved in assembly or sorting and selecting, they're often supported by sensor or even machine-vision systems to direct their actions. Otherwise, Hall Effect and proximity sensors in the gripper can provide sufficient feedback.

Advantages and limitations of pneumatic grippers

One key benefit of pneumatic grippers over other gripper types is that they're available in numerous sizes and grip forces, ranging from a few Newtons to several kilo-Newtons, and can be adapted for different applications — even those requiring thousands of repetitions per hour. Industrial pneumatic grippers also offer unrivaled repeatability for precision automation tasks. In addition, pneumatic grippers:

- Are cost and power effective to run
- Are lightweight and compact — especially when compared to certain motor and hydraulic-based options

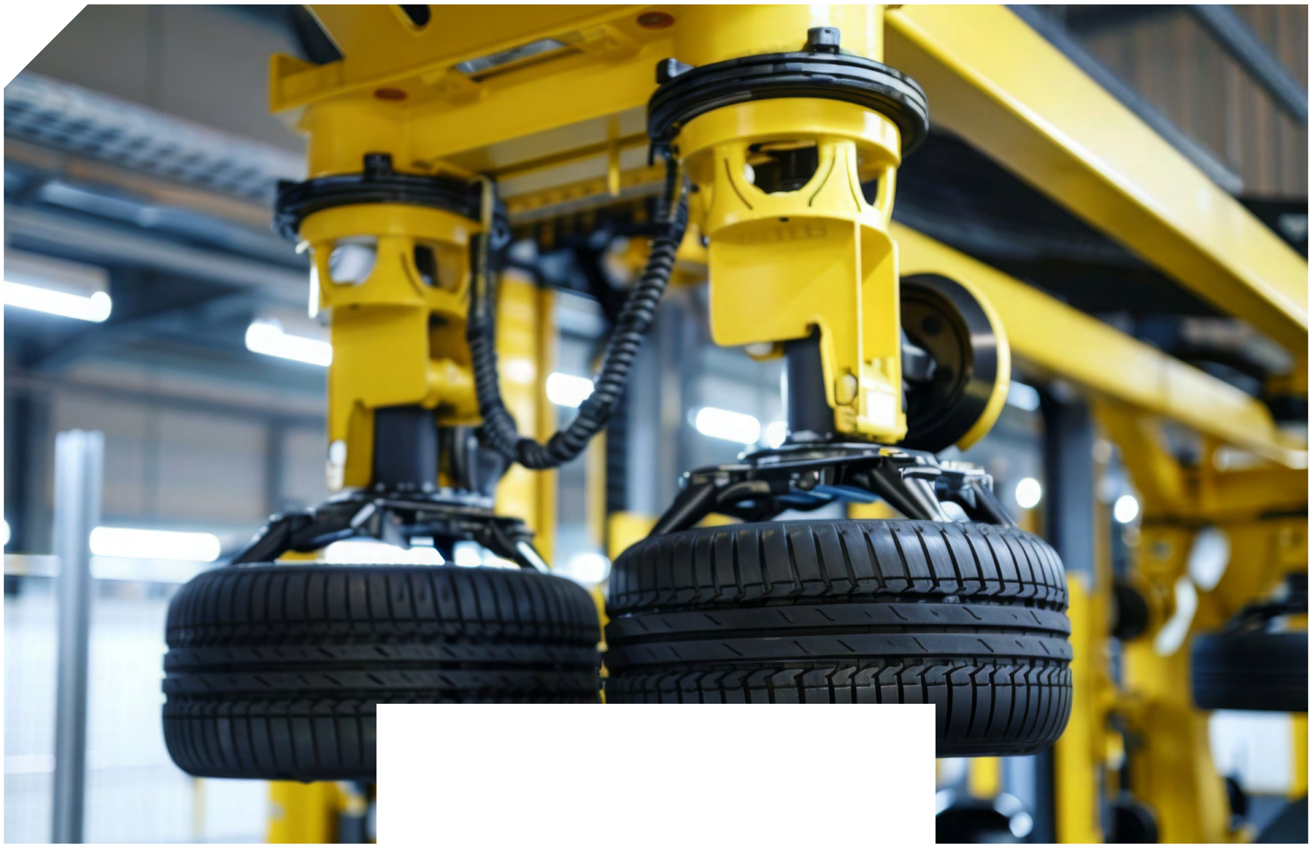
Unlike their hydraulic and electric counterparts, pneumatic grippers are largely unaffected by their working environments. That's in contrast with electrically actuated grippers with sensitive electronics than can malfunction in moist environments.

Of course, pneumatic grippers do have some drawbacks and limitations. These are primarily related to the operational cost and complexity of pneumatic designs and compressed-air systems in general. Initial setup of such systems can be costly and complicated. That said, there is economy of scale where an industrial operation already makes use of compressed-air systems elsewhere.

Pneumatic gripper selection criteria

Sizing and specifying pneumatic grippers for a given material-handling application should start with the clear definition of key design parameters.

Size and gripping force: Pneumatic grippers should open enough to accommodate the objects being handled. Required pneumatic-gripper finger force depends on the weight of objects being handled as well as the finger-to-object coefficient of friction, area of finger-to-object contact, and force to counteract that of the opposing fingers. Highly engineered gripper-finger materials and coatings can boost the finger-to-object coefficient of friction. Of course, the jaws of pneumatic grippers for use in food or pharmaceutical



applications must be made from or coated with FDA-approved materials.

There is wide variability in the ratio of the handled part size and weight — with lightweight yet bulky items often posing the greatest gripper design challenges.

Part geometry: Handled objects with complex geometries can often necessitate pneumatic grippers with three instead of two fingers. That's especially true where a series of workpieces may have slightly varying geometries. But where workpieces are consistent, two-finger grippers can incorporate customized surfaces and shapes to accommodate specific gripping points on these objects. The cost savings of two-finger grippers can often justify their use wherever this solution satisfies the operation's requirements.

Operating environment: Pneumatic gripper bearings, internal mechanical elements, and housings abound to satisfy clean and contaminated operating environments. Especially important are pneumatic gripper temperature ratings (that stipulate ranges within which a gripper will optimally function) as well as IP ratings that define the level of particulate matter and moisture a given gripper can resist before ingress.

Conclusion

Pneumatic grippers are robotic end effectors that are essential to material handling on production lines. These grippers hold, orient, and place workpieces and other objects for processing, assembly with other parts, or rejection — as off a conveyor through a quality-control station. Despite the drawbacks of compressed-air systems necessary for pneumatic gripper operation, these are often the cleanest, fastest, and most suitable choice for parts handling.