



Robotic Industries Association

# **Collaborative Robotics**

## **End User Applications White Paper**



Collaborative robotics, which brings humans and robots together in a shared workspace, continues to be one of the hottest topics in industry today. Human-robot collaboration is emerging across multiple sectors of manufacturing, logistics, professional services, and the consumer-facing service industries.

The Robotic Industries Association has conducted a study of end user applications across a variety of industrial and commercial settings. We explored end-use cases in automotive, aerospace, energy, home appliances, personal and household consumables, life sciences, and even a startup with a novel digital approach to manufacturing. We discussed their automation strategies and implementation procedures for adopting collaborative robotics, the advantages and limitations of the technologies, workforce preparation and training, and the lessons learned along the way. Due to the sensitive nature of their projects, some study participants have elected to remain anonymous.

This paper will build upon an [RIA study conducted in 2014](#) when collaborative robotics was still a very new concept. Many products on the market today were still in R&D, features were limited, skeptics were rampant, and tried-and-true applications were few and far between. Over the last few years, casual curiosity has given way to successful use cases with proven ROI. Applications that

were once limited to simple pick-and-place tasks are now varied. We're seeing human-robot collaboration in sorting, kitting, packing and palletizing, inspection, machine tending, gluing and sealing, polishing, assembly, intralogistics, and even [welding with cobots](#).

Now nearly all of the major robot manufacturers offer robots specifically designed for collaborative operations. Three main groups of collaborative robotics are covered in this discussion. Each has its place in the industrial landscape.

### **1. Power and Force Limiting Robots (PFLRs)**

These types of specialty industrial robots, often referred to as cobots, have inherent limits on their speed and the forces they can exert, and the payloads they can handle. In most cases, these robots can work in close proximity or directly with humans without the need for safety fencing or other peripheral safety devices.

### **2. Traditional Robots Used in Collaborative Applications**

These can be standard industrial robots, even high-payload models, which are able to work in proximity with humans through the aid of advanced software features in the latest robot controllers, coupled with the use of safety sensors to detect the presence of humans or objects.

### **3. Mobile Robots**

This category of collaborative robots



includes intelligent mobile platforms that are autonomous, meaning they not only determine the best route from one destination to another after learning the layout of a facility, but they also have the ability to automatically adjust the route, in real time, if they encounter an obstacle in their path. Many of these robots are designed to work around people. This category also includes mobile manipulators, which can consist of an autonomous mobile platform with a robotic arm mounted to it (usually an ad hoc system), or an autonomous mobile platform and robotic arm designed and manufactured as a single integrated unit with one controller.

### **Why Collaborative Robotics? Safety First**

The strategy behind adopting collaborative robotics as a form of automation is as varied as the many types of collaborative applications now in production or testing. The underlying reason for adopting collaborative robotics is usually safety, particularly for the humans working in close proximity to or directly with the robots. Sensors to control force, avoid collisions with humans and other equipment, and detect the presence of obstacles play a big role in this endeavor.

Manufacturers, integrators, and users stress the importance of considering the entire application or collaborative environment when evaluating safety. A thorough risk assessment is a must as prescribed

in the standard, *ANSI/RIA R15.06-2012, Industrial Robots and Robot Systems – Safety Requirements*.

A consumer goods manufacturer noted an example of a colleague wanting to use a cobot for loading razor blades into a machine. Even though it may be capable of performing the task, you don't want a collaborative robot holding a stack of several thousand sharp razor blades. In that case, it's no longer a collaborative application.

Beyond the robotic arm, you need to consider the tooling, the product you're handling, and the environment in which it's used. All aspects of the operation need to be factored in when evaluating whether an application is safe to operate as a collaborative system.

### **Leaders on the Forefront of Technology**

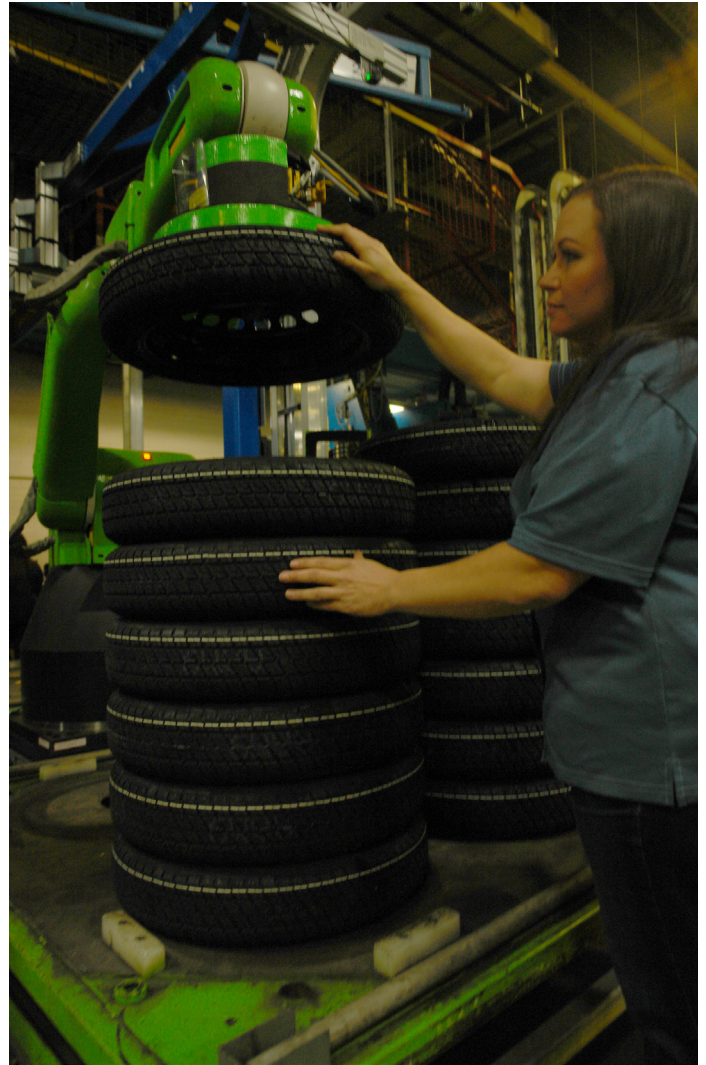
Many large multinational corporations that want to be on the forefront of technology are adopting robotics, and particularly collaborative robotics. They want to lead the market by incorporating disruptive technologies now rather than chasing after their competitors later. These thought leaders want to maintain their competitive advantage in quality, efficiency and cost, while elevating workforce safety.

Companies like General Motors have a long history of robotics innovations. The automaker has roughly 35,000 robots in production worldwide and is introducing new collaborative applications every month.

*"We look for technologies that make us more efficient, build on our scale, and give us high-quality products. In that light, collaborative robotics is not really that different. We will never compromise on quality or safety, so if you have a robot that gives you high-quality manufacturing capability and you add the safety piece of it, we're very interested. We like to use the latest and greatest technologies in our manufacturing plants." – Marty Linn, Manager of Advanced Automation Technologies and Principal Engineer of Robotics, GM*

Already a large-scale user of FANUC robots, GM is using both traditional robots in collaborative applications and power and force limiting robots, including the FANUC family of CR Series robots. These robots are recognized by their distinctive green color, a departure from FANUC's trademark yellow robots. GM has a common global manufacturing controls architecture and appreciates that FANUC robots, including the collaborative series, are compliant with that architecture.

GM is a heavy user of FANUC's Dual Check Safety technology. All of the major traditional robot manufacturers have their own versions of this [software-based technology](#) integrated in to their robot controllers. When combined with safety mechanisms, such as safety-rated sensors, the technology allows for human-robot collaborative operations even with high-payload robots.



*Photo Courtesy of General Motors Co.*

For example, all of GM's manufacturing body shop cells that weld closure systems like doors, hoods, and decklids use this technology. It allows humans and heavy-duty robots to share the same workspace when needed to load and unload components or change out fixtures. At GM these types of cells, on the order of 50 cells a plant, use light screens, safety scanners or safety mats, all Category 3 PLd certified safety devices, to monitor safe zones. Linn says their plants have been using this type of collaborative operation for 15 to 20 years.

For almost three years now, GM has been using FANUC CR-35iA collaborative robots and more recently its smaller payload versions, all with their green soft foam bodies, in a variety of human-robot collaborative applications. They use the 35 kg version to help GM team members stack spare tires and load them into vehicles.

With a machine vision device attached to the arm, the cobots are used in quality inspection to check the surface or dimensions of parts and assemblies. For bolt torqueing tasks, the cobot is used to position the torque tool onto the bolt and then torque it down to the specified force. In glue dispensing, the cobots are saving the employees from exposure to hot, smelly glue and increasing application accuracy.

The cobots are also used for headlight target positioning. A cobot holds a sensor while an operator adjusts the headlights to the target. They are also used in long-range radar calibration for vehicles equipped with advanced onboard features such as lane departure and collision alerts and avoidance capabilities. Again the cobots are used to position target sensors around the vehicle while operators make adjustments nearby.

By using robots that don't require safety fencing, GM's operators are able to walk freely among the cobots. That also allows GM to pack several different operations in to one station, saving floor space. The headlight

positioning application replaces previous hard automation, allowing GM to more easily test different vehicles and distances, while allowing employees easy access to the robots.

*"We're finding a lot of different applications where we can help our operators. They are happy to be using the latest tools and technologies that make their jobs easier to do and allow them to build the highest quality vehicles." – Marty Linn, GM*

### **Side by Side on the Assembly Line**

GE is another multinational corporation on the forefront of technology. Across the company, robotics is used in the aerospace, power generation, and healthcare divisions, including this [autonomous mobile robot at GE Healthcare](#). RIA and GE discussed the strategy behind introducing collaborative robotics at GE's commercial lighting factory in Hendersonville, North Carolina.

The Hendersonville facility is part of Current, powered by GE. This is a new startup within the GE family that goes beyond supplying energy-efficient LED lighting products to providing solutions for transforming lighting into a digital infrastructure for intelligent buildings and smart cities. Hendersonville is one of the top ten plants in all of GE for Brilliant Factory, an initiative that merges lean and digital manufacturing to boost productivity.

But unlike most automakers, Hendersonville is not heavily automated with robots. Most of the assembly operations are manual. A strategic

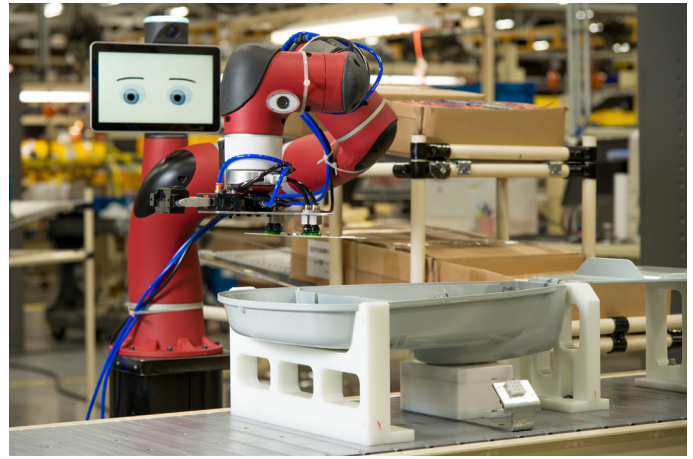


partnership between GE Ventures and cobot maker Rethink Robotics would change that. In 2015, the plant received the first production model of Rethink's new Sawyer collaborative robot, destined for GE's assembly line.

Hendersonville's outdoor light fixture assembly line is 40 to 50 feet long with seven operators standing along an indexing line. They start with the empty shell of an LED light fixture and at each station more components are inserted and screwed down or wires connected. One line can build up to 325 units a day. The tasks are all manual and very repetitive. GE engineers set out to automate some of that repetitive motion to reduce stress on their operators.

Their first application would be a learning experience. Sawyer was put to the task of placing components on the line, so that the operators could save time by not having to retrieve them. With Sawyer's support, the speed of the line increased.

However, for Sawyer to place the components on the line, they first had to be carefully organized and staged so the cobot could grab the components in the right order and orientation. GE's lean expert took one look at this setup and deemed it wasteful. The time and effort it took to stage the components for robotic manipulation quickly negated the gain in line speed.



*Photo Courtesy of Current, Powered by GE*

Sawyer was promptly "fired" and GE looked for a better opportunity to apply the cobot's efficiencies. Sawyer was soon inserting components in the light fixtures, but this time working with consistently shaped parts that were easily organized in to columns and presented to the cobot via PEZ-like dispensers, so that it could pick and place the parts in the correct location.



[Watch Sawyer on the job at GE](#)

The next task GE assigned to Sawyer they like to call the origami application. It takes place in the electronics manufacturing area where they

assemble power supplies called drivers. They start with a sheet metal box that has four sides with a cavity in the middle.

Previously, an operator had to load these metal boxes onto the line and then fold a flexible plastic sheet inside of the box to create a sealed cavity. The line can only hold about 30 boxes at a time, so the operator had to replenish the stack of boxes multiple times a day, pulling him away from his main job.

Sawyer was programmed to pick up these boxes, place them on the line, fold in the plastic sheets, and then push the boxes onto the line. This eliminated two hours of the operator's time.

### **Flexibility**

Even though the plant had to go through a couple of iterations before they found appropriate tasks for the cobot, its flexibility soon became evident. Sawyer is on a pedestal with wheels. When the first application failed in respect to lean principles, they were able to easily move the cobot and redeploy it.

*"We were able to move Sawyer to the other production area that day. Within four hours, we were roughing out a new task. Our products and technologies are changing so frequently that to invest in some expensive fixed automation solution would not apply. We needed a flexible solution and that's what*

*Sawyer brought to the table."* – Elliot Fishman, Manufacturing Engineer, Current, powered by GE

Today, cobots are making a larger contribution at GE. The latest application is used across four assembly lines. Sawyer is integrated with a Cartesian-style robot, and together they are applying silicone, or RTV, to a piece of clear flat glass that is used to cover the internal components of the LED light fixture.

Sawyer was *trained* to pick up the piece of glass with a suction gripper and place it on the XY table for the other robot to dispense RTV around the perimeter of the glass. When finished with the dispensing operation, the Cartesian robot alerts Sawyer to remove the glass and then the cobot presents it to the operator for installation on the light fixture. The operator in turn uses a suction cup to secure the glass and remove it from Sawyer's grasp. The RTV application is completely automated, requiring one less operator on the line.

The plant is also using Sawyer's integrated vision to check for a label affixed to the glass that indicates whether it's upside down, so it's not installed incorrectly. A recent software upgrade to the manufacturer's operating system called Itera helped empower Sawyer's vision capabilities. Eventually, GE hopes to use this vision capability to *teach* Sawyer to install the glass onto the fixture.

### **Ease of Programming, Teaching**

Notice we're using terms like teach and train.





*Photo Courtesy of Current, powered by GE*

This is another feature of many of these power and force limiting cobots. Rather than requiring complex coding to program tasks, the cobot's arm can be moved into position and then those positions recorded, making the teaching function similar to how you might demonstrate a task for a human operator. GE welcomed the ease of use.

*"I'm no robotics expert. With the simplicity of the Intera software, it's very easy to learn how to program robots. No more teach pendants. No more coding. You can move the arms. Move here, pick here, do this. That made it really easy to program tasks. Within the same day, we could move it somewhere else and program*

*a new task. That's pretty incredible for an automation solution."* – Elliot Fishman, Current, powered by GE

They were also able to program Sawyer to perform different interactions. When the operator pushes down with the suction cup on the glass to remove it from the cobot's grasp, it signals Sawyer to retrieve the next piece of glass and present it to the other robot for RTV application. If the operator notices something wrong with how the RTV was dispensed onto the glass, then a push up on Sawyer's elbow triggers it to take the glass back to the other robot for re-dispensing. The cobot's built-in force sensing allows for such functionality.

Sawyer's eyes move in the direction that the arm will move next, telegraphing its intent, much like humans tend to do. Users often say this has a humanizing effect and helps employees feel comfortable working in close proximity and directly with the cobot. In GE's case, these cobots are integrated right into the middle of the assembly line, safely working within inches of their human coworkers.

### **Tight Workspaces**

Whirlpool Corporation says floor space is also at a premium on their assembly lines. While the home appliance manufacturer uses many traditional high-payload robots in other parts of production for machine tending and fabricating the large drums for washing machines, the assembly lines are still mostly manual.



The assembly lines were historically designed for manual work and the nature of Whirlpool's products make the assembly processes quite complex. Automating them is particularly challenging in the way the lines are laid out in the factory and the manner in which parts are presented to the line. Recently, Whirlpool made a big push toward cobots to help tackle some of the repetitive, mundane tasks posing ergonomic risks to their workers.

Across the globe, Whirlpool has more than 50 Universal Robots in production. The cobots, like the UR10, are picking and placing components on the assembly line. Some are applying adhesives such as glues and sealants. Others have a camera mounted to the arm and are doing vision inspection to ensure that parts are produced, assembled, and wired correctly. They are also using FANUC's green-colored collaborative robots on one of their lines to help assemble appliances.

Whirlpool is evaluating Yaskawa Motoman's HC10 cobot for possible purchase. They are also investigating other types of pick-and-place applications and press tending with cobots.

Instead of having employees loading and unloading material from the presses, the robot would perform those repetitive tasks. [Press tending with collaborative robots](#) is becoming more common.



Like other manufacturers, Whirlpool is looking at power and force limiting robots for their ease of integration. They usually commission robot integrators to deploy their traditional robots, but Whirlpool was able to develop the in-house skillsets to deploy the cobots.

Whirlpool says they are more user-friendly, easier to program, and don't necessarily require an extensive background in robotics and automation to implement them. While Whirlpool appreciates the ease of Universal Robots' programming, they say the simplicity can sometimes work against you as applications become more challenging and complex.

### **Close Human-Robot Interaction**

Challenging and complex would describe many of the applications at Lockheed Martin Aeronautics in Fort Worth, Texas. Home to the

innovation behind the F-16 Fighting Falcon and the F-35 Lightning II, Air Force Plant 4 has spent the last 75 years changing the world of aviation, and also manufacturing technology.

Historically, the aerospace industry has seen limited use of collaborative robotics. That is changing. [Boeing's FAUB program](#) employs high-payload robots and mobile platforms to assemble the forward and aft fuselage sections of the 777 jetliner. The [Airbus FUTURASSAY project](#) is testing Kawada dual-arm humanoid robots for deburring and material handling.

Lockheed Martin's goal is to provide task-level automation solutions that reduce or eliminate strenuous and time-consuming manual processes, while providing maximum safety to technicians working nearby or directly with collaborative robotic equipment. Due to limited floor space and the complexity of some tasks, more of these robotic systems require close human interaction and collaboration.

The plant is experimenting with a UR cobot from Universal Robots to explore opportunities for automating inspection of panel gaps and mismatch during assembly. In the F-35 Aircraft Finishes Facility, Lockheed Martin is using three robotic spray cells, which use up to three traditional FANUC robots in each cell, simultaneously spraying coatings onto the aircraft. These traditional

robots have redundant safety features to prevent collision damage and human access to the spray cell.

*"We are exploring multiple automation and robotic applications, which typically involve traditional industrial robots with enhanced safety features to allow close operator support and monitoring. Traditional robots tend to have greater reach envelopes and payload ratings, which allow for a wider range of applications on our production floor." – Anthony Mann, Automation Team Lead, Lockheed Martin Aeronautics*

In 2016, Lockheed Martin implemented a robotic system that is both collaborative and mobile to mold low observable (LO) coatings directly to the contoured surfaces of aircraft. LO coatings reduce radar, infrared, and sonar detectability for stealth aircraft like the F-35 fighter jet.

The Mold-In-Place system consists of a traditional robot, a FANUC 900 with a 700 kg payload, mounted onto a 5 meter long mobile platform that an operator guides into position next to the aircraft. The molding process occurs in a standard aircraft preparation booth that does not restrict access to other workers. The system uses safety sensors, a teach pendant with a three-position enabling switch, and stanchion barriers to meet collaborative safety requirements during platform and robotic movements.

Mann explains that when the operator is using





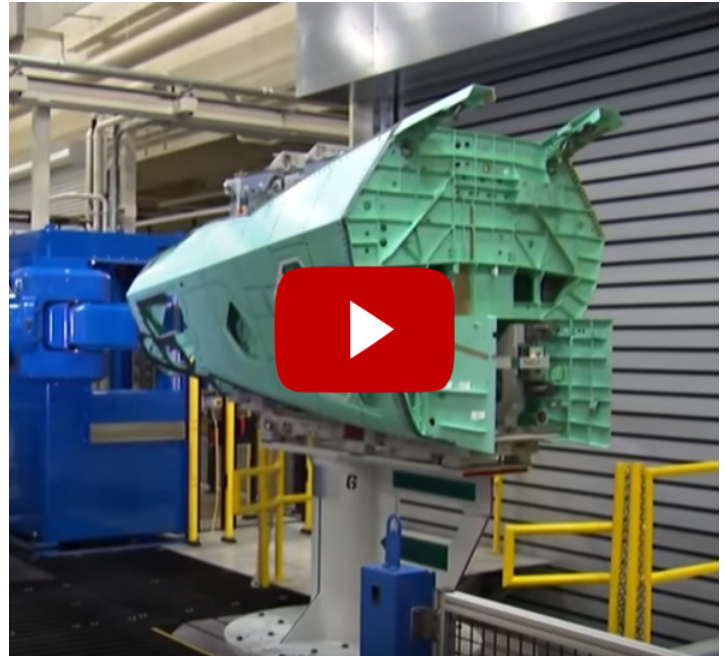
*Photo Courtesy of Lockheed Martin*

the robot to place the heavy composite mold tool, he needs to be in very close proximity to this moving 1-ton robot. The operator has to ensure that the mold tool is in the correct position and clear of other parts of the aircraft.

The same safety sensors that put a brake on the mobile platform if someone violates the restricted area around it, also detect anyone that comes within the working envelope of the robot and stops its movement until the space is cleared and the system is reset. If the operator is not depressing the button in just the right position and with proper pressure, he'll trip the sensors and stop the robot.

After the mold is placed in the proper position contacting the airplane, then the robot holds the mold in place while the LO coating material is pumped into the cavity by another machine.

The Mold-in-Place (MIP) system required a \$742,000 investment and saves \$6,000 per jet, or potentially \$27 million over the life of



[Catch a glimpse of the MIP system in this behind-the-scenes look at the build of the F-35 fighter jet.](#)

the program. The process reduces touch labor by 50 percent and allows concurrent work to be performed on the aircraft, eliminating a bottleneck for F-35 production.

Prior to MIP, Lockheed Martin applied stealth coatings to the F-35 engine intakes as a separate process in their paint shop. These robotically sprayed coatings contain high levels of volatile organic compounds, require significant preparation, and lengthy application times in a spray booth. MIP trimmed the process by two days and provides a green opportunity for Lockheed Martin to reduce their emissions footprint.

Jeff Drewett, Technical Fellow for Robotics and Automation, says by eliminating a robotic paint booth that would otherwise be required when Lockheed Martin went to full-rate production,

they save roughly \$20 million in capital expense. F-35 production is slowly ramping up and they expect to hit full-rate by 2020.

Going forward, Lockheed Martin is considering using both PFLRs and traditional robots in collaborative operations for a multitude of projects, including robotic drilling and countersinking of aircraft structures, installing fasteners and panels, and sealants application.

*"We are looking at ways of integrating robotic systems inside the current workspace of the operator, without having to have an additional cell built offline or taking up floor space. That's why we're taking a heavy look at collaborative robots and traditional robots with integrated safety. More and more, it has to be integrated into existing workspaces and can't always be put into a fixed, closed-off cell." – Anthony Mann, Lockheed Martin Aeronautics*

### **Mundane Tasks**

Laboratory environments also have tight workspaces with technicians working in close proximity to instruments and automation. High-throughput labs servicing large medical groups handle hundreds of test tubes a day, often relying on traditional four-axis SCARA and six-axis articulated robots for sorting, mixing, and capping and de-capping test tubes.

There are still the mundane tasks of transferring specimens between delicate



instruments among tightly populated lab benches. With collaborative robots like Precise Automation's PF400 SCARA robot, these high-throughput labs can now automate these repetitive tasks. Medical technicians can leave material handling tasks to the robots and focus their time on the science.

Laboratory users say robots are becoming so affordable and easy to implement, that it's more cost effective for them to buy a full robot unit than it would be to try to piece a motion system together with just motors and slides. If they



tried to piece together a Cartesian system, it will cost them more money than to buy an off-the-shelf robot.

Automation also allows these labs to drive down their costs, providing a competitive advantage and reducing the cost of testing. This makes testing more affordable for people battling chronic disease. DNA testing, in particular, can be very expensive. By reducing the cost barriers to DNA testing, cancers can be detected earlier.

A genomic sequencing system processing 96-well microplates will be completely automated with Precise Automation's P400 robots on rails. By taking a collection of instruments and having the robots service them with consumables and specimens, they are able to deliver the items that each machine needs when it needs them. Full automation will also allow the 24-hour lab to process samples around the clock.

The lab's electrical engineer responsible for automation engineering says that by automating with robots, they are able to reduce the human interaction in the clean room environment and eliminate some of the concerns about cross-contamination. Lab instruments are complicated devices, so they still need people in the lab to tend to the instruments in case of small faults, but he says they can reduce the number of people.

By using collaborative robots designed to

work safely with humans, they can also keep nearby lab instruments and processes online without shutting down the entire robotic cell to service one part of the process. This is vital when you have some test procedures that take hours to complete.

Large laboratories are not the only end users in the life sciences sector taking advantage of collaborative robotics. This [startup is racing for the cure](#).

### **Partial Automation**

A consumer goods manufacturer says collaborative robotics opens up the opportunity for partial automation. Historically, to automate a production or packaging process, it was an all-or-nothing proposition. You had to fence the entire production cell.

With the ability to have humans and robots working together in the same workspace, now you can automate specific pieces in that process, such as the types of tasks where a human might be prone to repetitive stress injury. With partial automation, you can get improvements in productivity, quality, and safety in areas where it makes sense to use a robot, but still take full advantage of the capabilities, skills, and creativity of the people working in the same production area.

This manufacturer has over 100 cobots by Universal Robots in production across their global locations. The majority are the UR10, which is the 10 kg model, because they need

the higher payload and reach. The cobots are used for end-of line palletizing of boxes where floor space is tight. There's not enough room for a traditional robot.

The cost of engineering is significantly lower due to the cobots' ease of integration. The application is also flexible. They can simply use a pallet jack to pick up one of the UR units and move it to another line as needed. Just like people are flexible and movable, automation also needs to be flexible and movable. They are investigating the possibility of putting some of these cobots on autonomous mobile bases for other applications.

They are also using UR cobots for case packing. The cobots are grouping products and then placing them into cases. Taking advantage of the built-in force sensing capabilities, these robots are able to wiggle products into place to make them fit into the open areas of each case, just like humans would. Again, these are very tight production spaces where it's advantageous to have PFLRs on the job.

The end-of-line palletizing and case packing applications have been in production for over two years. The user says the reaction from their employees has been positive, noting that the robots are doing monotonous tasks that people don't like to do. They see the robots as more than just a tool or machine. They want to impart a

personality on them, so they name them, or tape a face or eyes on the robots. They treat them like a part of the team.

This particular manufacturer is also piloting a collaborative application with traditional six-axis robots for handling rolls of material they call webs. The robot removes rolls from a pallet and loads them onto production machinery. Laser scanners monitor the area around the robot. If a human enters the area within a certain distance, the robot slows down.

If that person does not continue to approach the robot, it will continue to work but at this slower speed. This allows the robot to load one roll while an operator is threading a nearby roll onto the machine. If the human continues to approach the robot and enters the minimum safe stopping zone, the robot will stop.

These types of collaborative applications using speed and separation monitoring are less common in very tight floor spaces because the minimum safe stopping distances are typically a meter and a half, which results in a fairly large footprint incorporating the robot. In some instances, they can design a traditional robotic system using the safety-rated soft axis and space limiting functions of the robot along with traditional safeguarding fences and still have a cell with a smaller footprint than if they used laser scanners.

Partial automation is allowing robots do what they do best, so humans can concentrate on



what they do best. Bak USA is using Kawasaki duAro robots to [share tablet assembly tasks](#) with their human coworkers.

Nissan has Universal Robots cobots [helping assembly line workers install intake manifolds](#).

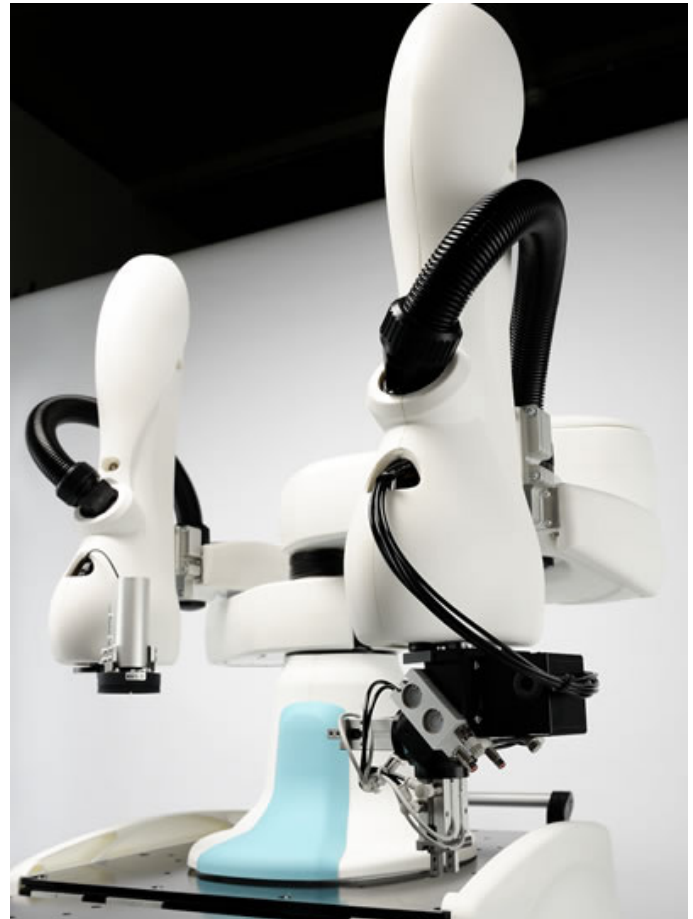
At Panda Confectionary, ABB Robotics YuMi collaborative dual-arm robot [packages chocolates on the line](#) while remaining flexible for quick changeovers when needed.

At STIHL, FANUC CR-35iA [robots act like a third hand](#), helping relieve the load for workers on the packaging line.

### Lights-Out Manufacturing

Manufacturers large and small are embracing the concept of lights-out manufacturing. Robots are making it easier to dim the lights on the factory floor. HIROTEC AMERICA, located in Auburn Hills, Michigan, is using a mobile manipulator to automate lower-volume mundane tasks on their shop floor in an effort to move one step closer to 24/7/365 operations.

HIROTEC is a Tier 1 automotive supplier to customers such as Mazda, GM and BMW. Established in 1932, the Japanese-owned company became an exclusive supplier of door panels to Mazda in the 1950s before branching out into engineering their own stamping dies, hemming equipment, and weld assembly lines.



U.S. operations opened in 1988. They have hundreds of traditional robots in production and have been highly automated since the 1990s. Robots are doing material joining, sealing, and material handling.

As a producer, HIROTEC has to run spare parts. For automotive OEMs, that often means making parts seven years or sometimes 10 years after they go out of production. Typically, at some point during that span, the volume drops so low that they have to produce them manually. The goal was to find a way to use collaborative robots to assist in making spare parts.

Enter “OTTOman” which is an amalgamation

coined by HIROTEC for OTTO Motors' autonomous mobile platform and Yaskawa Motoman's dual-arm robot. The technology merger creates a unique mobile manipulator.

*"We are always trying to find ways for our employees to add more value, while some of the*



*Photo Courtesy of HIROTEC AMERICA, Inc.*

*mundane work is done automatically. We need to be competitive, we need to have Americans working. We have such a hard time hiring people to do some of these mundane jobs. You have to automate in order to make that happen." – Gary Krus, Vice President of Business Development, HIROTEC America*

The collaborative mobile solution works among its human coworkers unhindered by safety fencing. The on-board dual-arm robot picks parts and dips them into vats of black oxide for corrosion protection, while the OTTO 1500 mobile platform provides the needed mobility.

HIROTEC needed a mobile solution because



[See how HIROTEC reaches for lights-outs manufacturing with a collaborative mobile robot.](#)

their fixtures need to be changed out, and parts need to be loaded and unloaded, and then moved to a bin. Just like a human, the mobile manipulator needs to be able to travel around a 15-meter circle performing these various process steps. Otherwise, they would need to add more robots to the mix.

Right now, one operator performs the entire job. HIROTEC is testing the mobile manipulator in the application to see how their workers react to OTTOman running up and down the aisleway. It's been in operation for three months, handling two loads of the black oxide process a day. The whole process takes about 45 minutes to an hour to complete. They estimate that the mobile solution could process up to eight loads a day if they had the volume to sustain it.

They chose this particular mobile platform because of its autonomous operation. Their



shop floor changes constantly depending on which systems they're building. Krus says OTTO's platform allows them to easily reprogram a path, or give it a new route to take. He also likes the 1500 kg payload. With a 600 kg robot and controls on top, they still have about 900 kg available to haul materials. The OTTO 1500 charges its own battery when it senses it's getting low and the Yaskawa dual-arm runs off of the mobile platform's battery.

Down the road, HIROTEC is envisioning a mobile collaborative robot that can do inspection, manual welding, sealer application, and maintenance tasks. To keep their lines running, weld caps, sealer barrels, and totes need to be routinely changed out. Krus would like to see a mobile robot handling those repetitive jobs.

### Introducing Mobility

HIROTEC was already heavily invested in robotics technology and with in-house expertise, but they say the introduction of this mobile manipulator was something different. Now they had an autonomous vehicle running around the shop.

Training was part informative and part safety. Krus stresses that people need to understand how to maintain a safe distance and what the lights mean on the mobile robot if it's coming at them, or going away from them, or if it's turning. OTTO has turn signals. Training is imperative when working



with this new breed of mobile collaborative robots.

A high-throughput lab is testing an automated delivery system using mobile robots to transport samples within their facility. The mobile robots will be operating in hallways and elevators occupied by people. Right now, live samples are transported by a person pushing around a cart.

Currently, they are testing an Omron Mobile Robot carrying fake samples within the production environment. They say it's been interesting to watch people's reactions to the mobile system. At first people give it a lot of space by walking one to three meters around it. Over time, they've noticed that the employees' apprehension has disappeared. They don't give the mobile robot a second thought, joking that it's just another coworker, but you don't have to talk to it in the elevator.

This is generation two for this particular lab. About 10 years ago they tested a mobile

platform by a different manufacturer, when the technology was still fairly new. The results were poor. The system collided with walls and got lost. Part of the R&D with this latest generation of mobile robots is to demonstrate to those workers who experienced earlier generations how “the technology has come leaps and bounds.”

Mobile robot technology has advanced to where many companies are now adopting mobile robots for intralogistics and machine tending tasks in their factories and warehouses. Honeywell Analytics is using MiR autonomous mobile robots to [transport work-in-progress inventory and finished goods](#) to and from assembly stations.

Fitz-Thors Engineering is helping one of their manufacturing customers [tend multiple machines](#) automatically with the KUKA KMR iiwa robotic platform.

Continental Automotive Systems uses the Aethon TUG to [transport racks of materials](#) across their manufacturing facility.

RIA is developing a [safety standard for industrial mobile robots](#) under the auspices of the American National Standards Institute (ANSI). RIA is accredited by ANSI as a Standards Developing Organization (SDO) operating under ANSI’s procedures. Until a standard is published, manufacturers are testing and piloting applications in controlled environments and performing risk

assessments.

### **Cost and Ease of Integration**

For startups and small to medium-sized enterprises (SMEs), the decision to make a foray into robotic automation has become less intimidating with the arrival of lower-cost power and force limiting robots that are easier to integrate. These smaller enterprises find the PFLRs easy to deploy and redeploy when applications change. Those we spoke with said they “sleep better at night” knowing their employees are safe. Cost is also a major factor.

A contract manufacturing startup leveraging 3D printing technology is focused on reducing their costs. Voodoo Manufacturing in Brooklyn, New York, has been in business since early 2015 when they spun off from Makerbot. They are 3D printing various types of plastic parts for fixtures, electrical and mechanical components, promotional items, and custom products for special events, such as a run of a few thousand toys for Mattel, awards for the VH1 Hip Hop Honors, and giveaways for Microsoft for the Democratic and Republican national conventions.

Voodoo chose a power and force limiting robot because they didn’t want to spend a lot of money on an arm that might not fit their needs as the business matures. We discussed Voodoo’s strategy with their chief product officer.

*“As a startup, we have limited resources. A more affordable arm was really our only option.”*

*Performance will one day truly matter to us, but at this early part of our journey into robotic automation, we're much more interested in having flexibility and something that's easier to integrate. We were looking for the best arm dollar for dollar.” – Jonathan Schwartz, Cofounder & CPO, Voodoo Manufacturing*

Voodoo is using Universal Robots' UR10 cobot to harvest the output from several of their 3D printing machines. Still in testing in their engineering lab, this is essentially a machine-tending application with the 10 kg payload robot unloading 3D printed parts from the printers and preparing the machine for the next build.

When the process is done manually, a technician has to remove the build plate with the 3D printed part on it and then load a clean build plate into the printer. The printer sits idle until someone harvests the part.

Voodoo's goal is to reduce their costs by 90 percent in three years. They know a



*Photo Courtesy of Voodoo Manufacturing*

large portion of that percentage will come from reducing labor costs through robotic automation. A lot of their process has the potential to be automated. They chose the harvesting step because they thought it would be the easiest and fastest to automate, but would also have a significant impact.

Right now, production is running an 8-hour shift, 5 days a week. By automating harvesting, Voodoo would be able to keep their printers running 24/7.

With Voodoo's Skywalker system, which encompasses the printers, the robotic arm, tooling, and peripherals, the entire process is automated. When one of the 3D printers finishes printing a part, Voodoo's proprietary operating system signals the UR10 that the printer is done. The cobot then grabs the build plate using an adaptive gripper designed for collaborative applications and removes it from the printer. The cobot takes the build plate with the 3D printed part on it and places it on a track where a few dozen plates can be lined up awaiting the post-printing step. Then the cobot grabs a clean build plate from a plate hopper, which is a stack of plates that is refreshed about once a day, and places it in the printer. The cobot then signals the software that the printer is ready for the next build and printing starts automatically.

Initially, they set up the lab system to harvest nine 3D printers mounted in server racks around the cobot. The next step is to expand



the system to 27 printers served by the same cobot. The goal beyond that is to mount the cobot on either a rail system or a mobile platform, so it can move around the factory. Once mobile, they think the cobot would be capable of tending about 100 printers, based on the average print time and how long it takes to harvest a printer.



[Go behind the scenes of Project Skywalker.](#)

Voodoo has about 200 printers total, between the factory and the engineering lab. Utilization is 20 to 30 percent with most of the 3D printers harvested manually. With the Skywalker system in the lab running 24/7 lights-out, they are close to 100 percent utilization.

Once they attain higher reliability and mobility, they plan to move the Skywalker system into production. Within the next couple years, they plan to scale to about 500 printers. There are also other opportunities for automation, including removing the 3D printed parts from the build plates and cleaning them, inspecting parts for quality, and organizing parts for orders and packing

them into boxes, all of which are performed manually today.

*"In our minds, manufacturing shouldn't be about working in a position where you're forced into a role like a robot, as opposed to doing what humans are best at which is thinking critically and using your creative and analytical skills to run our factory. The way factories will be built, and should be built, is not with this hard line between human workers and robots. There are tasks that robots are just better at. We won't have to let anyone go because of this. In fact, it will make us more competitive, which means we can grow the company, grow the team, and hire more people."* – Jonathan Schwartz, Voodoo Manufacturing

### Limitations

While collaborative robots are opening doors for startups and providing competitive advantage for large multinationals, these tools may come with trade-offs. Speed and payload limitations were noted by nearly all of the end users in RIA's study. This is especially true with power and force limiting robots, which must trade power for inherent safety.

Because Whirlpool makes large appliances, a lot of their parts and materials are rather large and heavy. Even with the UR's 10 kg payload, it's not necessarily sufficient given that the payload is not intended for the robot arm to be at full extension. Whirlpool's throughput is high and the assembly lines move fast. The PFLR speeds are sometimes not adequate enough to keep up with the demands of the line, so they end up

using multiple robots to compensate.

They point out that a robot can only do a fraction of what a human operator is doing. For example, wire connections are challenging for cobots. Most processes are also on a continuous conveyor system, so the robot has a constantly moving target, which is difficult to maintain with limited repeatability.

Traditional robots in collaborative applications where safety scanners and other safety peripherals are used to create safe zones also come with limitations. Users sometimes must trade space for safety, as the footprint required for safe stopping distances may be fairly large depending on the size and reach of the robot.

Lockheed Martin says some of the drawbacks in trying to develop and integrate their robotic systems include steep development and maintenance costs, robotic accuracy limitations, sizable footprints, and the need for specially trained personnel. They are exploring new methods and technology for increasing robotic accuracy, while developing flexible automation solutions where floor space is limited.

### **Preparing Your Workforce**

End users introduce collaborative robotics to their facilities in many different ways, but all seem to agree on one aspect: It's important to prepare and engage your workforce



before placing the robots on the production floor.

GM's Linn stresses the importance of engaging your workforce in the introduction of any new technology, but especially this collaborative robot technology. GM includes everybody from the engineering, safety and maintenance groups, to the operators on the floor that are working next to the robots, making sure all possible hazards are identified, discussed and addressed.

For the new cobots in particular, since as Linn puts it they are a "completely different paradigm" in manufacturing, they made sure everyone had a full understanding of what the cobots are, what they are used for, and why they are safe. He also said that third-party certification to clearly written standards is an absolute must.

GE had a novel way to introduce Sawyer to their employees. The plant in Hendersonville has a tradition of passing out free batteries to their workers when daylight savings time begins and ends, which has become the unofficial biannual reminder to change your batteries in your smoke detectors. GE engineers set up Sawyer next to the cafeteria with a box full of batteries, and the cobot grabbed them out of the box and put them into each employee's hand.

*"We had many discussions about how to delicately introduce this robot to our facility. Even before the battery event, we posted a big poster board with a picture of Sawyer, a brief bio, what he is, what he does, how we plan to use him on site, and what it can offer to employees as a tool. We also solicited ideas of how they could use the robot in their production areas. In the next phase we set up a demo area at a main intersection. We were building, programming and testing the robot right in the middle of the assembly floor. By the time it hit the production line, everyone was very familiar with the robot. Our gradual introduction made for a successful implementation." – David Martin, Plant Manager, Current, powered by GE*

Whirlpool also takes a gradual, hands-on approach to introducing their workforce to collaborative robots. They hold informal workshops where operators have the opportunity to engage with the technology and understand how it works. Once it's

closer to deployment, they place the robot on the factory floor and provide further explanation of its purpose and how it will help the operators, also allowing them to give feedback before the application goes into production.

At Lockheed Martin, an extensive level of training is required to prepare operators who must support and work alongside the robots. Implementation engineers receive in-depth training on operating the robots so they can ensure the successful integration and performance of the automated process. Mann says most coworkers react positively towards automation and robots as a measure of progress and ingenuity. Some are apprehensive due to the perceived complexity of the technology. Lockheed Martin tries to address these human factors during the training process to highlight the benefits of automating, including a better quality of work life.

## Conclusion

Collaborative robotics is still an emerging technology. The largest group of potential users, small and medium-sized enterprises, are just beginning to realize its advantages and better understand the limitations. The proving ground still tends to be large multinational companies, but the scale is tipping. Companies of all sizes are taking advantage of the technology's greater safety, flexibility, ease of integration and redeployment, space savings, cost efficiency, faster ROI, and in many cases, programming ease. Workers are getting used to sharing the



shop floor with their new collaborators.

The robots and enabling technologies in this space have advanced considerably in just the last five years to allow for a wide variety of applications across many industrial and commercial sectors. The brand options and product features are expanding rapidly to help drive down pricing and spur more technological advancement among competitive offerings. Collaborative robotics can take many forms, whether they are power and force limiting robots, traditional robots with functional safety technologies, or autonomous mobile robots.

Mobile robots are perhaps where their stationary collaborative cousins were just a few years ago. They tend to attract large early adopters that have the resources to pilot applications and mitigate the risks. What the current robot safety standards did for the wider assimilation of power and force limiting robots, we expect the impending mobile robot safety guidelines will do for autonomous mobile robots in the near future. Safety shall always be priority.

In the future, we expect to see more direct interaction between humans and robots. Not just working in proximity *to* each other, but working *with* each other. Handing off parts and components and working collaboratively on assemblies. That will be the mark of true collaboration, our partnership with the robots.