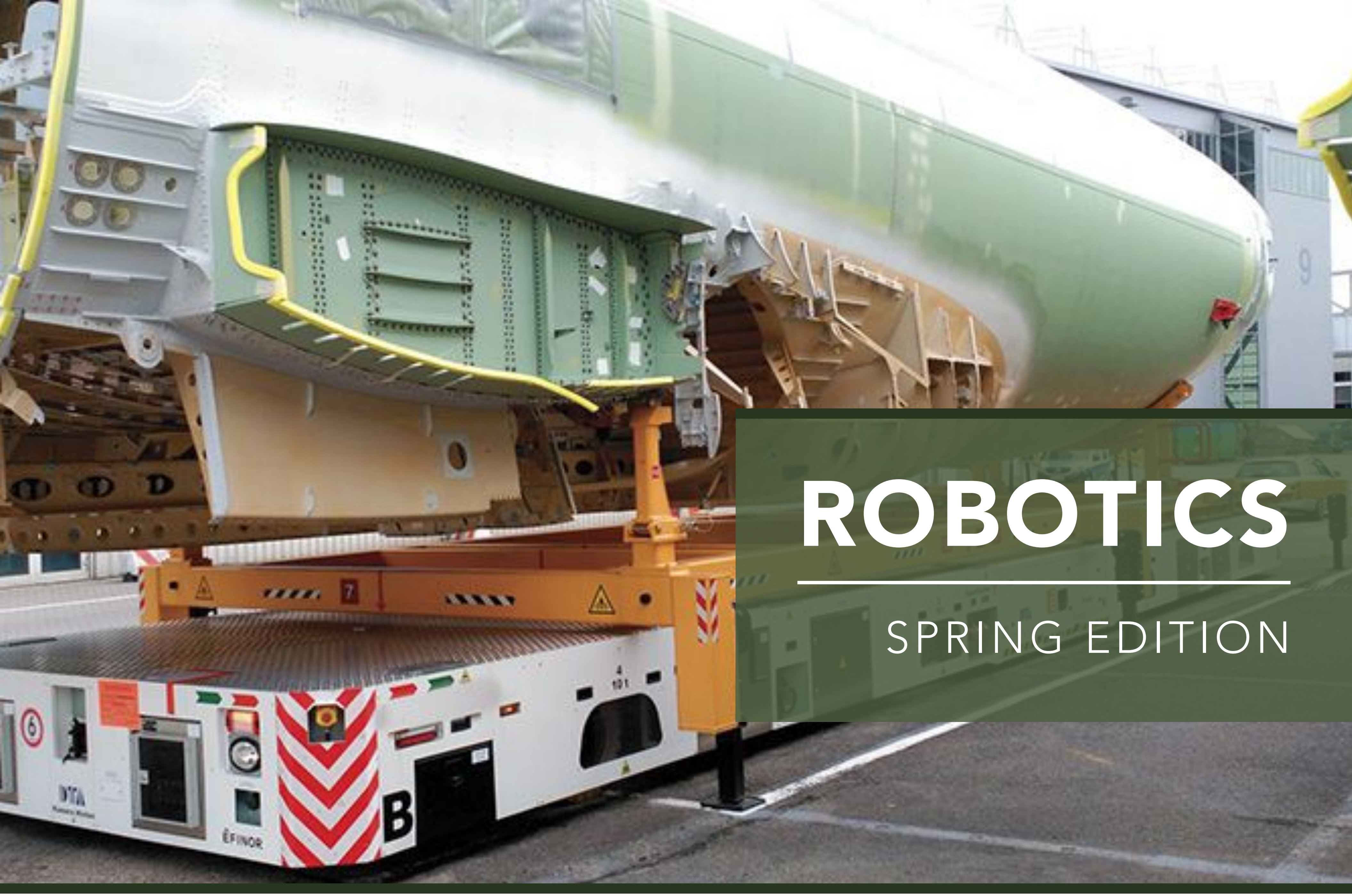

ROBOTICS

SPRING EDITION

CONTROL ENGINEERING eBOOK

PLANT ENGINEERING eBOOK

OMRON

PERFORMANCE MOTION DEVICES
MOTION CONTROL AT ITS CORE

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Six industrial robotics trends for 2023

Robotics are becoming more important and manufacturers are recognizing their growing role in many different industries and applications. Six industry trends are highlighted.

External factors, from the pandemic to geopolitical insecurities and supply chain issues, have had an outsize impact on the industrial robotics sector in recent years.

At the same time, internal factors, such as technological and usability advancements also exert influence on industrial robot development and adoption.

There's a lot of information to sift through, which makes identifying the most influential trends a real challenge. However, there are six trends industry experts are paying particular attention to.

1. Labor and demographics

Scott Marsic, group product manager – robotics, at Epson America Inc. said labor shortages are "far and away, the number one trend" driving industrial automation adoption.

"The United States' manufacturing sector is doing great work, but there are more jobs than there are people to fill them and that presents a problem."

Labor issues are global, said Kary Zate, senior director, marketing communications at Locus Robotics.

"You've got labor shortages, an aging population in the warehouse, and a younger

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generation that's not really interested in working in warehouse environments, because, frankly, it's hard work that requires people to walk 10 to 15 miles a day in a cart-based environment. It's very taxing."

With finding and retaining talent a major challenge for industry, a growing number of companies are turning to industrial automation to fill labor gaps, improve productivity, and stay competitive in a challenging macroeconomic landscape, Zate said.

2. Digitalization drives

The pandemic accelerated both automation adoption and the digital transformation across the industrial sector, said Lian Jye Su, research director at market analyst firm ABI Research.

"This trend includes remote monitoring software and software that enables or otherwise facilitates the adoption of industrial automation," said Su.

"There is no faster way to automate, especially when deploying a mix of robot brands, than to use these types of software. The traditional approach – hiring engineers to commission a robotic solution—can take weeks and months and that means a missed opportunity for a lot of these manufacturers."

Explore any industry tradeshow and you will find a wide range of digitalization tools from AI and augmented reality to digital twins geared towards manufacturing applications, Marsic said.

"It's an exciting time in robotics and digitalization and these technologies are helping

to attract new folks to robotics programming roles. For a programmer, the opportunity to work with AI and augmented reality and have their code deployed on industrial robots is pretty cool."

3. Cobot and mobile robot use increasing

Collaborative robots remain the fastest growing segment of the industrial robotics sector, Su said.

"There's been a lot of positive feedback in recent years about how cobots are easy to deploy and, over time, cobots have found their niche in the industrial robotics sector and it has proven to be one that can complement both human labor and traditional industrial robots. I don't think that growth is slowing down any time soon."

According to ABI Research, the cobot market had a global valuation of $475 million in 2020, expanded to $600 million in 2021 and is expected to reach $8 billion by 2030, at a projected CAGR of 32.5%.

At the same time, mobile robots are also seeing rapid surge in popularity, Su said. "Just ten years ago, mobile robots were a luxury, now they are found in almost every industry segment and location from deep sea oil rigs to manufacturing and warehouse facilities."

Global robotics Venture Capital (VC) investment reached US$5.7 billion in 2021, at 38% year-on-year growth, with autonomous mobile robots attracting huge interest, according to ABI Research.

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4. Reshoring initiatives

Labor costs overseas are rising quickly, while at the same time, the cost of automation is dropping significantly. These are just two of the factors that are helping to drive reshoring initiatives across the United States and other leading economies, Masic said.

"Today, there are several additional issues to contend with from intellectual property and tariffs to geopolitics, and supply chain challenges. Companies need to bring back manufacturing quickly and the best way to do that, especially in the middle of a labor crisis, is with automation."

And by shortening supply lines, reshoring can also reduce emissions and generate environmental benefits that help to make manufacturing more sustainable.

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5. Robots are becoming more usable

The increasing usability of industrial robot systems makes it easier than ever for companies of all sizes and technical skill levels to deploy automation.

“The drive for simplicity is a really important trend,” Masic said. “People want to get their automation up and running quickly. This requires an easy-to-use operating system and extensive customer support throughout the entire process. The need for simplicity is being driven by new customers and new users coming into the automation space. We saw this trend before the pandemic, but since 2020 it has really blown up.”

The rising popularity of the robotics-as-a-service model has made automation adoption easier and less capital intensive, giving operators the ability to seamlessly scale to meet changing volumes and seasonal spikes in just minutes vs. the typical time frames that can take weeks or months, Zate said.

6. Increased focus on sustainability

There is growing concern around sustainability and climate issues among robot manufacturers and their customers, Masic said.

“Sustainability and environmental responsibility are long-time core values of the Epson organization. For example, by moving away from ground-based sources of materials as much as possible and by exploring the whole lifecycle of our products to discover which parts can be reused.”

From the outset, Locus Robotics developed its business model based on sustainability principles, including widespread refurbishment of parts, Zate said.

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"We like to say 'No robot ever dies.' Sustainability is something that we have always taken seriously and is part our DNA. Today, sustainable manufacturing is really gaining widespread traction both in the robotics industry and among our customers."

RaaS is a key component of Locus Robotics' sustainability mission, Zate said: "Because our robots can be refurbished, we can bring them back in, repair them, upgrade them with new types of hardware, new types of software. This means that our customers have the latest and greatest automation at all times."

Emmet Cole

Emmet Cole, *contributing editor, Association for Advancing Automation (A3).*

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Logistics Industry | Fully Autonomous RFID-based Inventory System Uses OMRON Mobile Robots

How did Omron's autonomous mobile robots (AMRs) help smart inventory solutions provider T&W Operations eliminate manual and forklift-dependent processes in their fully autonomous RFID inventory system? Watch this video to learn about the game-changing Omron AMR technology that incorporates dynamic mapping capabilities and a mobile base that can safely carry heavy payloads throughout manufacturing and logistics facilities.

AMRs help eliminate manual processes in autonomous RFID inventory system

KYLE O'BRIEN
Omron

Self-navigating mobile robotic technologies, autonomous mobile robots (AMRs), can help support a variety of payloads and provide a foundation to verify contents of warehouse containers.

T&W Operations provides smart radio frequency identification (RFID) inventory products and looked automate all manual and forklift-dependent processes for shipping/receiving and warehousing. Building upon earlier versions, the company used autonomous mobile robots (AMRs) to replace all manual processes. Both applications — the shipping/receiving RFID system and the manufacturing RFID system are autonomous.

Heavy-payload AMRs with RFID

Heavy-payload AMRs with RFID, safe navigation enabled the company to build a complete, labor cost reduction solution for warehouses, improving accuracy and cleanliness in logistics and warehousing facilities while mitigating the challenges of today's labor shortage. Key benefits of the new solution include:

- A hands-off RFID verification application. Whether it's quality system checks, manifest generation, or another need, the AMRs facilitate an automated conveyor system.

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- Mobile bases that safely carry heavy payloads. The AMRs have built-in safety features that can carry more than 3300 lb, including T&W's expandable towers that reach up to 30 feet.

- Mapping technology that responds to obstacles in real time. The AMRs have self-navigating software that detects objects in the way and finds the easiest way to get around them, ensuring safe movement around human workers.

Figure 1: The T&W Expandable Robotic Tower Inventory System (TIS-ER) uses Omron Automation LD-250 mobile robot with a payload of up to 120 kg (265 lb) for a reach of 10 ft, and the Omron HD-1500 heavy-duty mobile robot with a payload of 1500 kg (3307 lb) for a reach of 30 ft. The mobile "tower" travels autonomously through warehouse aisles, collecting RFID tag data and communicating to the warehouse management system. Courtesy: Omron Automation

Leveraging RFID with automation

T&W's original Tower Inventory System (TIS) required a few manual and forklift-operated processes. To make it easier for customers to implement RFID-based content verification, the company used AMR technology as a foundation for the T&W Expandable Robotic Tower Inventory System (TIS-ER).

Two AMRs were used for the inventory system, one of which used the Omron LD-250, a mobile robot with a payload of up to 120 kg (265 lb). The system can expand to a height of 10 feet, all of which is

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mounted atop the LD-250 to operate in warehouses with inventory racks less than 10 feet tall.

Figure 2: T&W's TIS-ER is designed to retrieve the container via the automated conveyor and proceeds to the RFID portal where the contents are again verified without human interaction. Courtesy: Omron Automation

For warehouses with higher racks, another version used the Omron HD-1500, a heavy-duty mobile robot with a payload of 1500 kg (3307 lb), which supports a system that can expand to heights of 30 feet. This provides benefits to warehouses with tall racks since all inventories can be scanned and analyzed in one sitting. While the AMR moves, the tower adjusts to varying rack and ceiling heights.

T&W also created an AMR-based product to help customers use RFID in the manufacturing space. The AMR is fitted with a powered conveyor that picks up containers while contents are validated against a contents database to ensure the package contains items needed for the next operation.

Once this operation is complete, the robot retrieves the container via the automated conveyor and proceeds to the RFID portal where the contents are verified without human interaction.

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Autonomous mobile robots use navigation software, avoid obstacles respond to a dynamic real-time environment

AMRs are designed to move autonomously through dynamic and peopled environments without requiring any facility modifications. After an initial "teaching" session in which an operator directs an AMR to create a map of the facility, the onboard self-navigating software will determine the best routes to reach a given destination and identify any unexpected obstacles in the way. AMRs can work as part of a coordinated fleet. AMRs are easy to setup and are flexible for re-deployment amid any changes to warehouse layout, maximizing space usage. Since they have built-in, safety-rated laser scanners and are programmed with safety settings that prevent collisions with obstacles (including humans), they can operate in close proximity to human workers and other equipment to decrease risk of injury or damage.

The AMR-based products also help maintain cleanliness while maintaining 100% inventory accuracy by eliminating human interaction. They let warehouse associates to engage in more fulfilling and creative tasks by leaving routine contents verification work to an autonomous system.

Kyle O'Brien

Kyle O'Brien *is industry manager – logistic at Omron Automation.*

Taking robotics automation out of the building with AGVs

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Automated guided vehicles (AGVs) are being used by companies for outdoor applications in a variety of different industries and can provide a strong return on investment (ROI).

Automated guided vehicles (AGVs) use becoming increasingly common, with these mobile robots boosting efficiency across a wide variety of applications. However, the use of AGVs has, until recently, been largely considered an indoor application. This is now changing.

As vehicle suppliers and integrators become more experienced, and the autonomous navigation technology used to drive AGVs becomes more flexible and robust, these vehicles are being used increasingly to transport goods and materials between buildings and beyond. Why is this trend only coming to the fore now? And what should users be looking for from an outdoor AGV.

Outdoor AGVs: A growing trend

AGVs have not traditionally been used in outdoor applications because of the vehicle positioning challenges posed by such changeable environments and the potential for varied and inclement weather. However, applications in which AGVs are used outdoors are now appearing, and the technology is becoming more proven.

Giuliano Bavaj, managing director at Esatroll, creator of several customized outdoor AGV models, said, "We are seeing a strong trend emerging, where more companies are looking to employ AGVs in outdoor applications. Whereas previously only around

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Figure 1: AGV transports steel coils at Acerinox in Spain. Courtesy: Bluebotics

10% of the enquiries we receive concerned outdoor use, this has risen sharply and outdoor now accounts for approximately 30%. Although there are complex challenges to resolve in using an AGV outdoors, automating the movement of heavy materials offers many benefits and considerable cost savings."

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Increasing AGV applications: Seaports, production, warehouses

Gonzalo de Sebastian, sales director at DTA, which makes AGVs for heavy industrial applications, said, "Outdoor automation using AGVs started at seaports, but we are seeing a sharp rise in interest across different sectors, as payback for a vehicle can be between just one and three years. The number of applications in which outdoor AGVs are being used is escalating."

Typical uses include moving goods from a production facility to a warehouse that may be in a different building hundreds of meters away. Traditionally forklifts, trucks, tractors or camions would have been used for this work.

However, this is just one in a growing range of outdoor use cases. De Sebastian said, "We see applications for steel mills, where very heavy steel coils need to be moved significant distances. Also, in foundries and automotive manufacturing, moving, for example, car chassis between buildings."

AGVs navigating the outdoors

One of the biggest challenges for outdoor AGVs is the weather. Vehicles must be built to withstand heavy rain, dust and other inclement environmental conditions. All electronics must be protected and may sometimes require regulation using thermostats, and weather-resistant components used where necessary (for example, in the case of outward-facing safety laser scanners). All mechanical components also must be properly treated to withstand the elements.

Automated guided vehicles are available with a variety of different navigation systems, from basic physical line-following models to more modern vehicles based on so-called natural navigation.

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Figure 2: DTA Dolphin AGV transports aircraft fuselage at Acerinox in Spain. Courtesy: Bluebotics

For outdoor applications, natural navigation offers clear advantages because it requires no permanent changes to the area in which vehicles are operating (for example, no laying of magnetic tape or installing of inductive wires underground), enabling vehicles to be installed relatively quickly and their routes easily modified if an operation evolves.

De Sebastian said, "Every application is unique, so as an AGV supplier we need to provide flexible, open solutions that can be tailormade to meet a specific site's needs. In dynamic outdoor settings, we recommend the use of natural feature-matching navigation as it offers the greatest flexibility, easy installation, and provides a secure, safe solution that is designed for use in busy areas and can be adapted to changing needs as required."

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Figure 3: Esatroll AGVs move tires between buildings at Michelin's plant in Cuneo, Italy. Courtesy: Bluebotics

By using advanced fleet management software that syncs with a vehicle's navigation system, AGVs can interface with other sensors and types of equipment such as handshaking with automatic doors and opening them when an AGV approaches.

Return on investment for AGVs

The return on investment (ROI) possible with AGVs, compared to using human-driven vehicles, can be very interesting. Automated versions can pay for themselves in as little as a year.

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To move materials manually may require several operators each day and require multiple heavy-duty forklifts and/or trucks. Alongside the cost of labor and capital investment, the vehicles will require regular maintenance and may use high-polluting fuel. If operations run over three shifts, a full 24/7, the breakeven on automated vehicles can be very quick. What's more, electric-powered AGVs have little maintenance and no emissions. Operations can run without risk of accident and with a level of consistency, reliability and accuracy that cannot be achieved manually.

Bavaj said, "We see some applications where the ROI is less than one year, and we have customers, where an automatic shuttle saves 1,000 Euros a day compared with using traditional trucks."

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Sebastian said, "Only one operator is needed to give orders and there is no risk of accidents."

Outdoor AGVs, greater safety, rapid payback

In many outdoor applications, the use of AGVs to move heavy materials can provide an ROI in as little as one year and usually within a maximum of three.

Bavaj said, "Outdoor AGVs will continue to grow in number because the business case is so clear. Their use reduces traffic, increases safety in working environments, and delivers great operational flexibility. There are really no disadvantages and much to be gained."

Matt Wade

Matt Wade, *head of marketing at BlueBotics.*

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World-class Motion Control Solutions

We put performance in motion. 30 years of motion control innovation. Your partner in motion control success. ISO 9001:2015 and ISO 13485:2016 certified. Breakthrough common motion language. Brushless DC (BDLC), DC Brush, and step motor support. If it needs motion control, it needs Performance Motion Devices. A range of products for limitless design flexibility, including ICs, modules and boards.

Force Control in Actuators and Robot End Effectors

In this article we will focus on servo actuators that function as end effectors, often mounted on transport systems such as robotics arms and gantries. These devices include linear actuators, force feedback actuators, voice coils, and more. Understanding their capabilities and properties will help you ensure that your next application will deliver the goods without dropping the ball!

Introduction

Motors and end effectors come in many shapes and sizes but, compared to actuators that transport an object from point A to point B and focus on position control, end effectors commonly also integrate force sensing to ensure that objects being carried aren't crushed or dropped. Interestingly, the sensing function may not require a separate physical hardware device. It may instead be achieved by electronics that measure current flow through the actuator coils with a high precision thereby allowing a sensed torque to be inferred.

Linear servo actuators

Rotary to linear actuators

Any discussion of end effectors starts with a discussion of linear servo actuators. There are a few varieties but ironically the most common configuration actually uses a rotary

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motor coupled with a lead screw to convert the motor's rotation into linear motion. This is shown in Figure 1.

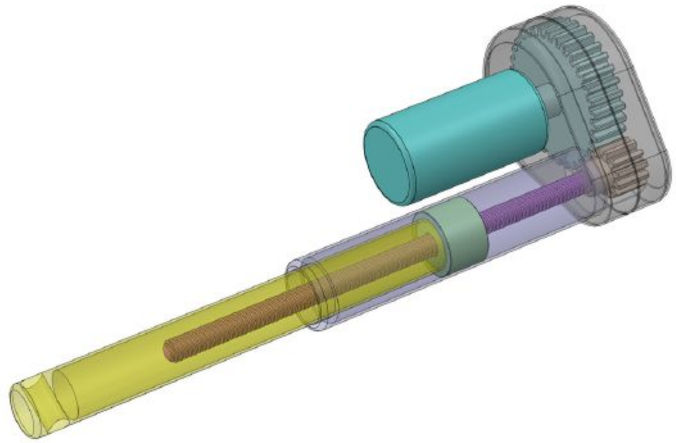

Figure 1: Linear Actuator Using Rotary Motor & Lead Screw

The rotary motor used is most often a DC Brush or Brushless DC type. But as it turns out a step motor can also be used. With a step motor there is no encoder because step motors are devices that can inherently control position.

Rotary motor to linear actuators such as this come in a vast variety of sizes, strokes, and force outputs. Because of the way force is generated - by rotating a motor and then mechanically converting the rotational torque into linear force, these actuators have high force output per unit of weight. In fact they are even used as an alternative to hydraulic pistons in some applications. They have only moderate acceleration and speed, however, again for the same reason – the motor's rotation is mechanically reduced by the gearing mechanism.

At low to medium torque output levels, the most common application for actuators of this type is positioning. If a servo motor is used the rotary motor's encoder provides feedback to the servo control system which allows complex trapezoidal or even s-curve profiles to be executed for end point position control. The delivered positional accuracy is a function of the encoder resolution and the gearing system.

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The overall range of applications that this type of actuator is used in is vast. They include electronics manufacturing machinery, semiconductor equipment, bio tech and laboratory automation, textile, industrial automation, and more.

Linear direct drive motors

The second category of linear servo actuators is Direct Drive Linear Brushless DC motors. Like a normal rotary Brushless DC motor, these are commutated motors which typically use an encoder for position control. Brushless DC motors are commutated electronically and therefore compared to DC Brush motors have no wear and tear of the commutating brushes. Direct drive here means linear motion is directly generated by the motor coils and magnets. No gears or lead screws are needed.

The diagram below shows how this is achieved. The linear version of the Brushless DC motor is essentially an unwrapped rotary motor. They both have a stator – the part that houses the coils, and they both have a rotor – the part that contains the permanent magnets (although it should be mentioned that rotor is a confusing term for a linear motor since it doesn't rotate. Nevertheless, we will use this term because there is no other standard accepted term for this part of the motor in a linear motor).

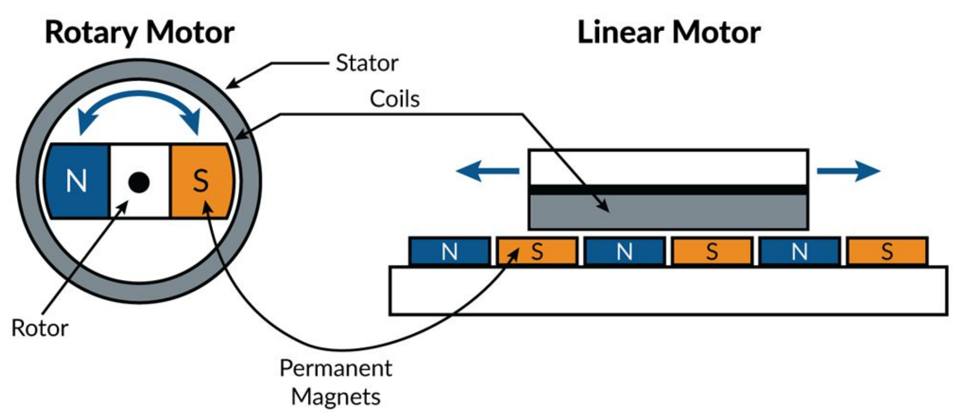

Figure 2: Direct Drive Linear Brushless DC Motor

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Two different configurations of the stator and rotor are possible, one where the stator (the part with the coils) is stationary and the rotor (the part with the magnets) moves, and the opposite configuration where the stator moves and the rotor is stationary. Both of these configurations are shown below:

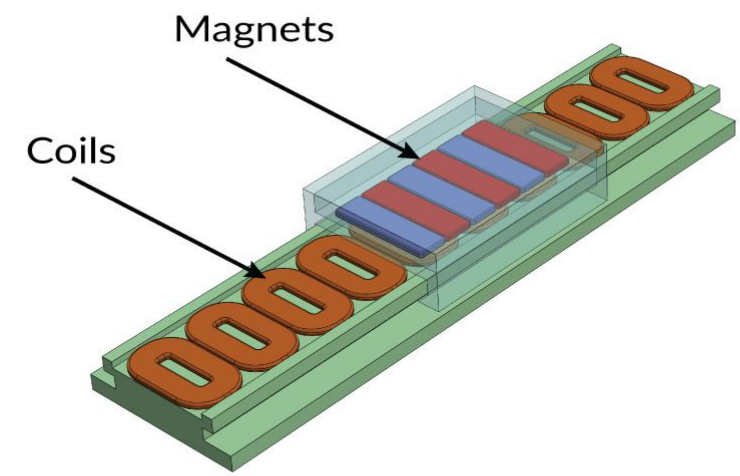

Figure 3a: Linear Brushless DC Motor with Stationary Stator

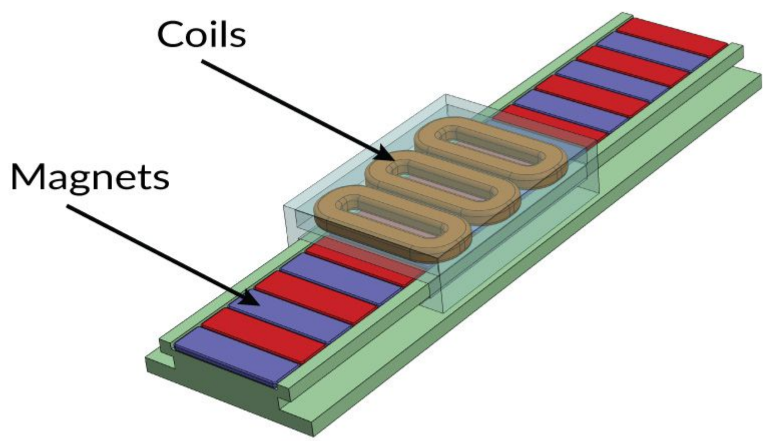

Figure 3b: Linear Brushless DC Motor with Moving Stator

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There is a different mechanical arrangement of the motor which uses a rod-shaped rotor as opposed to the 'track' shaped configurations shown above. The rod contains magnets and as before, either the rod can move with the stator staying stationary or the rod can be stationary with the stator travelling across it. Such actuators are shown in the diagram below (Figure 4).

Whichever arrangement is used the linear Brushless DC motor is the workhorse for applications that demand ultra high reliability and fast response time. Compared to rotary to linear actuators discussed earlier direct drive motors have very high acceleration. Torque output is low to moderate but with the use of rare earth magnets can actually be surprisingly high.

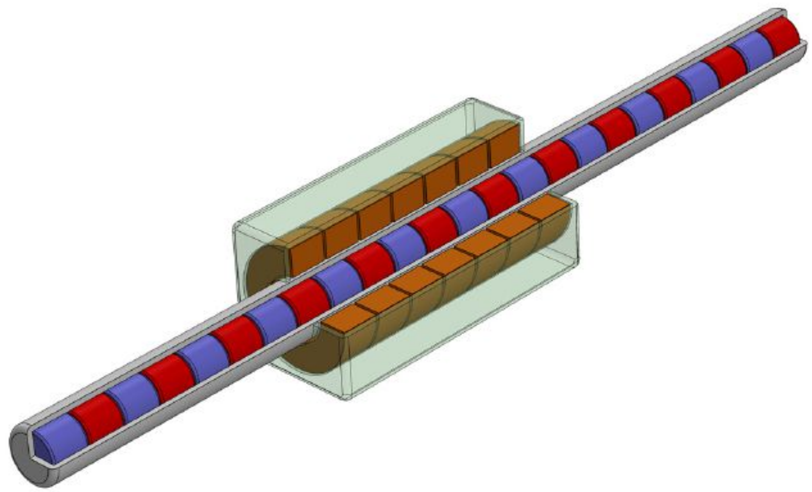

Figure 4: Linear Brushless DC Motor with Rod-Shaped Rotor

Although direct drive motors are more expensive, they still find frequent use in industries such as laboratory automation, semiconductor equipment, and electronics manufacturing equipment.

Before closing, an important quality of direct drive actuators is that force can be controlled rather precisely without the need for a force sensor. As long as high-quality bearings are used so that external drag is minimal, external torque presented to the actuator will be 'felt' directly by the servo system.

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By comparison, with a rotary to linear converting actuator described earlier reflected forces are not felt by the servo as accurately. This is due to the internal gearing of such a device and the attendant friction. Friction 'consumes' the external force before it can be delivered to the motor and sensed by the servo controller, resulting in a reduced ability to accurately sense force via the servo controller.

We will talk more about force control in both of these actuator types a bit later.

Direct drive linear DC Brush motors

Another important category of direct drive linear actuators is the Linear DC Motor, which in turn has two sub-flavors: a moving magnetic rod arrangement, and a voice coil arrangement. The first of these is shown below (Figure 5).

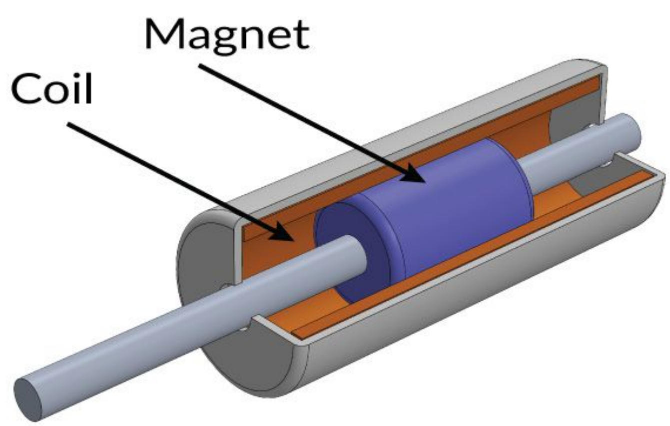

Figure 5: Moving Magnet Linear DC Motor Actuator

The magnetic rod style DC linear actuator can deliver modest torques and speeds with a small to modest stroke distance. Its main advantage is simplicity and therefore reliability and low cost. When the coils are energized the magnetic fields interact with magnets mounted on the rod which in turn generate force.

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An actuator such as this can be purchased as a packaged unit already containing bearings supporting the rod, or as an open frame where the machine designer must supply the bearing support for the rod.

Voice coil actuators reverse the role of the stator and the rod magnets. This type of actuator generally has a short stroke, modest torque output, and extremely fast response time. The speed is due to the fact that the moving portion can be very light, consisting of little more than the motor coils themselves held together by an adhesive such as epoxy.

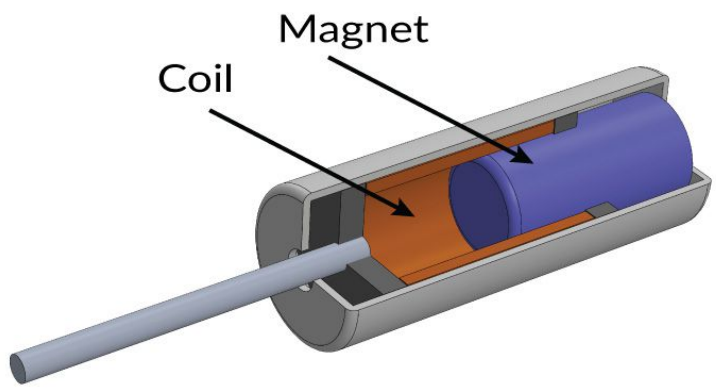

Figure 6: Voice Coil DC Motor Actuator

The drawing above shows a voice coil motor with a protruding rod, but many voice coils 'actuate' air or light rather than a mechanical rod. A stereo HIFI speaker is a classic example of such a voice coil, pushing a thin flat membrane which results in sound waves being created. Similarly, if the membrane is a mirror the reflection of light waves can be controlled at high frequency.

Note that both of these two DC linear actuator types can be coupled with a sensor to provide programmable positioning. In this configuration they are driven by a servo controller which continually adjusts the coil current to maintain a commanded position or torque.

Applications for positioning linear DC motor or voice coil motors are varied and include precision optics, scientific instruments, valve controllers, and others.

Piezo motor actuators

For a discussion of linear actuators, especially those used in high precision applications, one last actuator type must be mentioned namely the Piezo motor shown in Figure 7.

Piezo motors, which may be assembled in both a linear and rotary configuration, are electromechanical devices which use the elastic deformation of piezoelectric materials in conjunction with specialized electronics to control forward and backward motion.

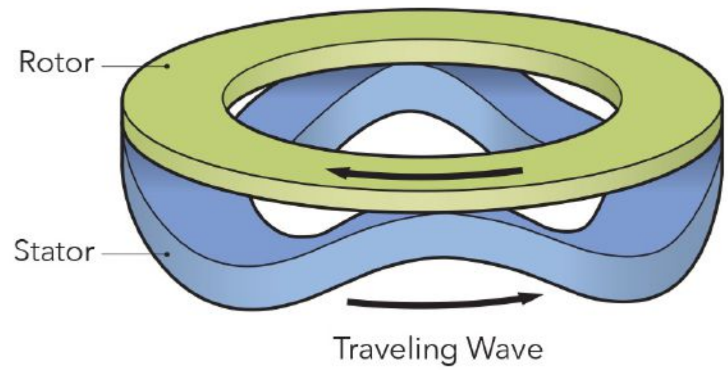

Figure 7: Piezo Motor

To create motion the electronics set up a standing wave in the piezoelectric material (which functions as the motor stator) that directly contacts a textured platen functioning as the rotor. By controlling the phase of the standing wave forwards or backwards motion occurs. Piezo motors are seldom used for force control but excel in positioning applications, especially those that require small, precise strokes.

Force control key concepts

With this primer on linear actuators complete, let's talk about one of the key differences between motors used for transport and motors used as end effectors. This dif-

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ference is the need for force control. End effectors often care just as much (and sometimes more) about the force applied by the actuator as the position of the actuator. Examples of applications where force control is critical include grippers, screw-cap applicators, web tensioners, press-fit tools, packaging equipment, and others.

A robotic gripper is a good model to understand how sensing and controlling force can be important for end effector applications. In a gripper, the object being carried may vary in size or orientation resulting in a different mechanical engagement point. But once contact is made the gripper should apply a consistent force on the object – large enough to hold it securely but not so large as to damage it.

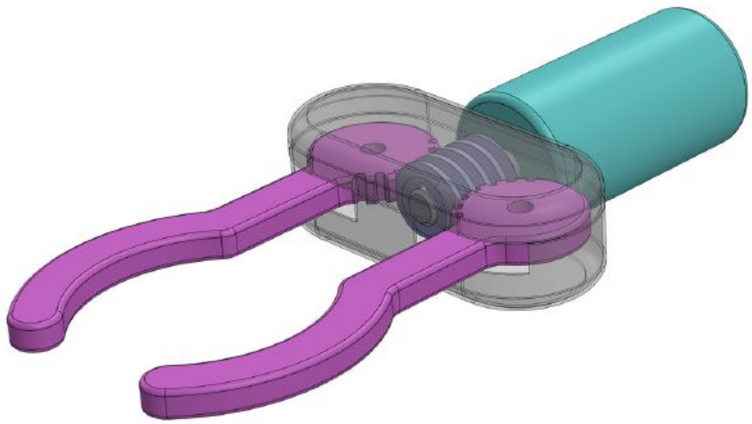

Figure 8: Example of Robotic Gripper Mechanism

How can this kind of force control be achieved? There are several techniques but two popular approaches could be Stop Trajectory When Force Threshold Reached, and Continue Trajectory But Limit Force Output. Both are detailed on the next page.

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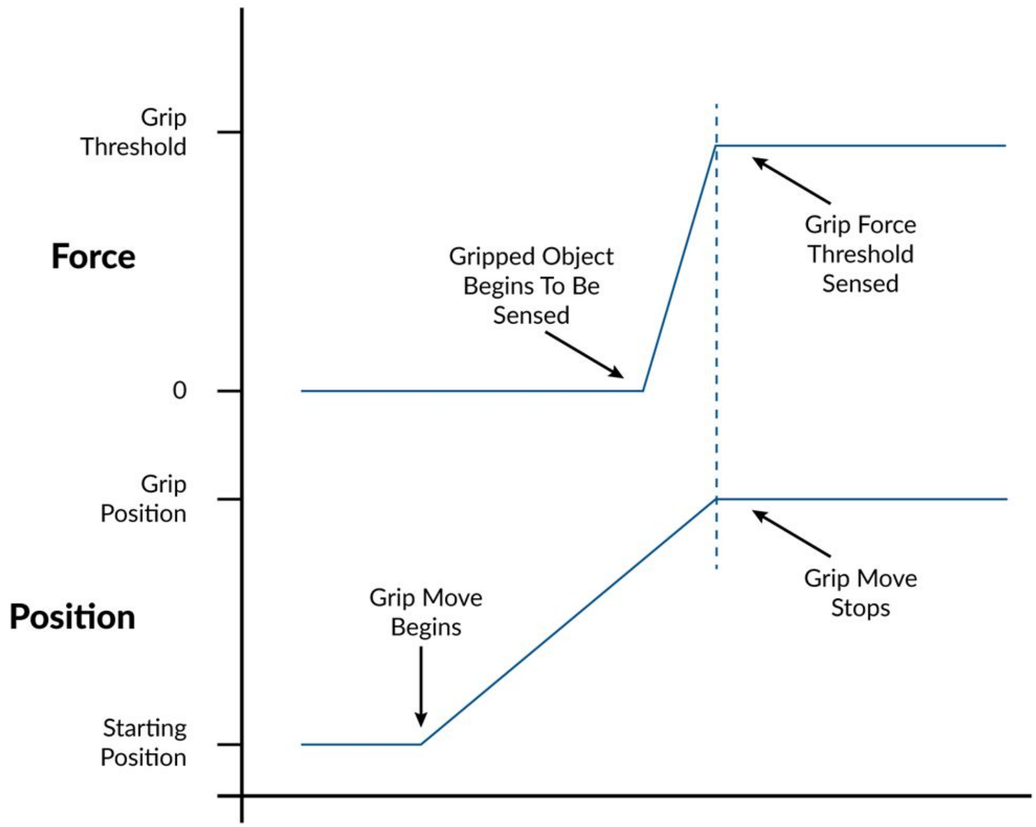

Figure 9: Stop Trajectory When Force Threshold Reached

In the first approach the gripper is controlled by a servo PID which continuously monitors the motor torque command which can be converted to applied torque by knowing the motors' torque output to current (amperage) ratio. At the start, the gripper is not in contact with the object and begins a trajectory move to approach the object to be gripped. As the move proceeds, at some point the gripper begins to make contact and this is sensed in the servo loop as the motor command torque needed to follow the commanded trajectory increases. Once the desired grip force has been achieved the

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motion profile is halted. Note that the force ramp is an indicator of the compliance of the object being gripped. A more compliant object would result in a flatter force ramp.

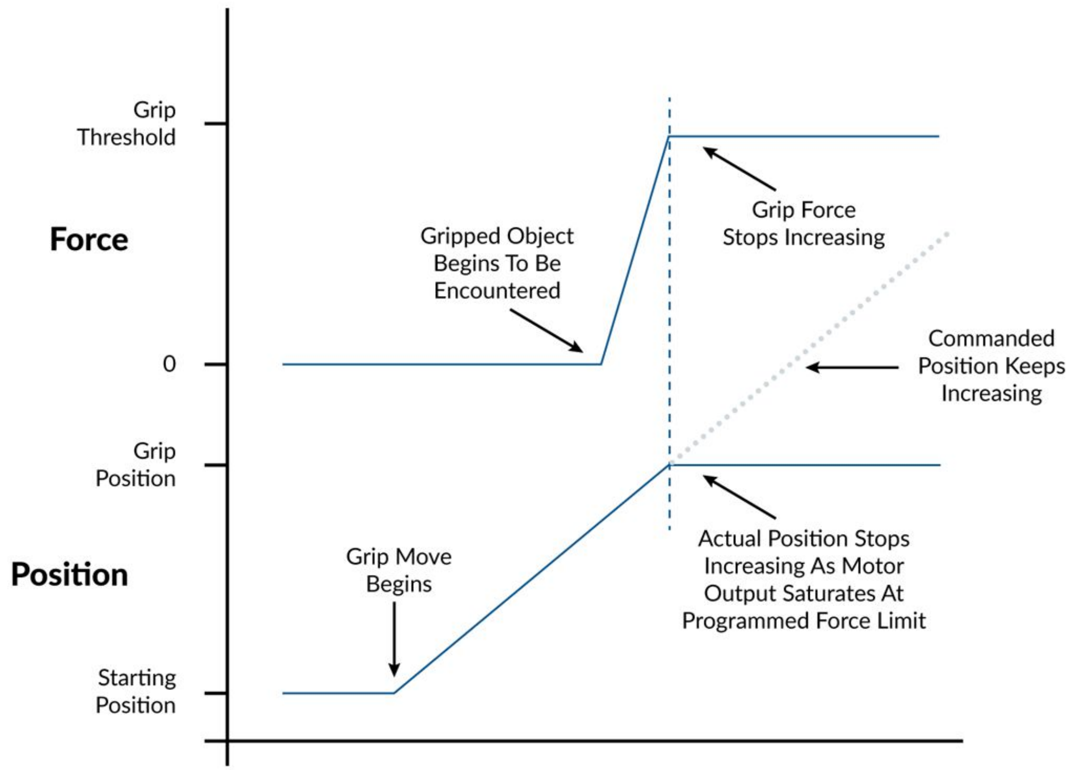

Figure 10: Continue Trajectory But Limit Force Output

In the second approach the gripper similarly approaches the object using a commanded trajectory move but the servo loop does not monitor the force output of the servo loop. Instead, a current output limit is installed in the servo loop so that even if the PID tries to follow the trajectory, the force it applies is no greater than the desired force threshold. At the point where the grip force equals the desired threshold the

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commanded trajectory continues moving but the actual position stops, resulting in the servo error rapidly increasing.

Algorithms and filters

What advanced algorithmic magic is needed to detect force in a servo control loop? As it turns out no magic at all. The common PID loop can implement both of the strategies described above as long as it has the ability to record and compare the output torque command (first approach described above) and as long as it supports a programmable torque limit (second approach).

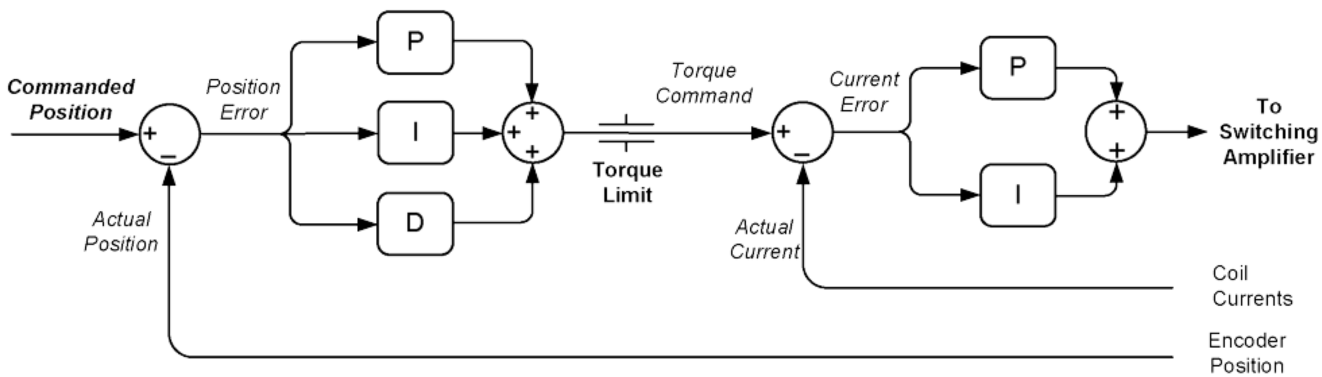

Figure 11: PID Position Loop with Torque Limit and Torque Loop

The diagram above shows what such a PID loop typically looks like. Note that there are two parts to this loop: a position loop and a current loop (also called a torque loop). The current loop is critical because accurate force control here is predicated on the ability to output a precise current through the motor coils. This in turn is enabled by the availability of accurate motor coil current sensors; generally, either Hall effect sensors or dropping resistors located in the amplifier.

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The other assumption for force control with these schemes is that there is a relatively small amount of friction between the actuator and the object being sensed. The direct drive motor excels at meeting this requirement, but even geared motors can sense force if the gear ratio is modest and the gearbox has low friction.

What about applications where this assumption isn't true, for example, the lead screw rotary to linear actuators discussed earlier in the article? As mentioned, force control using actuators such as this can still be achieved using a strain gauge. To control force in such an application a common approach is to add an outer loop controller that commands either a velocity or torque loop used to drive the motor. Such a cascaded Force/Velocity loop is shown in the servo diagram below.

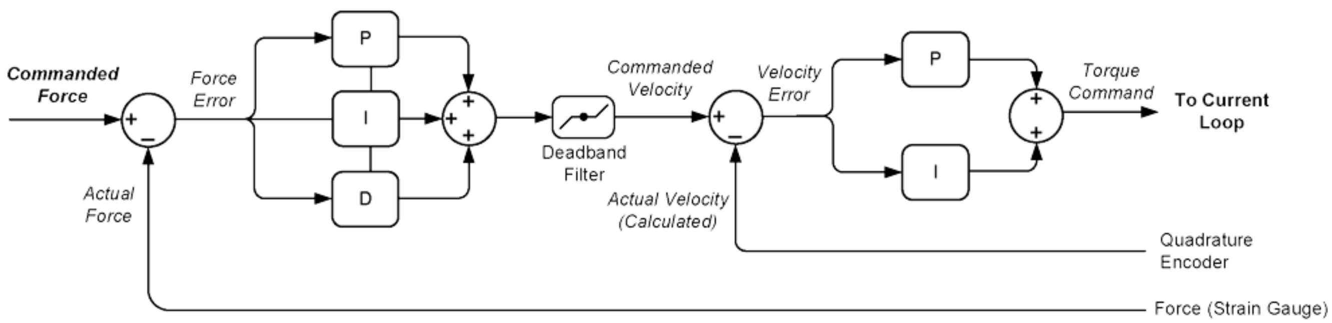

Figure 12: Force Control Loop Using External Strain Gauge

Here, the commanded force command is explicitly combined with the force sensor value and passed through a PID filter. This outer loop then sends a corrective signal to a downstream velocity loop. The motor is commanded forward or backwards on a continual basis to precisely maintain the commanded force.

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In the diagram above note the inclusion of a deadband filter, located at the output of the force loop. Deadband filters are useful for reducing hunting when the command velocity or torque is near zero. It is programmed with an upper and lower limit, which when so programmed creates a hysteresis function.

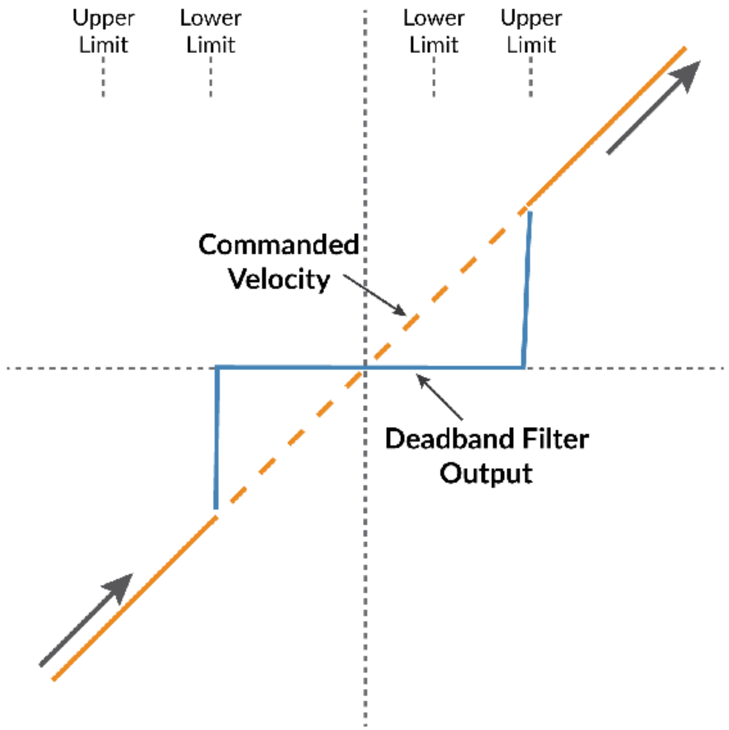

Figure 13: Deadband Filter

Example applications

Servo-based remote teleoperation

While grippers are a helpful vehicle to talk about force sensing and control, the general use of servo motors to sense the presence of objects and even the nature of objects

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within the end effector's motion range leads us to another interesting application for force sensing servo systems – remote teleoperation with force feedback.

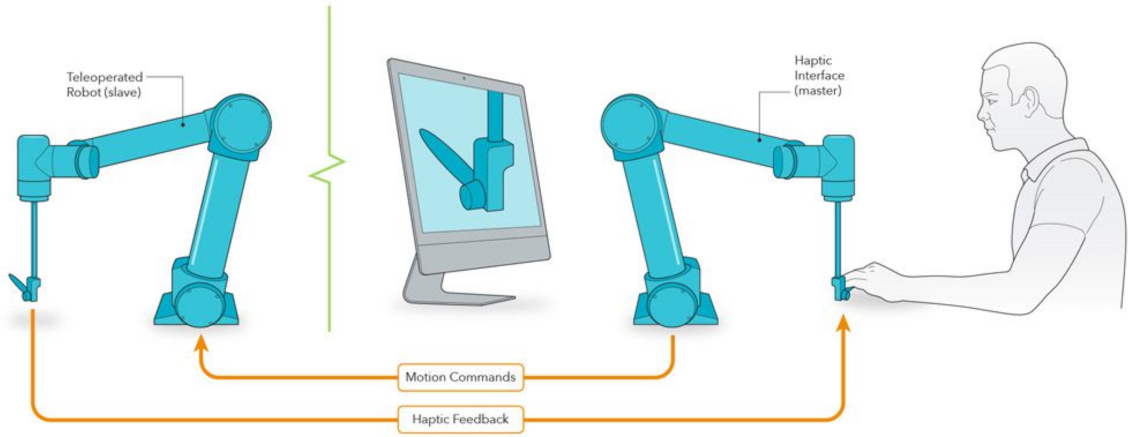

Figure 14: Servo-based Remote Teleoperation Setup

Figure 14 shows the configuration for such a setup. A human operator manipulates some sort of mechanical replica of the servo-actuated device being remotely controlled and in turn receives force feedback information according to the force being 'felt' by the remotely operated device. Applications for such a system include robotic surgery, nuclear materials manipulation, underwater robotics, dangerous materials handling, and more.

How does such a system work? As it turns out such a system is essentially a two-directional version of the servo-based force application & sensing discussed in the previous sections of this article. Both the human operator's mechanism and the remotely operated mechanism have servo control systems that can command motor position & torque and report this information back to its tele-counterpart.

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An example illustrates this. In a remote teleoperated system the remote mechanism is unimpeded as it moves in a direction commanded by the operator. The amount of force needed to undertake the move in the remote mechanism is small since there is nothing pushing back. That small amount of force is applied to the teleoperator's actuation mechanism, which is experienced by the operator as zero, or nearly zero, resistance to the move.

Now imagine the remote mechanism encounters a wall. As the teleoperator continues to push his actuator forward the force output by the remote mechanism's motor to obey this move will increase rapidly. This force, still being continuously output back to the operator's actuator will be felt by the operator is an impediment. As they try to push forward, they cannot – their actuator fights back reflecting the force output being sent back by the remote mechanism.

What is interesting and especially powerful about teleoperated mechanisms such as this is that the operator is not only able to feel the presence (or not) of a wall, but subtle gradations of force as well, depending on the physical nature of the object encountered. So the operator can feel the difference between a hard wall, a pliable material, a material that initially has a hard surface layer but then gives way to a softer interior, etc. Adding to this, because the data flow and servo control systems on both ends of the system are all computer controlled it is possible to arrange for force reduction or multiplication in the system. For example the remote mechanism could be a very small object such as a syringe needle under the control of a ultra-miniature servo motor.
In such a system the operator could feel the needle penetrating objects even as small as a biological cell because the force projected to the operator's mechanism could be multiplied a thousand or even a million times.

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It's fair to say that the development of remote teleoperated mechanisms such as these is still in its infancy. Many of the possible applications are still in the research lab. Other applications though, such as remotely operated surgical robotics, have been commercialized and in use for years.

Virtual motion systems (VMS)

To close out our discussion of linear actuators, end effectors, and force feedback, we will take a quick look at the very interesting world of Virtual Motion Systems, known as VMS for short, but also called haptic systems.

Virtual motion systems can be thought of as remote teleoperated systems where instead of a remote mechanism actually interacting with a physical object, the physical object along with the space it resides in is virtual. It exists only in the mind of a programmed computer which simulates the force the user would experience if they (for example) extended their hand, swung a sword, or operated the controls of a simulated airplane.

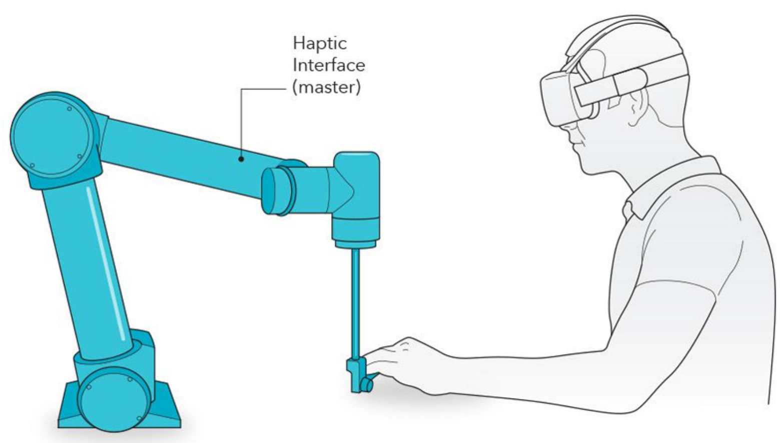

Figure 15: Typical VMS (Virtual Motion System) Setup

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The core of such a system is the same. The operator interacts with a servo-based system that can sense the operator's movements and impart a force that the operator can feel. The mechanical system that the operator interacts with doesn't necessarily have to match the system being controlled but does in fact do so for some systems.

The most direct example is a commercial airplane simulator. For these devices the operators sit in a detailed and accurate replica of the airplane cockpit being simulated. When they handle controls which can move during flight such as the steering wheel (known as a yoke) they feel exactly what they would feel in the real world. This can include the effect of inclement weather and all manner of physical real-world conditions experienced by the simulated airplane as it travels on a simulated flight.

In VMS's that do not have a physical replica of the operating environment the operator often wears a VR helmet capable of projecting a simulated image of the environment being interacted with. An example of such a system might allow users to 'feel' the contours of an object such as a molecule. The operator might hold a force feedback joystick in their hands, which in combination with the VR helmet would allow them to explore the contours of the object by 'touching' it.

Development of Virtual Motion Systems has occurred in fits and starts, generally starting in the research lab and then, for some applications, making it into the commercial or even consumer worlds. The challenge for wider adoption is mainly the cost and complexity of the motion control systems needed. However with the recent emphasis on development of the 'metaverse', perhaps VMS devices will see wider adoption in the future.

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Summary

Linear motors form the heart of many robotic and gantry transport system end effectors. While in many cases the goal of the end effector is to control the end move position, an equally common requirement is to control or sense force. Such force-sensing and controlling actuators are used in a wide array of industrial, laboratory, and scientific machinery.

Direct drive servo actuators or actuators with low friction can sense and control force without the need for an external force sensor. Rotary to linear actuators on the other hand often use a strain gauge and a special servo control loop to control force with high precision.

When used in force feedback applications these same end effectors and actuators open the door to Virtual Motion systems that can serve as ultra-realistic flight simulators, remotely operated robot arms, high end gaming consoles, and more.

Robotic welding system enables more welding applications for collaborative robots

Collaborative robots (cobots) can improve weld times and inefficiencies on the plant floor.

Collaborative robots (cobot) have been around for more than 15 years, and recent sensing and motion control technologies are improving quality while reducing weld process time on a 30-pass weld by more than 80%. With such advances in collaborative robot welding, in-demand skilled welders can shift focus to weldments requiring more human finesse. Collaborative robot use in the welding industry has exploded, largely due to the ease of programming, versatility and affordability systems offer, helping fill the gap between manual welding and traditional robotic welding cells. The shortage of skilled labor was present even before the COVID-19 pandemic and recent supply chain struggles and has become more acute during recent years, further fueling fabricators' need for simple, flexible automation tools.

Cobot welding systems began by working on easy weld tasks, like simple welds on repetitive and consistent steel parts, typically with smaller weld wire diameters. Recently, cobot welding system integrators like are enabling a broader range of weld applications through the development of new configurations and technologies on their cobot welding platform. These new developments include heavy-duty packages for welding with larger weld diameters (up to 1/16 inches or sometimes larger), push-pull packages for welding aluminum and other soft wires, various deployment options that add versatility and software features like touch sensing, multi-pass and through-the-arc seam tracking. Each of these evolutions enables more types of applications in a fabrication shop, such

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as heavy weldments, larger parts, various materials and components where automation-level upstream production consistency cannot be maintained.

Using a cobot to improve inefficiencies

Managing production inconsistencies is a key need for numerous manufacturers, particularly those doing large weldments. Even with upstream improvements, such as lasers, computer numerical control (CNC) press brakes, etc., and better fixturing, inconsistencies still exist in the weld shop. A through-the-arc seam tracking feature for a collaborative robot welding tool helps manages variations Through-the-arc seam tracking technology enables path correction during live welding by monitoring and using welding arc electrical characteristics to adjust the cobot path in microseconds. The feature enables automation use on applications that were inconsistent, like with plates that distort while welding and assemblies

Figure 1: The Vectis Automation's ArcPilot is a through-the-arc seam tracking feature in the Vectis Automation Cobot Welding Tool (a system powered by cobots from Universal Robots) to help manage variations. Through-the-arc seam tracking enables path correction during live welding by monitoring and using welding arc's electrical characteristics to make cobot path adjustments in microseconds. The heavy-duty XL version of the Vectis Cobot Welding Tool can handle multi-pass welds and large wire diameters, common applications that can benefit from through-the-arc seam tracking. Courtesy: Vectis Automation

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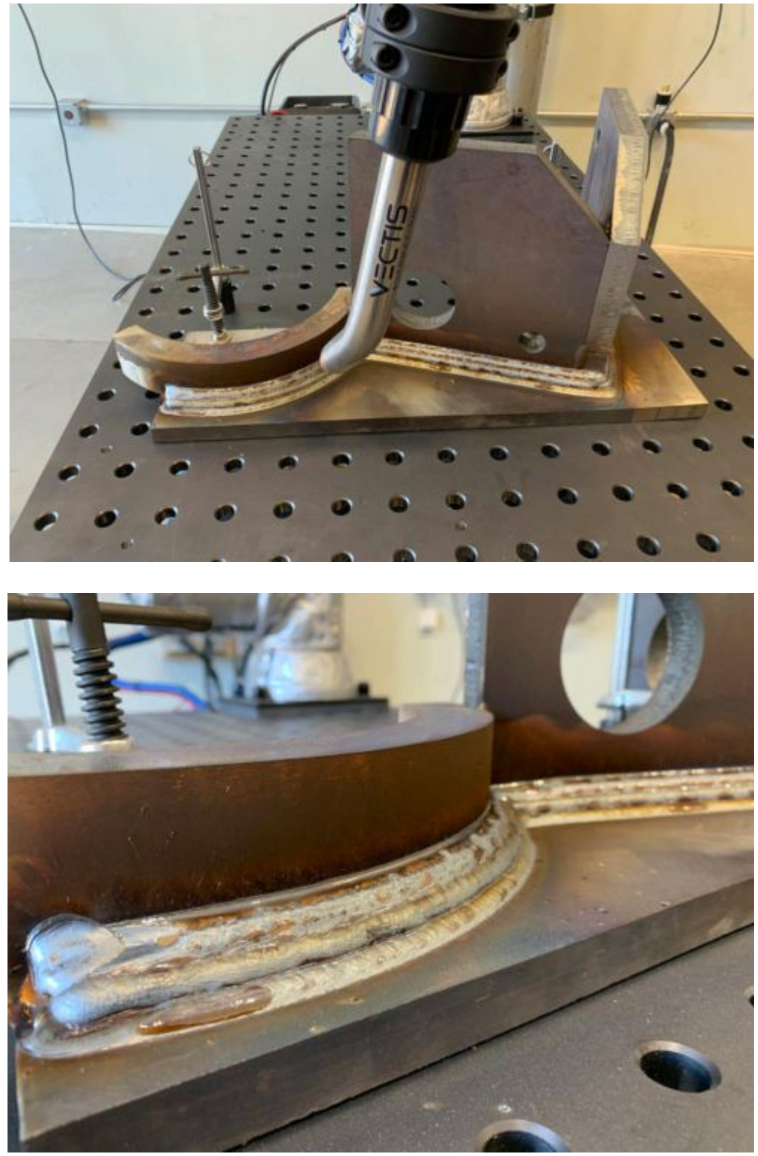
where slot-and-tab construction isn't viable or where precision fixturing would not be economical. The tracking technology allows cobots to tackle heavy-plate weldments. These weldments tend to have inconsistencies due to the nature of their construction and the potential for more distortion during welding.

The tracking adjusts the cobots programmed path based on an ongoing comparison of those readings, improving quality and consistency, especially where impossible with upstream processes and fixturing (such as distortion on heavy-plate parts). The seam tracking feature can correct both contact-tip-to-work ("CTWD," "stickout") distance and steer the cobot to stay in the center of symmetrical joints An algorithm correlates a cobot correction path in the joint at the proper tip-to-work distance.



Figures 2a and 2b: A multipass heavy weld is shown using the Vectis Cobot Welding Tool. Courtesy: Vectis Automation

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Control system design for robotic motion

The control system design for the tracking system integrates robust and speedy electrical arc parameter readings, components that can sense minute variances in high-amperage circuits, filtering algorithms to manage the various waveforms of the weld arc, fast data-crunching to determine where to steer the cobot in real-time and all the while making sure it is easy to use for the customer.

Figure 3: Vectis' ArcPilot through-the-arc seam tracking "steers" the cobot (left) along a symmetrical fillet joint, even with variances in the part relative to original programming, creating a high-quality, automated weld (right). Courtesy: Vectis Automation

The through-the-arc seam tracking technology can also be used in conjunction with Vectis' multi-pass software to correctly offset subsequent weld passes using the root pass that was seam-tracked. When combined, this technology combo has enabled productivity gains for heavy weldment fabricators. As cobots become more prolific in the welding and cutting market, new technologies like through-the-arc seam tracking will continue to increase the portfolio of viable applications.

Josh Pawley

Josh Pawley *is VP of business development at Vectis Automation.*

Improving usability is growing trend in industrial robotics

As collaborative and industrial robots grow in manufacturing, enhancing their usability so anyone can use them is a growing trend and priority for companies.

One of the most powerful trends in industrial robotics over the past decade has been the growing popularity of new programming methods and interfaces designed to make robots easy to program – even for non-experts.

Collaborative robots have been at the forefront of this trend, inspired by the goal of making industrial automation accessible to companies of all sizes and skill levels. But usability is vital across the entire spectrum of industrial automation and is an issue for both expert and non-expert robot operators alike.

Today, industrial robots can be programmed in numerous ways that score high on usability and don't require a Ph.D. or coding experience to handle. Hand-guiding (in which you literally guide your robot arm by hand to program it instead of painstakingly inputting every coordinate on a clunky teach pendant) and offline programming software are prime examples of the type of advances that have made industrial automation easier to use than ever before.

The days of robot programming being performed through an old-fashioned teaching pendant are, in most cases, gone. This era's new industrial robots can be programmed by a smartphone app, modern teach pendant, or tablet, and through intuitive and extremely user-friendly interfaces.

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Reducing robot complexity

Usability is the most important factor when it comes to customer perceptions of automation, said Ben Gibbs, CEO at READY Robotics –a Columbus, Ohio-based company that has developed Forge/OS, a universal operating system for industrial automation.

“This is true not only of automation but technology in general. If you had to write 100 lines of code to send an email, would you ever send an email? Instead, you click a couple of buttons and a whole bunch of ‘magic’ happens beneath the hood. That’s where we need to be with robotics.”

Forge/OS makes programming easy through abstraction and no code programming capabilities. First, it abstracts all the robot-specific programming languages using a common set of APIs. Second, the Task Canvas application provides a no-code programming interface in which end-users chain building blocks into flow charts.

“End-users don’t need to know any of these robot-specific languages,” Gibbs said. “They just need to know how to create flowcharts to be able to program both cobots and industrial robots from leading brands like Fanuc, ABB, Yaskawa, Epsom, Kawasaki, and Universal Robots, the exact same way.”

While SMEs have benefitted greatly from the emergence of user-friendly programming tools and interfaces, companies of all sizes are struggling to find labor at all skill levels and price points, which drives interest in easy-to-deploy automation among large companies too.

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Courtesy: Chris Vavra, CFE Media and Technology

"Whether you are a large enterprise or a small machine shop, you can benefit from robots. And you shouldn't have to be a Ph.D. roboticist or a seasoned robot programmer to be able to use them," Gibbs said.

Enhancing simplicity with robotics

Hanover, New Hampshire-based Hypertherm Inc. is a pioneer in the development of offline programming tools designed to take the pain out of industrial robot programming.

Hypertherm's Robotmaster software, which was first launched twenty years ago, has always been designed with ease of use in mind, says Natalie Adams, Head of Product Marketing – Robotics at Hypertherm.

"Our goal is to help manufacturers transition their labor-intensive manual processes to automated systems and we do this by simplifying the robot programming process," Adams said. "We want to abolish time-consuming, tedious, and complicated teach pendant-based robot programming processes. This reduces the deployment time and makes robot programming very simple to do."

Robotmaster enables end-users –including those with little or no previous programming experience– to program many of the leading industrial robot brands with ease. The process begins when an end-user imports a CAD/CAM model of the part they want to work on into the Robotmaster software. The end-user simply selects the edges they wish to perform a process on –such as cutting, polishing, trimming, or deburring. Next, a robot program is generated that tells the robot exactly what to do.

"Once the program is created based on the CAD model and end-user inputs, a second interface within the software allows the user to take that CAD model and bring it into a robotic system. This allows flexibility. You can switch robot cells without having to recreate the program. And you can switch robot brands without having to reprogram the part."

Robotmaster eliminates the need for complex CAD/CAM software solutions. And it relegates the teach pendant to a device that's used only for turning the robot on and off.

Next-level robot usability

Techniques like hand-guiding and user-friendly universal programming interfaces are great for lowering the barriers to automation adoption, but providing robots with the intelligence to perform a wide range of tasks autonomously brings usability to the next level by virtually eliminating manual programming altogether, said Rob Ravensbergen, marketing

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director at Omnirobotic, a Laval, Canada-based company that has developed a suite of technologies designed to provide robots with autonomous programming capabilities.

“Enabling industrial robots to function autonomously is the next step in usability,” Ravensbergen said. “The biggest benefit of autonomous functionality is not just the savings in programming and deployment times, but that robots can respond effectively to high mix production. Users only need to load predefined process instructions and the robot can process highly varied batches of parts.”

Omnirobotic’s 3D perception tools, when combined with the company’s task planning and motion planning Shape-to-Motion software, enable people to easily set up autonomous robot applications. For end-users, this means that there is minimal positioning and fixturing required. It also means that no manual programming is required to set up an application.

”Our technology enables humans to work in collaboration with industrial robots rather than having to drag them ‘bare knuckle’ through every step of every process that needs to get done,” Ravensbergen said. “Being able to just push a button and have the robot execute an entire process with limited preparation and no real fixturing or jigging is a huge enabler for integrators, manufacturing engineers, and production people.”

The primary users of Shape-to-Motion are manufacturers in aerospace, heavy equipment, and metal fabrication, but integrators are also drawn by the technology’s ability to eliminate a huge amount of repetitive programming work.

Emmet Cole

Emmet Cole, *contributing editor, Association for Advancing Automation (A3).*

Successfully implementing robots in an unpredictable future

Manufacturing has gone through many changes in recent years and the rising labor gap and the need for continued productivity has companies turning toward robotics. Three robotic myths and five steps for successful implementation are highlighted.

The COVID-19 pandemic and the resulting great resignation have put manufacturers in a bind. They have many unfilled jobs, but the demand remains and supply chain issues remain a continuing challenge. Robots can help fill some of the gap, said Mark Cianciosa, regional automation manager at Acieta, in his presentation "Robots Prepare Manufacturers for an Unpredictable Future" at IMTS 2022 in Chicago.

Three myths about robots, automation

While robots can help manufacturers be more productive and give companies constant production, some have held off because old beliefs about them doing more harm than good continue persisting. Cianciosa highlighted three myths that continue to persist about robots and their role in manufacturing.

1. Robots are expensive and hard to justify during uncertain times. Thanks to technology advances, robots have gotten cheaper over the years. They're also more versatile than they were even 10 years ago. Cianciosa said robotic automation is a lower-risk investment than dedicated equipment. If demand changes or new products are introduced, a robot can be redeployed and adapted quickly.

2. Automation is only for high production jobs. Cianciosa said that's not true any-

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Mark Cianciosa, regional automation manager at Acieta, in his presentation "Robots Prepare Manufacturers for an Unpredictable Future" at IMTS 2022 in Chicago. Courtesy: Chris Vavra, CFE Media and Technology

more. Technology has simplified the process and has made small part runs more efficient. One of the reasons cobots are so popular right now because they're so easy to program.

3. Robots steal jobs. Companies using robots find they need more people to handle increased volumes. In short, robots create a virtuous circle of investment, growth and job creation. These jobs, Cianciosa added, are better suited for humans and take advantage of people's natural skills and talents.

Jobs are badly needed in manufacturing to begin with. There are many workers about to retire and there aren't nearly enough people available to take their place on the production line. Cianciosa said there's a 7 million worker gap as of right now. The COVID-19

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pandemic and the resulting Great Resignation have put companies in a bind. High demand and supply chain issues are forcing companies to react. Increasing robots and automation in their facilities is the easiest solution, but even that only goes so far.

"Robots can take the place of 3.5 human workers, but with 40,000 being implemented a year, we're not even touching this number," he said.

Five steps to robot implementation success

Implementing robots can help manufacturers improve their productivity and fill some of the blanks on the production floor. Implementing them, however, is another story. This proceeds needs to be given careful and deliberate consideration. Cianciosa highlighted five steps companies should take when implementing robots in their company.

1. Company-wide support. Cianciosa said that while it starts with getting buy-in from senior management, it has to go further than that. Everyone impacted by a robot needs to be involved. This includes plant management, information technology (IT) staff, the shop floor and safety managers, among others. It's also imperative to educate everyone about robotic automation so there are no misconceptions about what they can and can't do—especially if plant floor staff are worried they will be replaced. They need to be assured robots will do the opposite.

2. Define success. There needs to be a consensus on what will make the project successful. It can be anything from increased production or beating projected return on investment (ROI) goals. Whatever it is, Cianciosa said the plan can't be vague and broad. There needs to be a specific target at the end. "It's okay to be specific and have big goals," he said.

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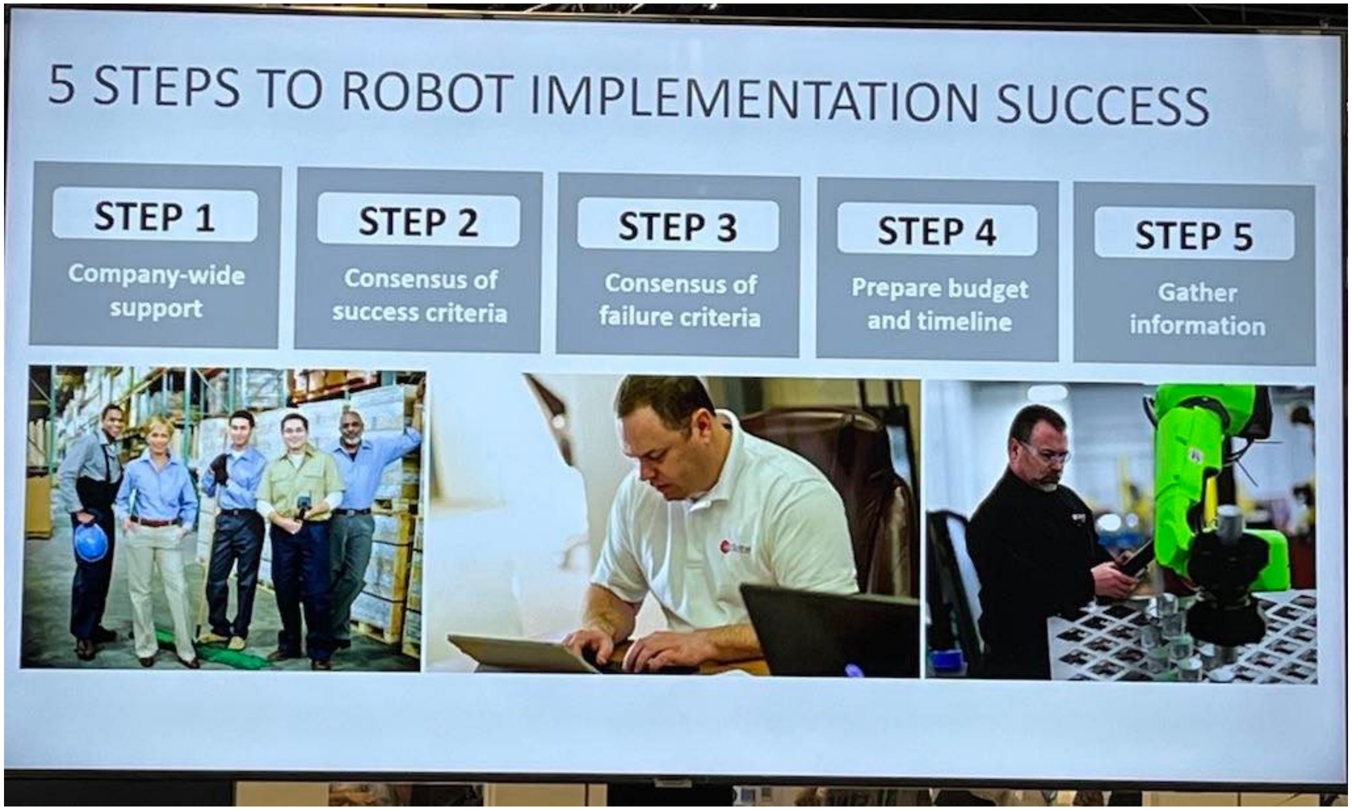

The five steps to a successful robotic implementation are company-wide support, defining success and failure, preparing a budget and timeline and gathering information about the company's operations. Courtesy: Chris Vavra, CFE Media and Technology

3. Define failure. On the opposite end of the spectrum, the plan should also specifically quantify what failure means. This includes organizational support on the front end of the project, but also how, from a logistical standpoint, everything might and might not come together. If the project will have a negative impact on quality, Cianciosa said, then the plan needs to be retooled or rethought so it can be successful.

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4. Prepare a budget and timeline. When it comes to the budget, the customer can get cagey with specific dollar amounts. Cianciosa argued they should be specific because it'll help the integrator get an idea of what will work within the dollar amount being given to them. The timeline also should have specific goals and estimates on everything from the purchase date to installation to implementation.

5. Gather information. The integrator should learn as much as they can about the company and the layout of the facility. Technical information such as 3D models, machine manuals, upstream and downstream processes, material specifications and more should be gathered. Non-technical information such as process cycle times and annual volumes also are critical, Cianciosa said.

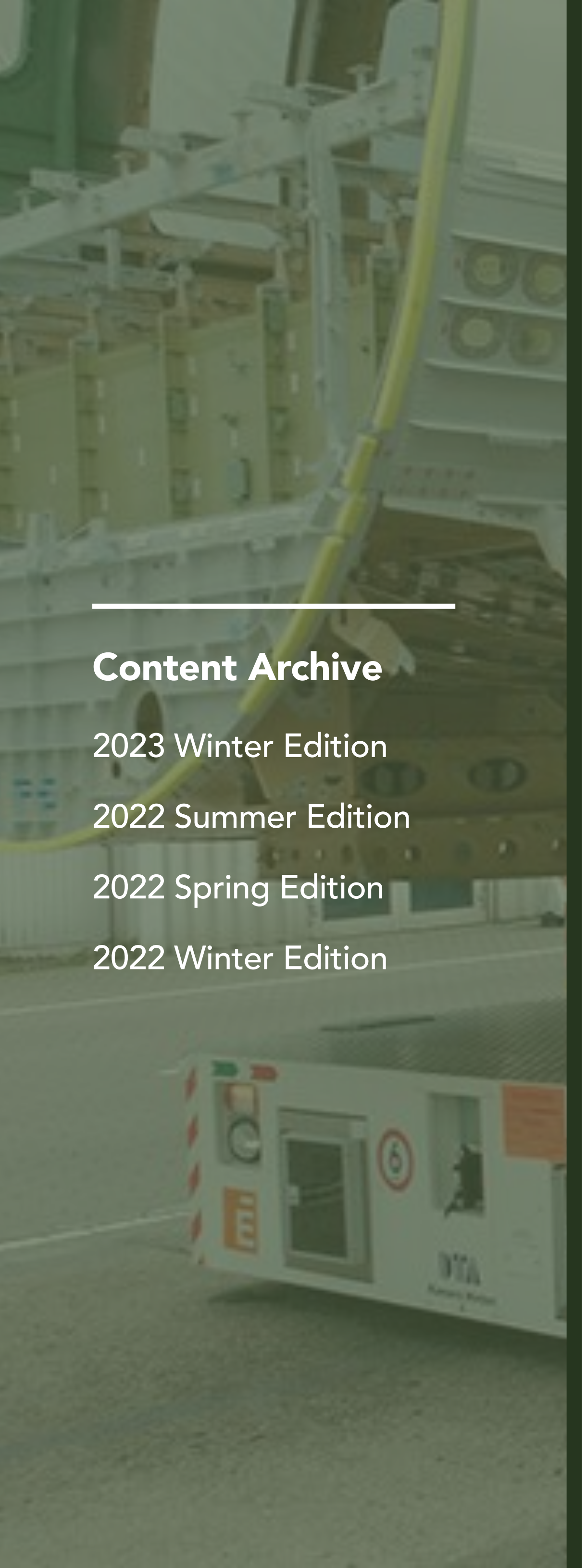
Robotic automation benefits for manufacturers

The need for automation has increased, but persistent fears about robots' role on the plant floor have kept some companies from following through, but strong customer demand and the need for production are forcing them to take the great leap. The rewards, though, outweigh the concerns they might have.

Cianciosa said, "Robotic automation can help manufacturers protect their team, protect their production, protect their customers and protect their bottom line."

Chris Vavra

Chris Vavra, *web content manager, CFE Media and Technology.*



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