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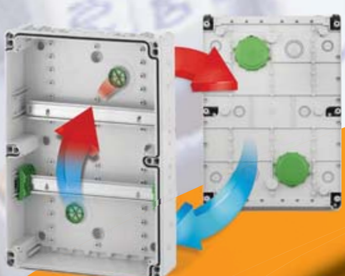

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MachineDesign
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Volume 94, Issue 8

“Spot is a general-purpose robot, and as I’ll describe, you can adapt it for a wide variety of things.”

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From the Editor

By **Bob Vavra**, Senior Content Director

Bridging the Manufacturing Chasm

Digital solutions bring with them no shortage of hype, but when will that translate into widespread adoption?

IT WAS HARD TO WALK more than a few feet at September's IMTS Show in Chicago without experiencing the impact of digital transformation. From new product offerings to connected systems to the hundreds of informational sessions during that week, everyone was talking about the new digital tools and strategies that are transforming the manufacturing landscape.

Software gives us new insights on the condition of our plant. Additive manufacturing adds a new dimension to product development and parts suppliers. The digital twin allows designers to build a replica of the operational model and test it in a virtual world before it is deployed online. Artificial intelligence can make the right decisions easier to find and implement, saving time and money. The push for sustainability defines energy as a manageable commodity, and then looks at alternative fuels and materials to pursue environmental improvement without sacrificing productivity.

They all are great solutions—all available today, all tested, all capable of fulfilling most of the hype around their deployment. Now all that is needed is for manufacturers to adopt them.

That is proving to be a slower process than anyone might have expected. Here's a preview of this year's *Machine Design Salary & Career Survey*, which will be released online later this month: Of all of these solutions, 3D printing leads in deployment among survey respondents…at just 30%.

In a list of 16 emerging technologies, only 3D printing and software reliability have been embraced by as many as one in four design and operations leaders as an impactful technology today. The use of 5G was cited by just 22% of respondents. IoT, machine learning and sensor integration failed to tick above 20%. Augmented reality and the coming concept of the metaverse failed to make any sort of an impact.

Some might be tempted to call this a technology gap between the available technology and its implementation. When 80% of your potential customers don't yet consider your solution to be part of *their* solution, that's not a gap; it's a chasm.

We have a similar yawning crevice when talking about finding the workers needed to implement this technology. We have talked about a "skills gap" for decades. It now is a skills chasm. In the *Machine Design* survey, 79% of respondents say there is an engineer shortage, and 71.4% are struggling to find engineers.

Taken individually, these technologies are transformative in their own right. Taken as a connected system of technologies, as many industry leaders now are touting, the potential improvements in safety, profitability, productivity, sustainability and quality represent a generational opportunity to change the way we make everything we use. It is a true Industrial Revolution that does not need a number to define it.

That will never happen until and unless we build a bridge across this knowledge chasm. We must connect the practical uses of this technology with the end-users. We have to build on the foundations important to them by answering the question they ask: "How will this make *my* operation better?" ■

MachineDesign

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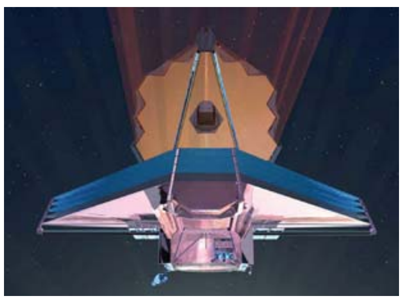

Gallery: Postcards from the James Webb Space Telescope

Here are some awesome images of incredibly large, incredibly distant stars and galaxies.

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FEATURED VIDEO

On the Cusp of Quantum Computing

Classiq Technologies' Erik Garcell touches on some of the issues that probably need to be addressed before there is widespread adoption of quantum computing.

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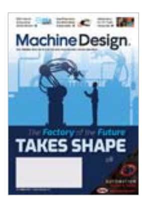

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An Aerobotix robots similar to the ones used on the F-22 carry out maintenance on an F-35 using a process called Mold In Place (MIP). *Courtesy Aerobotix*

Robots Keep F-22 Raptor Fighters Healthy and Stealthy

Air inlets on F-22s are precisely sanded and painted by a coordinated team of robots, saving time and money.

ONE OF THE U.S. Air Force's most critical and time-consuming tasks is keeping its fleet of aircraft well maintained and operational. With some planes, such as the B-2 Bomber and F-22 Raptor, that includes keeping the radar-absorbent coating clean and smooth.

On the twin-engined F-22s, maintaining the coating, which helps maximize its stealthiness and survivability, is particularly difficult on the air inlet ducts. The inlets ensure smooth air flows into the engines despite turbulent air coming at the ducts from several directions. Small objects, possibly even hail, being sucked into the engine at high speed can likely put some scratches in the inlet's surface finish.

To keep the plane performing at its best, the Air Force refurbishes the ducts periodically, sanding off the weathered coating and applying a new one. Since 2016, the Air Force has been using robots from Aerobotix to handle these chores.

Aerobotix received funding from the Air Force's Small Business Innovation Research and Small Business Technology Transfer programs to develop its robotic painting system. On the F-22, it can restore the performance coatings on inlet ducts far more quickly, cost efficiently and accurately than doing so by hand.

The automated painting system for the F-22s uses two robots working at the forward and aft ends of the ducts to sand and spray-coat them. Three of these systems have been installed at the F-22 Depot at the headquarters of the Ogden Air Logistics Complex at Hill Air Force Base, Utah.

"Our robotic technology can paint inlet ducts using only about 300 hours of labor, rather than the 1,600 hours it takes to do it manually," says project manager Bret Benvenuti, a senior robotics engineer at Aerobotix. "That's a labor saving of around 80%, so it really helps solve the challenge of getting these aircraft back into service quicker. And we estimate that since 2016, we've helped the Air Force save $8.8 million, $220,000 per aircraft, in maintenance costs.

The robots also improve accuracy and quality control, giving refurbished F-22s a lower radar signature.

"Recoating inlets manually requires that maintenance workers wear protective suits and respirators and spend hundreds of hours crawling around on their hands and knees inside of them," says project lead Nathan Morgan, an Aerobotix field engineer. "Under those conditions, it's nearly impossible for workers to manually apply the coatings at consistent speeds and thicknesses. The robots achieve better results while also curbing the amount of rework needed and number of worker injuries."

The robots also save money on materials. For example, they spray on more coating before its pot life expires, significantly reducing waste. The highly engineered coatings cost around $1,000 per gallon, and more efficient use can save about $40,000 per aircraft, according to Aerobotix.

Aerobotix engineers recently added the ability to adjust the spray paths so the robots could more efficiently handle aircraft that need only the bypass screen areas of the inlets to be recoated or to spray only the exterior of the inlets' forward outer lip. "Coating the lip while the aft robot is spraying the inlets saves two to three days in labor," Benvenuti explains.

Aerobotix has also added a measurement device that uses Terahertz technology to measure the finished coating's thickness. "It measures all the quality points much faster and more accurately than what has been done in the past," he says.

The company is now looking to adapt the robots to simultaneously coat other exterior sections of the aircraft, including chines, which will create further labor savings.

Aerobotix refurbished its first F-22 in 2016, just finished work on its 40th and is on track to restore its 50th by early 2023. The company has also developed similar automated painting systems for coating F/A-18E and F/A-18F Super Hornets and F-35 Lightning IIs. ■

Cover Story

A Robot Dog Demonstrates How Mobile Manipulation Affects Automation

Agile mobile platforms can deliver a new set of capabilities. Dynamic sensing for autonomous inspection is just one.

by Rehana Begg, Senior Editor

Hyundai Motor Group

Spot was conspicuous by its absence during Marc Raibert's keynote presentation at Automate 2022. But that didn't stop the captive audience of robotics and automation enthusiasts from cooing over the tricks the robot dog was able to pull off in a video clip.

For the most part, attendees would have been familiar with Spot's YouTube videos released over the years, where its dance antics and bloopers have become fodder for viral public relations campaigns. In one video celebrating the acquisition of Boston Dynamics by Hyundai Motor Group in 2021, Spot grooves with K-Pop sensation BTS. In another, the Rolling Stones team up with a pack of robot dogs that mimic Mick Jagger's dance moves.

On the surface it seems antithetical that the Boston Dynamics founder/chairman should be on stage to sanction a dancing robot dog. Make no mistake; Raibert, a roboticist with a PhD in robotic techniques that model biological behavior, is acutely aware of the mass market appeal of the choreographed videos—where the use of legs and arms are used as a form of expression and alter perceptions of what a robot can actually do.

Humans tend to anthropomorphize robots—whether it is from Boston Dynamics or anywhere else—and public misperceptions can partly be chalked up to a lack of everyday experience with robots. "The fact is, we're not very far along with mobile robotics doing precise operations, but we're making progress," said Raibert, who spent decades developing robots with advanced mobility, dexterity and perception intelligence before he designed Spot to navigate rough terrain, climb stairs or augment dangerous human work where traditional automation has failed.

AT A GLANCE:

- Boston Dynamics' Spot delivers a new set of capabilities for manufacturers.
- The mobile platform can be mounted with a range of payloads to enhance data gathering such as thermal imaging, LiDAR or 3D scanning intended for such tasks as digital twin creation.
- The robot dog can collect limitless quantities of site data in places where humans can but shouldn't go.

In industrial applications, Spot, a robot dog, may be integrated with a thermal camera, an arm for grasping objects and a thermal imaging camera, as well as dedicated processing (Spot CORE I/O) for additional on-robot computation. *Rightpoint*

What the dancing robot does demonstrate, Raibert argued, is that mobile manipulation is one of the most important robotic opportunities. He said static manipulation is proving to be successful in some kinds of manufacturing, but remains limited.

During his keynote at Collision on June 8, 2022, Raibert discussed his Today and Tomorrow robot concepts. "Spot is a general-purpose robot, and as I'll describe, you can adapt it for a wide variety of things," said Raibert. "It's not an appliance; it doesn't just toast your bread, it toasts your bread, delivers your margaritas, it does a lot of things."

Mobile Manipulation

Spot is a general-purpose, four-legged mobile platform that weighs 60 lb. It is compact, rugged and portable, and is designed to go where humans go. The robot dog is an omni-directional, customizable platform that can be adapted for a variety of different tasks; it can be mounted with a range of payloads to enhance data gathering such as thermal imaging, LiDAR or 3D scanning intended for such tasks as digital twin creation.

Spot has sensors built in on all four sides that help navigate through simple functions. In industrial applications, the platform may be integrated with a thermal camera, an arm for grasping objects (some people see it as a head), a Spot CAM (which comes with an optional PTZ camera), Spot CORE I/O (dedicated processing for additional on-robot computation) and Spot GXP (a power regulating and Ethernet port).

Since it moves around, tasks are no longer performed in a fixed location, and this allows businesses to think differently about the function of robotics. Singularities (a configuration in which the robot end-effector becomes blocked in a certain direction) and self-interference "are really different when you have a base that can move around," said Raibert.

Part of Boston Dynamics go-to-market approach is a reliance on early adopters to help cultivate use cases across industries, ranging from mining, power and utilities, manufacturing, and oil and gas to NASA's Jet Propulsion Lab. According to Raibert, there are about 1,000 Spots; 100 universities doing experiments; and about a variety of industrial facilities using Spot for such tasks as preventive maintenance inspections, remote detection, thermal, radiation and gas leak detection, and scanning facilities with a view to developing digital twins.

Perception and Intelligence

A human pilots the robot dog so it can collect data and piece together a map of the path. Spot can then be instructed to go around the path autonomously. This procedure is especially relevant where Spot is preprogrammed for "rounds and readings" in environments where routine, repeatable inspections are needed or where hundreds of pieces of equipment need to be scanned. In facilities where legacy equipment need inspection and where adding fixed sensors would not be economical, Spot can read analog gauge readings.

Raibert characterized Spot's body manipulations for the most part as being athletic intelligence—how the robot perceives its environment and functions by moving, balancing and maneuvering around obstacles—as opposed to cognitive intelligence, which involves planning for events. Boston Dynamics has interest in leveraging both types of intelligence to bolster a fully functioning hardware system.

Operationalizing Autonomous Data Collection

Before Spot's commercial release in 2020, Boston Dynamics turned to Rightpoint, a Chicago-based IoT consultancy, to address a gap in its user experience. "They were using a fairly bulky laptop that you had to sling over your shoulder and walk around with, and it just wasn't a great experience to drive or control Spot," said Ben Johnson, senior vice president of digital products, Rightpoint.

His team collaborated with Boston Dynamics in concepting, designing and developing line-of-site manipulation using either an Android tablet or a joystick to control directly where Spot was going, as well as the use of telemanipulation—or non-line-of-sight control—using the cameras to view what Spot sees in parallel with the development of Boston Dynamics' cloud-based software (Scout).

High Fidelity Experience

From where Johnson stands, Spot is at its core an image processor and a robot that moves from Point A to Point B. "So much of the control system is the processing," he said. Among the bugs his team needed to resolve was how to convert sensor data into a user-friendly control experience, as well as to enhance Spot's line of sight by reimagining Spot's camera positioning and the image the user sees. "Initially, Spot had two cameras in front that were pointing down to the ground and the two image streams intersected," explained Johnson.

Mobile gaming provided the inspiration. "Thinking through joystick controls, we also wanted to think about a driving experience that included the ability to see the camera," Johnson said. In addition to a straight-on view that would allow the person driving the robot to see where the robot was headed, his team would figure out how to use image processing on the tablet to transform the two image streams from the robot into an image that a human operator would expect to see. The current version, a composition of multiple images, was "a big hurdle to overcome," said Johnson.

Thankfully, it wasn't all work and no play. The Android tablet translates touch gestures into commands and articulations for the robot. Occasionally, those commands would get backed up and Spot would not know what to do. The results can be comedic, he said, as some of the parody videos on stress-testing can attest. "The robot just did not know where to go because the instructions it was receiving were confused or jumbled up," Johnson quipped.

"But robotics is hard; when engineers are thinking about a connected product,

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so much of the challenge is in building the physical manifestation of servos and motors and positioning systems," Johnson said. "The user experience on top of this is just a thin layer. A lot of the time you have to focus on the core mechanics, and that can be challenging."

The robot dog has gone through many iterations since then, and Rightpoint continues to help build a safe and more robust platform. "As a society, we have gravitated to where we really do expect high fidelity experiences," Johnson said.

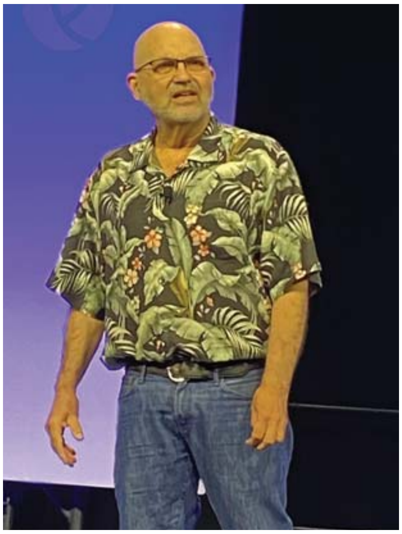
During a public relations campaign, Boston Dynamic's robots were programmed to conduct physical movements to mimic the choreography of K-pop group BTS. The video is about the enormous potential offered by Hyundai's new robotics in daily life and enabling progress for humanity. *Hyundai Motor Company*

Today, Tomorrow and Future Ambitions

Spot did make an appearance at IMTS 2022, where it put on a show to the delight of attendees. During the presentation, Eric Foellmer, vice president of marketing at Boston Dynamics, shared a slide depicting New York City's Easter Parade in 1900. The procession was made up of horse-drawn carriages, except for one car. His next slide, an image taken just 13 years later, depicted the reverse: The parade then was made up of a cavalcade of cars and just one horse and buggy. "The automotive industry had transformed the entire parade in a little more than a decade," explained Foellmer, hoping to impress upon the audience that the introduction of robots into our daily lives has similarly triggered an inflection point.

In addition to Spot, Boston Dynamics is paving the way forward with two other applications. Stretch is a commercial robot designed to unload boxes and containers in warehouse, shipping and logistics applications. Atlas is a humanoid, bipedal R&D robot with a dynamic hydraulic power unit. The HPU enables it to deliver high power to 28 hydraulic joints that give it the ability to perform parkour, including the agility to perform backflips.

"Adding cognitive intelligence to the robot is really going to be important, and I am starting to work on that problem," said Raibert at IMTS. "That means making robots understand their surroundings.



Marc Raibert, chairman and founder, Boston Dynamics talks about the agility, dexterity, perception and intelligence of advanced robots. *Machine Design*

Robots should be aware of their own behavior. So, if they knock over boxes, they are going to have to figure out a plan to pick them up. I think someday, they will be able to watch another robot or a person do a task, and figure out how to do the task themselves. And they also need to use reasoning and cognitive sense."

Raibert's IMTS presentation in June concluded with a cliffhanger: "Stay tuned…"

Those paying attention would have guessed impending plans. In August, Hyundai and Boston Dynamics announced an initial investment of $400 million to establish the Boston Dynamics AI Institute. Located in Kendall Square research community in Cambridge, Mass., the institute will be led by Raibert with the goal to invest resources in four disciplines—namely, cognitive AI, athletic AI and organic hardware design, as well as ethics and policy. ■

***EDITOR NOTE:** For more insights into the robot-human relationship and the changing nature of the automated industrial workforce, be sure to check out this issue's "One More Thing…" feature on p. 32.*

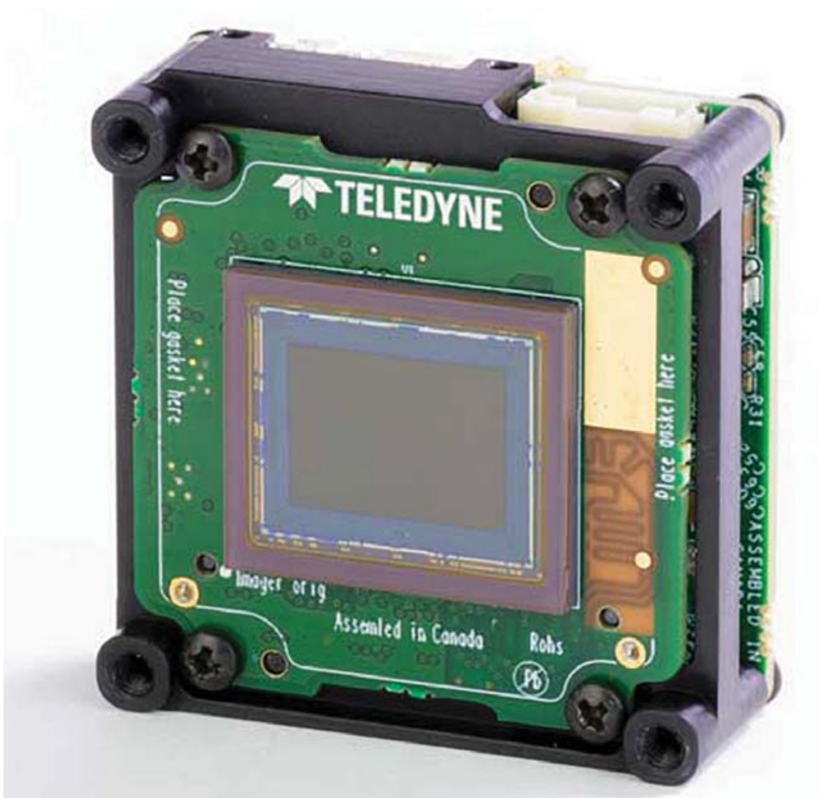
10 Considerations for Designing a Machine Vision System

Refer to this checklist of prerequisites before taking on the task.

by Filip Szymanski, Technical Content Specialist, Teledyne Vision Solutions

Machine vision systems serve a vast range of industries and markets. They are used in factories, laboratories, studios, hospitals and inspection stations all over the world—and even on other planets. But how do you design one?

When designing a machine vision system there are many factors that can affect the overall performance. Many of these elements are integral to the camera choice, but there are additional external factors that can have a significant impact on the final image. This article will explore 10 of these considerations and what to look out for when painting the full picture that makes up a vision system.



A Teledyne Lumenera Board-Level Camera with a 1.1-in. sensor. *Teledyne Vision Solutions*

1. Environment

Images are captured in every corner of the world. In a corporate or residential building, it is common to see security systems, and while driving there can be toll booths with embedded systems and small board-level modules connected to aerial imaging drones.

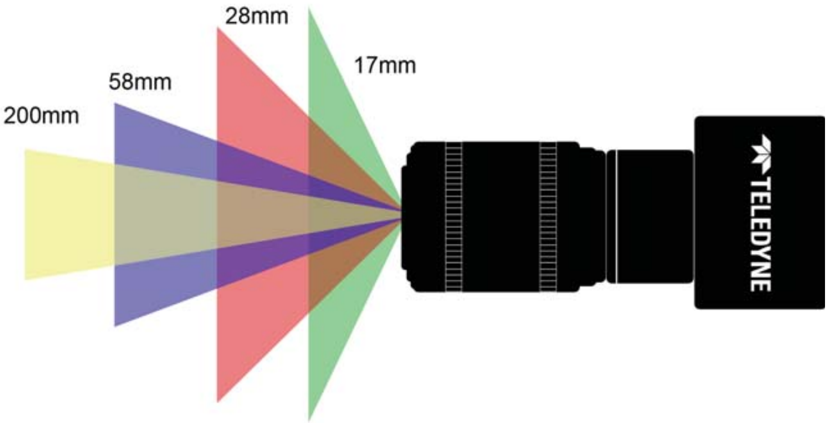
The range of environments that require reliable imaging solutions is broad, and while these systems are often generalized as machine vision systems, it's clear that imaging solutions extend well beyond factory floor applications.

The conditions a vision system operates within determine many of the specifications necessary to deliver the required image, including weather conditions such as direct sunlight, rain, snow, heat and other external factors that are outside our scope of control. However, a vision system can be designed with these in consideration. Factors such as additional light can be included in a system, or adequate housing to ensure the camera and its sensor are protected from harsh weather. In short, systems can be adapted to ensure that a camera always has a clear image.

2. Sensor

When deciding on a camera for a vision system, most of its performance resides with the image sensor. Understanding what a camera is capable of fundamentally comes down to the type of sensor being used. On the other hand, two different cameras with the same sensor are not necessarily going to output the same type of image. In fact, they most likely will have some noticeable differences. Therefore, looking at the rest of these considerations is quite important.

The format of the sensor will decide a lot about the matching optics and how the images will look. Formats abound, but some common ones include APS-C, 1.1-in., 1-in. and 2/3-in. When using a larger sensor size, a vision system can often benefit from more pixels, resulting in a higher resolution image. However, there are several other specifications that are equally important. Details such as full well capacity, quantum efficiency and shutter type all play a part in how the sensor can deal with various targets in unique situations.



A camera lens showing the difference in field of view based on the focal length. *Teledyne Vision Solutions*

3. Lens

After deciding on the internal aspects of a camera, a vision system needs some help focusing on a target that can only be accomplished with a lens. In machine vision systems the camera size can vary based on the application. With larger systems, a zoom lens may be required depending on the targeted image. With machine vision, many cameras are locked on a specific target area and take advantage of prime lenses with a fixed focal length.

Each lens has a specific mounting system based on the manufacturer and the sensor it will be attached to. Common lens mounts for machine vision include C-mount, CS-mount and M42-mount. Therefore, before choosing a lens, the first step is to review required sensor specifications.

The main specification for a lens is the focal length. As focal length decreases, the field of view (FoV) inversely increases. This means that as the area the lens can capture increases, the magnification of each element decreases. Other specifications are also valuable to consider, such as working distance and aperture.

4. Lighting

Arguably the most important piece of a vision system is the lighting. This is because no matter how sensitive a camera sensor is in low light, there is no substitute for the clarity obtained from a well-illuminated target. Lighting can also take many forms that can help reveal new information about a target.

Area lights are a more general-purpose solution for even distribution, so long as the target is a good distance from the source to prevent hot spots from occurring. Ring lights are useful when dealing with highly reflective surfaces since they are able to reduce reflections. Other lights include dome lights for machined metals and structured light for 3D object mapping; even introducing colored light can add details and increase contrast.

5. Filters

If there is excess unwanted light passing through the lens, it can reduce important detail. There are many kinds of filters that can be used to reduce and remove certain light. The two main kinds of color filters are dichroic and absorptive. The main difference between these is that dichroic filters are designed to reflect undesired wavelengths while absorptive filters absorb extra wavelengths to only transmit the ones required.

Filtering out color is not the only use for filters. Neutral Density (ND) filters reduce the overall light levels, whereas polarizers remove polarized light, which reduces reflected light. Antireflective (AR) coatings help reduce reflection within the vision system. This is particularly useful for applications such as intelligent traffic systems (ITS) where a reduction in glare can increase the accuracy of optical character recognition (OCR) software.

6. Frame Rate

The speed of a camera can be measured in frames per second (fps). A camera with a higher frame rate can capture more images. This also affects each image that is captured due to the exposure time of each image being reduced as the frame rate increases. This results in less blur as the camera captures fast-moving targets such as objects on a conveyor belt. The drawback to short exposures is the lack of time the sensor is able to collect light during each shot. In these cases, a larger pixel size for the sensor often helps increase the overall brightness of each image.

7. Noise and Gain

When a high frame rate is a must and short exposure can not be avoided, the camera gain can potentially make up for the reduced brightness. The reason why gain cannot be the easy solution for all lighting challenges is because of the noise that it introduces. As the gain is increased, so is the noise which reduces the clarity of an image. The increase in gain allows for the camera to increase the sensor sensitivity. This means the vision system can take in a brighter image with less light but also reduce clarity from read noise and dark current noise.

8. Bit Depth and Dynamic Range

To accurately measure certain targets, a vision system needs to have high enough bit depth. The higher the bit depth, the higher the degree of variance between pixels. On the other hand, the dynamic range represents the ability of a camera to make out details from the brightest

Filtering out color is not the only use for filters. Neutral Density (ND) filters reduce the overall light levels, whereas polarizers remove polarized light, which reduces reflected light. Antireflective (AR) coatings help reduce reflection within the vision system.

A Teledyne DALSA Genie Nano with a GigE interface. *Teledyne Vision Solutions* sections of the image to the darkest.

In outdoor applications more than 8-bit is rarely needed unless there is a need for high-precision measurement like photogrammetry. However, outdoor imaging can benefit greatly from a high dynamic range by capturing data in bright sunlight such as the sky, which is often overexposed in many images, and capturing detail in the shadows of a target. One possible solution could be to increase the gain or exposure time, but this would only result in getting detail in the shadows while reducing the data in already bright sections. A high dynamic range can ensure that there is clarity in each part of the image.

9. Software

Even with high-end hardware, the camera can only do what the software demands. The fundamental forms of software components are image acquisition and control, along with image processing software. The primary source of image data comes from image acquisition and control software which takes raw data from the camera and interprets it for the end-user. One of the common ways this is done is when a color camera takes an image, the pixel data is filtered through a physical Bayer filter, and then the software takes that data to construct a color image.

The next stage in the software tree has to do with what is done with the image data. This can involve a variety of tasks for machine vision such as inspection, analysis and editing for applications such as quality control when a target passes by the camera and needs to be tested.

10. Interface

As camera technology continues to push forward and result in a vast amount of image data, it is important to develop methods for delivering that data. Camera interfaces have branched out in several ways to provide a range of options for any imaging application. The four most common solutions are USB3, GigE, CoaXpress (CXP) and Camera Link High Speed (CLHS). The main attributes to consider when looking into a vision system interface are the required bandwidth, synchronization, ease of deployment and cable length.

Putting it All Together

There are certainly many considerations involved when building a machine vision system, which is why many companies turn to systems integrators to help them with this task. System integrators, in turn, rely on high-performance OEM components that deliver the results. The key is to define what you need your vision system to do, and then identify the elements of the system that can produce the desired results. ■

Automation & IIoT

Industry 5.0
Ushers in a New Era of Human-Centric Contributions to Production Processes

Computers are critical to Industry 4.0 and 5.0, but human workers and their creativity are still vital as well.

Korn Vitthayanukarun/Dreamstime

by Andreas Eschbach,
CEO & Founder, eschbach North America Inc.

Industry 5.0 is the next step on the path to more efficient production processes. Like many other industrial sectors, in the last few years the chemical industry has focused heavily on digitalizing production plants. But now, with their cognitive skills and creativity, humans will once again play a vital role in production—backed by advancements in artificial intelligence (AI) and machine learning (ML) technologies.

In the course of Industry 4.0, many companies invested in cyber-physical systems, data processing and cloud computing to create highly efficient production environments. Production people often took a subordinate role in these concepts as reliance on machines usurped the creative significance that plant floor workers bring to the successful outcome of production procedures in process industries. Furthermore, continued development in AI opens many new possibilities for machine-human collaboration. AI is already used in R&D, for instance.

However, in production, human-machine collaboration—or, to put it another way, machine-assisted humans—is still in its infancy. But here, too, human skills remain indispensable, such as when creative solutions are required for unexpected problems or to solve global crises. Computers lack the cognitive skills to adapt quickly to ever-changing situations such as those created by the COVID-19 pandemic and subsequent restrictions on working conditions.

Enhancements in M2M Communication

Essentially, the idea behind Industry 5.0 is that production processes will be controlled by humans who are supported by efficient cognitive assistance systems. After all, it is only when more and more data is available that humans can collaborate with machines—as a team—and make necessary decisions on a solid basis. In other words, machine-to-machine and human-to-machine communication must be extended with digitally supported, integrated communication between the workers.

The chemical industry will benefit from this approach in many ways, such as with safer processes, increased productivity and resource efficiency, and opportunities to pursue an economically viable switch to carbon neutrality. Increasingly complex workflow and systems are required to achieve these goals. These days, enormous data volumes are available to manage these issues. As long as everything runs according to plan, this is not a problem. But when things don't turn out as expected, problems can arise that, in most cases, require human intervention. To make the necessary decisions quickly, people don't need a flood of information, just the right information. That is the key task of cognitive assistance systems.

Implementation in One or Several Steps

What must companies do to implement Industry 5.0 in their production processes? They must develop a new understanding of human-machine collaboration; in other words, enable a greater extent of employee knowledge to be included in a digital system rather than simply using people as a monitoring tool for equipment or machinery. While a certain level of automation must exist, it is not necessary for a complete Industry 4.0 concept to have been implemented. Depending on the initial situation, companies can either start immediately with a comprehensive 5.0 concept or proceed in stages.

Regardless of the automation level, there is a lot of knowledge retained by employees. Routines that have more or less become second-nature to them are especially suitable for being digitalized. One example of this is at shift handover. No matter how often this has been done in the past, things will not always run smoothly with the usual analog procedure. Various studies shown that 50% of all mistakes in plants and factories are made in the first 30 min. after a shift change. And mistakes can have serious consequences, especially in the chemical industry.

Digitalizing Knowledge and Communication

Although there is already software that supports personnel at shift handover on the market, most of these only fulfill Industry 4.0 requirements. In the future, it will be important to network the cyber-physical and human levels to a greater extent, not only at shift handover but also, for example, with OEE (Overall Equipment Effectiveness) reporting. To do this, the knowledge and communication of all concerned, such as rotating and day-shift teams, production and site managers, and the company's top management, must be largely digitalized to ensure complete transparency for everyone.

Shift-handover management is one approach that can be used to achieve this. It ensures clearly structured processes in operational control and company communication and can be used regardless of the extent to which Industry 4.0 concepts are implemented. Information from every point of a production process can be captured, analyzed and integrated into other company-critical systems, such as ERP (Enterprise Resource Planning), maintenance management (i.e., SAP) and production planning.

User Acceptance Through Local Adaptation

Companies can use shift-handover management software to define uniform standards for the respective processes. This gives them a complete overview of routine actions, special events and plant capacity that can be easily reviewed. In short, it is a cockpit for plant management.

The successful introduction of global concepts that have a significant effect on operational procedures depends largely on the degree of user acceptance. Because few plants in the chemical industry are exactly the same, it is essential for company-wide standards to be adapted. The workers on site know best how operational reality needs to be mapped. Because most of the workers are not IT experts, the software provides a configuration environment that lets applications be modified via a graphical user interface without any programming.

Comprehensive Plant Process Management

Shift-handover management can provide functionality designed precisely to suit the human side of the processes and the operational organization. This enables a high level of interoperability between smart machines, other systems and the workers. With the ability to integrate company-wide standards and allow local modifications, the shift-handover software can be operated for decades.

Digitalized communication through shift-handover management not only enables Industry 5.0-compatible shift changes and morning meetings but can also support effective issue management. In other words, production personnel can quickly recognize special events, such as a malfunction in the process, a contaminant leak or an accident, and communicate it to all levels in the company. Key Performance Indicators (KPIs) can also be routed to external systems or be analyzed directly in the software.

Mobile Networking of Shift Personnel

Additional capabilities for digital communication are to increase the safety of routine tasks and support compliance management. During their regular inspections, workers can download lists of tasks and specific actions to their mobile

devices and report the results to the plant operators in the control room. Deviations can be documented with photos and displayed in the shift report or discussed at the morning meeting. Following this, the information is sent to the person responsible for corrective actions.

Digitalized communication is designed to increase asset performance. To do this, machine productivity is measured exactly, and performance losses and their causes are also recognized. This information is available not only in production but can be aggregated across all levels of the company through to top management. To ensure shift employees always have an eye on product quality, data can be enabled and displayed from laboratory systems and the like. In the case of escalating deviations, workers can either be instructed what to do or a message can be sent to an external system.

Conclusion and Outlook

Industry 5.0 allows the skills and creativity of people to be used to increase the safety and productivity of the processes. AI-supported technologies will provide support and, with extensive networking, enable the highest possible level of interaction between humans and machines and also between employees. Shift personnel in chemical production plants will continue to work 24/7 but will have to carry out fewer routine tasks. This gives the industry an opportunity to create new, appealing jobs that provide more value to the organization. In the future, employees will also delegate more complex tasks to machines, which will then become as natural as when we say "Alexa, play some music." But one thing will probably never change: Success or failure will ultimately depend on humans, not machines. ■

Auremar/Dreamstime

Hybrid Manufacturing Techniques Enable Production of a **Bionic Hand**

A new approach to prosthetic design using 3D printing restores mobility while remaining affordable.

PSYONIC prosthetic arm and PSYONIC Founder & CEO Aadeel Akhtar. *Photo credits: Formlabs*

by **Rehana Begg**, Senior Editor

Medical device manufacturing has a reputation for demanding high upfront R&D costs. But for one med-tech start-up that reality is not getting in the way of developing a bionic hand that could restore a patient's mobility at an achievable price point.

The story behind using hybrid manufacturing methods—including 3D printing, injection and silicone molding, as well as CNC machines—in the creation of the Ability Hand was born as much from a need to bring down costs as it was from ingenuity.

Prosthetic hands are out-of-reach for 90% of patients who can't afford advanced prosthetic arms, highlighted a press release issued by Psyonic and 3D printing company Formlabs. For San Diego-based Psyonic, creating an FDA-registered, Medicare-covered, industry-defining upper-limb prosthesis from scratch would be a defining milestone.

"Some of the biggest challenges we've faced is how do we make this hand still low cost for us to manufacture, but more durable than anything else that's out there?" noted Psyonic's CEO, Aadeell Akhtar. "And when we first started building these hands, we were 3D printing the entire thing and making it super cost-effective."

To be next-generation, a prosthesis needs to be "fast to respond to user inputs, tough and durable so as to not break during daily tasks, lightweight so as to not tire the user and cramp their arm, and deliver real, sensory feedback," asserted Psyonic's press release.

Lightweight, Durable Materials

While CNC machining, injection molding and initial costs are prohibitive for a start-up, 3D printing could offer a way to prototype rapidly and at a low scale and cost, according to James Austin, Psyonic's lead mechanical engineer.

"In the early iterations of the carbon fiber mold, SLA 3D printing was actually quite important," said Austin. "We didn't have the resources to produce molds for the carbon fiber, for example, by machining. So, what we did instead was we would produce molds using High

Temp Resin. This was fragile, but heat resistant, which allowed us to press the carbon fiber sheets into the exact shape we wanted, put them in an oven for high temperature to cure them, and then adhere them to our hand."

He explained that 3D-printed molds for manufacturing carbon fiber parts can reduce costs and lower lead times. The molds can be printed at low cost and within a few hours. Psyonic used High Temp Resin and Rigid 10K Resin

to achieve complicated mold shapes with fine details for their early prototyping, short-term tests. High Temp Resin has a heat deflection temperature (HDT) of 238°C @ 0.45 MPa and is able to sustain the heat and pressure of an autoclave.

"If we didn't like the shape, we just changed it in CAD, put it on the 3D printer again, had another High Temp Resin block come out and we were good to iterate," Austin said.

But for long-term sustainability, the engineers eventually switched over to machining molds.

Advanced Functionality

Restricted by their budget, the engineers needed to resourceful: They turned to reverse engineering and 3D printers to speed along development and reduce delays in production. "For smaller parts, we actually have the capacity to fairly easily reverse engineer the shape and form, and then simply produce them ourselves in-house," Austin said.

The Psyonic team also found they needed to mold the fingers in order to improve durability and switched to 3D molds. This method was supported by feedback from hundreds of patients and clinicians who complained about their $50,000 bionic hand breaking.

"They would accidentally hit it on the side of a table and, because the fingers were made out of rigid 3D-printed components, they would just snap at the joints and break," said Akhtar. "But our own fingers, they're flexible. When you hit them, they actually flex out of the way and come back. And it was that kind of functionality that we wanted to build into our prosthetic hand to make them more durable than anything else."

> *"If we didn't like the shape, we just changed it in CAD, put it on the 3D printer again, had another High Temp Resin block come out and we were good to iterate."*

To mold the fingers, explained Austin, the molds needed to be super smooth and printed at high resolution, making SLA (stereolithography) a better fit. Psyonic used Clear Resin, which has a higher resolution than fused deposition modeling (FDM) 3D printers. "We would produce these molds by taking the inverse of the finger or thumb shape that we wanted, subtracting it from a block, adding runners and inlets for the two-part silicone to be injected," Austin said. "Once that mold had been designed and printed on a 3D printer, we would put a plastic 3D printed bone inside it, which forms the skeleton of the finger."

This method is not without limitations. Austin explained that Clear Resin can get worn down over time. When that happens, it's easy enough to print another batch of molds and have them ready within 24 hours, he said.

Highest Resolution

Austin said he used the highest resolution possible when printing on the Form 3 (25 microns) for creating both end-use parts and molds. For tough 1500 Resin parts, such as the drivetrains, this is needed because they fit together very precisely. "They have a very tight fit inside the hand and around the motors and gears," said Austin. "Any variation or tolerance in this could cause the gears to grind or the parts not to fit, so they need to be made as precisely as possible in order to achieve optimal fit and functionality."

The molds are run at high resolution to ensure smooth surface and washed thoroughly with the Form Wash to get a slick surface. "The smooth result is reflected in the silicone that we mold in those parts afterwards," said Austin.

Rapid Prototyping

Prototyping plays a significant role in medical device design. Feedback from patients and end-users at this phase is invaluable and medical device manufacturers go through hundreds of prototypes before a part is ready for field testing. Austin noted that there were occasions when he had reworked a design in response to seeing a patient

break the device in ways that had not been accounted for.

Austin pointed out the objective was to balance and optimize the manufacturing method. "A lot of prototypes will start out being made in FDM printed plastic or in SLA printed resin, and then once we decide we're settled on a fairly final design, we may get it remade using, for example, a CNC machine in metal, which is more expensive and more time consuming, but more durable long-term," he said.

"Some things are perfectly fine to be kept as SLA; they work great in resin. Some things have a bit more durability once we switch them over to metal," said Austin. "Having all these options means that we can really mix-and-match to optimize for any individual part, to really make sure that we get the best bang for our buck. The lowest manufacturing cost, but the highest performance."

The next phase of growth for Psyonic will be to focus on the North American market, with the production of Ability Hands ramping in late 2022.

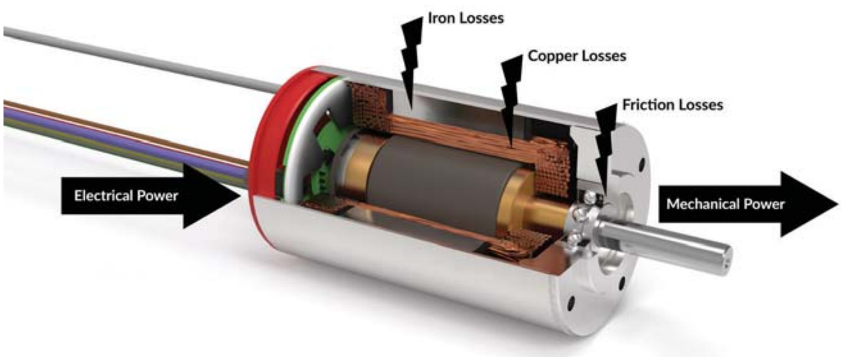
What patients really want is to do the normal activities of daily living, noted Akhtar. Advancing the mechatronic interface alone can be is a strong motivator for pursuing advanced innovations in the design of the prosthesis.

Garrett Anderson, a retired U.S. Army sergeant whose right arm was amputated below the elbow following a roadside bombing incident while deployed in Iraq, is one of the first power-users of the Ability Hand. "Earlier this year was the first time I actually could feel touching my daughter's hand with this prosthetic hand because of the sensory feedback," he said. ■

Understanding Losses in BLDC Motors

Engineers who have a firm handle on losses in BLDC motors can better design efficient motors for their specific applications.

by Samuel Klein,
Application Engineer, Portescap



This cutaway of a Portescap BLDC motor shows where various losses arise and the pathway from electrical to mechanical power (Electrical power – (Friction losses + Copper losses + Iron losses) = Mechanical power). *Photo credits: Portescap*

Brushless DC (BLDC) motors transform electrical power into mechanical power. However, there's no such thing as a perfect motor; there are always losses in the transformation. The three main types of losses created during the conversion are friction losses, copper losses and iron losses.

Friction losses are caused by the ball and bush bearings, and they are function of the application's use (speed, load and acceleration) and environment (temperature, dirt and other factors), plus the bearing's intrinsic characteristics such as material, wear, lubricants and sealing.

Copper losses, also called joule losses, are created by the coil's resistance. Torque is linearly proportional to the current, so the more torque a motor provides, the higher the copper losses. This follows the quadratic function shown here:

Copper Losses = $R \times I^2$

R is resistance and I is current.

Keep in mind that the resistance will increase as the motor heats up (according to the equation below). This will reduce the efficiency.

$R = R_0 \times (1 + (y \times \Delta Temp))$

R_0 is the resistance value at ambient (usually listed in the datasheet), and y is resistance factor of copper (0.004/°C).

Iron losses can be easily misunderstood but they have a substantial effect on motor performance. The losses depend greatly on the frequency of the variation of the magnetic flux into a material, so more losses are generated the faster a motor rotates.

A small experiment can explain this phenomenon. When a magnet is thrown into a slightly ferromagnetic tube—like copper or aluminum—the speed of the falling magnet is much lower than what would be expected.

Why does this happen?

Lenz's Law states that:

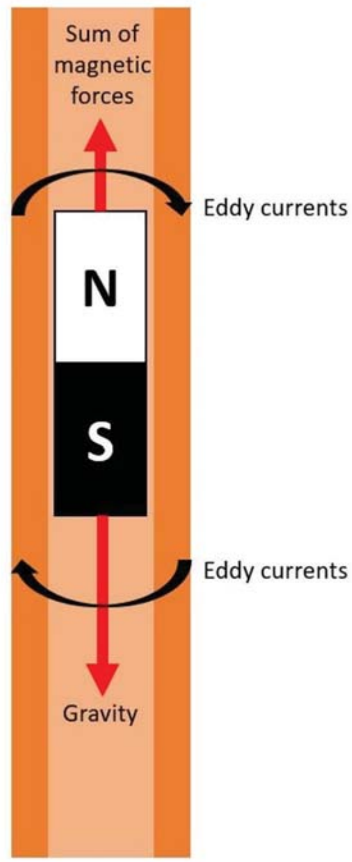
Induced EMF = $-\Delta\phi/\Delta t$

$\Delta\phi$ is the rate of change in magnetic flux and Δt is the corresponding change in time.

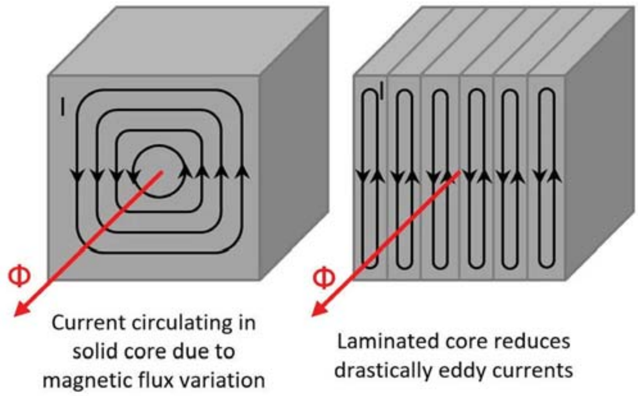
According to Lenz's law, when the magnet falls through the tube, the changing magnetic field induces current that flows in a direction that opposes the change in the magnetic field that produced it, thereby reducing the magnet's speed.

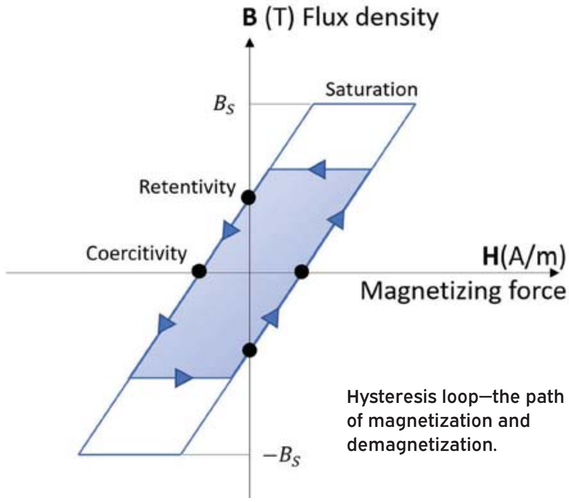
Iron losses are generated by two phenomena: eddy currents and hysteresis.

Eddy currents. Faraday's law states that a magnetic field interacting with a conductor induces a current through it.



This image illustrates Lenz's law as demonstrated by a magnet falling into a copper tube.





Hysteresis loop—the path of magnetization and demagnetization.

And, since the material has a specific electrical resistance, it creates some iron losses (R × I2). So eddy current are calculated using:

Eddy current losses = $R \times I^2 \approx C \times B^2 \times f^2 \times t^2 \times V$

Where: C is a constant depending on the motor design and materials; B is the magnetic field into the materials (T); f is the frequency of magnetic reversal per second (Hz); t is the material's thickness (m); and V is the volume of the conductor (m^3)

The previous formula shows the parameters that play a large role in creating eddy current losses above. Not surprisingly, the frequency of magnetic field reversal has a substantial influence, as does the motor's speed. The intensity of the magnetic field and even the thickness of the material also play important roles.

An effective way to reduce the impact of the material's thickness is by laminating the core material (as shown in the image above). This creates a shorter path for the current to travel through, thereby splitting it into several small currents. Because losses are created with the squared value of the current, this approach is highly effective. So, to avoid current flowing between two laminations, insulate the laminations from each other with a coating.

Hysteresis. When the magnetic flux is reversed into a ferromagnetic material, energy is lost as the material magnetizes and demagnetizes. To remove the remaining flux density, an opposite magnetic flux should pass the point of coercivity (as shown above).

These losses depend primarily on the magnetic induction in the circuit, but also on material properties such as permeability, volume and the flux variation's frequency. That's why it is important to select the right material for the right speed.

The Steinmetz equation can be used to calculate hysteresis losses and understand the influence of each parameter. It states:

Hysteresis losses = $k \times V \times f \times B \times n$

Where k is a constant of the material; V is the volume of the magnetic circuit (m^3); f is the magnetic field's frequency; B is the maximum induction in the magnetic circuit (T) and n is a coefficient (between 1.6 and 2) that depends on the material.

Getting the Right Motor

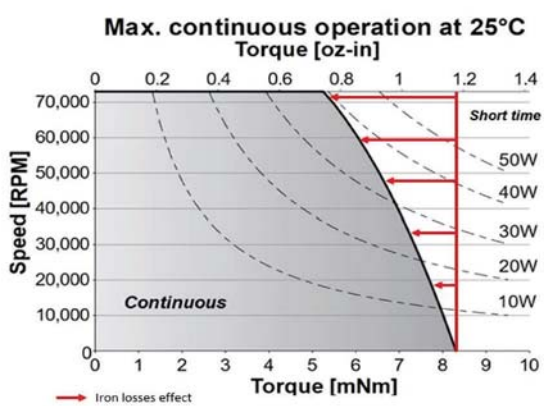
An BLDC motor's various limit its maximum power, since it would burn if it exceeded a specific temperature depending on the motor design. This makes it critical to select the right motor based on the specific torque-speed working point.

Copper losses are mainly created when the motor is generating torque, and iron losses usually occur at high speeds. Consequently, the figure below shows that for a given motor, the maximum possible continuous torque decreases when speed increases.

Changing the number of poles of a magnet can have a major influence on motor performance. Typically, long motors have two-pole magnets and can run at high speeds. Although this can increase the motor's maximum torque, it also increases iron losses and thus reduces the maximum continuous speed.

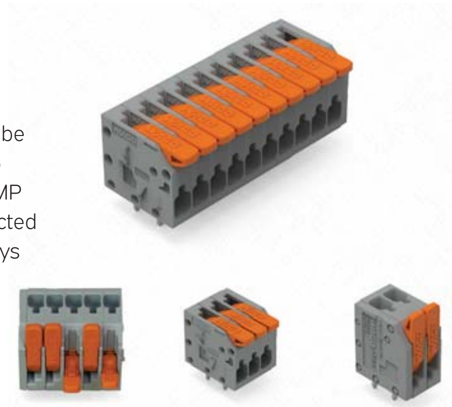
Iron losses depend highly on the frequency of variation of magnetic flux for a similar speed, so increasing the number of poles increases the number of variations for one motor turn. For eddy current losses, this happens with the square of the increased frequency and can quickly reduce a motor's efficiency.

When selecting an electric motor, it is critical that engineers consider the different losses. Because the motor's limits are thermal, iron losses play a role in the motor's efficiency, especially at high speeds or in multipolar, high-torque designs. Optimizing the ratio between copper and iron losses will save energy and improve motor designs. ■



This graph shows the effect of iron losses on the power curve of a BLDC motor, the Portescap 16ECS36.

PCB-Free Terminal Block Allows Easy Wiring



The 2601 Series a super-compact, tool-free PCB terminal block with lever technology, allowing quick and easy wiring for cross-sections from 26 to 14 AWG. With the ability to be connected both vertically and horizontally to the PCB and with a pin spacing of just 3.5 mm, this terminal block takes up minimal space on the board. The Push-In CAGE CLAMP connection technology, solid and fine-stranded conductors with ferrules can be connected simply by pushing them into the block. The levers ensure that the contact point is always secure; making the PCB terminal blocks ideal for device connections in the field, no matter the performance class.

WAGO

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Three-Phase Filter Meets Standards Requirements

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Ad Index

One More Thing...

The "Robot Stole My Job" Debate Rages On

Kittipong Jirasukhanont/ Dreamstime

The extent to which robots and automation shift jobs remains contentious. Researchers offer a few new insights.

by Rehana Begg, Senior Editor

Fears about working alongside robots is a perpetual concern, especially as it relates to the effects on worker displacement and productivity.

A comprehensive understanding of how it will impact the industrial equilibrium remains unclear. Some studies have concluded that the impact varies among industries, population and geographies.

Robotics adoption is concentrated in manufacturing, with automotive, electronics and plastics leading the way, so there is something to be said for the way robots affect routine manual occupations and blue-collar work. This holds especially true for machinists, assemblers, material handlers and welders.

"Adding one more robot in a commuting zone (geographic areas used for economic analysis) reduces employment by six workers in that area," according to one estimate reported in an MIT study, "Robots and Jobs: Evidence from US Labor Markets."

That study noted that a more holistic understanding of the impact of emerging automation technology is needed.

In a new paper published by the American Psychological Association, researchers found that workers in the U.S. and parts of Asia feel job insecurity from robots, but the jury is still out on whether their fears are justified.

According to the study's lead researcher, Kai Chi Yam, PhD, an associate professor of management at the National University of Singapore, "It doesn't look like robots are taking over that many jobs yet, at least not in the United States, so a lot of these fears are rather subjective."

Who Moved my Cheese?

A key takeaway according to Yam's report is that we now have evidence that increased exposure to robots leads to increased job insecurity. The authors noted that while "self-affirmed individuals do experience lower levels of job insecurity after being exposed to robots, we do not know if this reduced job insecurity would in turn lower burnout and incivility." The researchers conducted experiments and analyzed data from participants in the U.S., Singapore, India and Taiwan. Their paper is the culmination of six studies—including two pilot studies, an archival study across 185 U.S. metropolitan areas, a preregistered experiment conducted in Singapore, an experience-sampling study among engineers conducted in India and an online experiment.

A few more germane takeaways:

- **Automation and incivility.** Working with industrial robots was linked to greater reports of burnout and workplace incivility in an experiment with 118 engineers employed by an Indian auto manufacturing company.
- **Buffering negativity.** An online experiment with 400 participants found that self-affirmation exercises, where people are encouraged to think positively about themselves and their uniquely human characteristics, may help lessen workplace robot fears. "Most people are overestimating the capabilities of robots and underestimating their own capabilities," Yam said in a press release.
- **Pundits play a part.** Some media coverage may be unnecessarily heightening fears among the general public. "Media reports on new technologies like robots and algorithms tend to be apocalyptic in nature, so people may develop an irrational fear about them," Yam said.

Yam and his colleagues conclude that technology transforms the nature of work, but that people's fears seem fundamentally unchanged.

"The Rise of Robots Increases Job Insecurity and Maladaptive Workplace Behaviors: Multi-Method Evidence," was published online in the *Journal of Applied Psychology*. ■

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