EIT eBook | Volume 2, Issue 2

EMPOWERING INNOVATION TOGETHER™ with Grant Imahara

GENERATION ROBOT

Designing Robotic Hands

Robotic Gesturing Meets Sign Language

Anatomy of a Service Robot

Engineering Robots for Zero Gravity

MOUSER ELECTRONICS

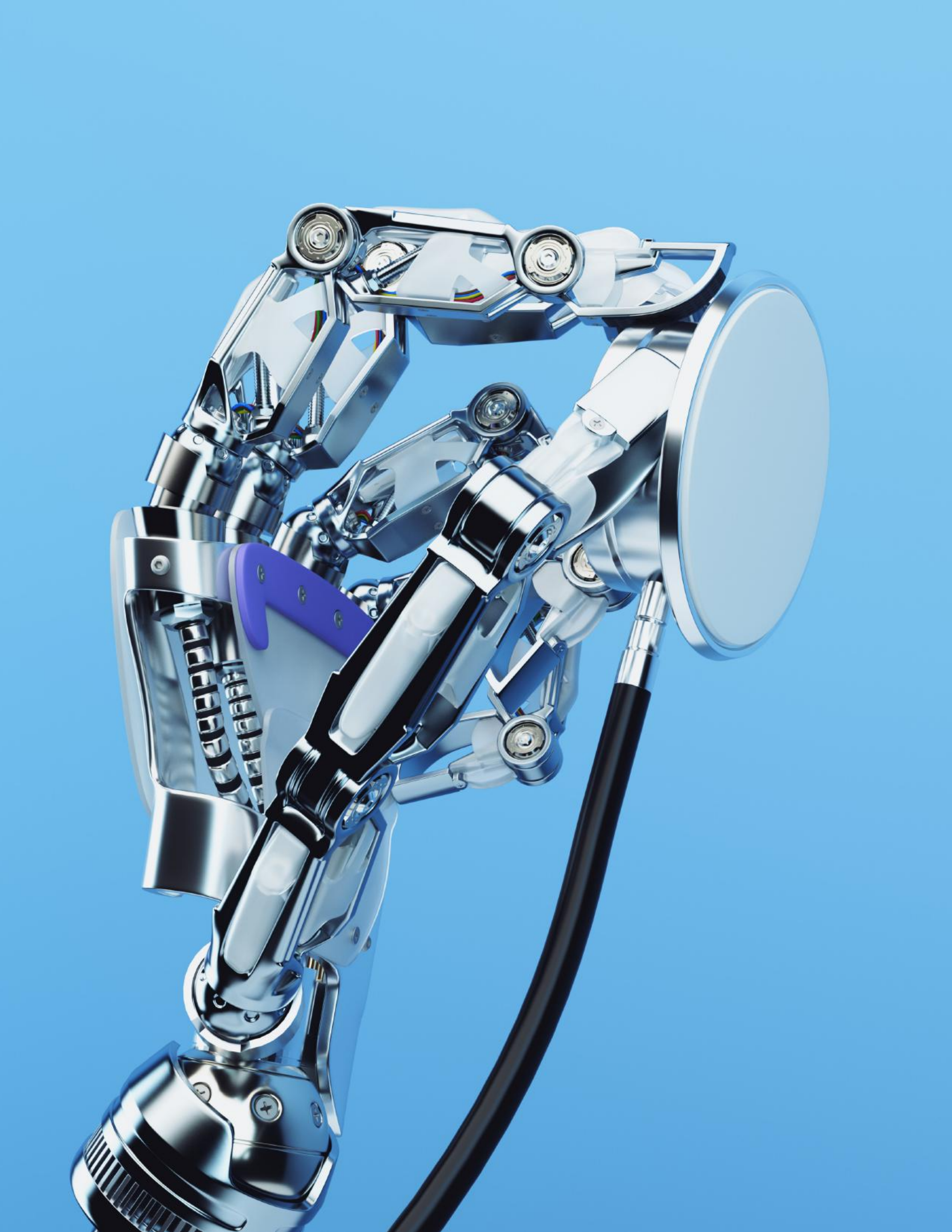


TABLE OF CONTENTS

WELCOME FROM THE EDITOR

If you're just now joining us for Mouser's 2018 Empowering Innovation Together™ (EIT) program, welcome! This year's EIT program—Generation Robot—explores robotics as a technology capable of impacting and changing our lives in the 21st century much like the automobile impacted the 20th century and changed life as we knew it.

In our last segment, we explored collaborative robots and featured a compelling video hosted by celebrity engineer and Mouser partner Grant Imahara, as well as the ***Collaborative Robots* eBook**, which features cobots in industrial environments, identifies design considerations and solutions, and discusses motor control in complex robotics. The accompanying blogs featured our favorite robots from our favorite shows and movies: ***Star Wars***, ***Star Trek***, ***Lost in Space***, and ***Dr. Who***.

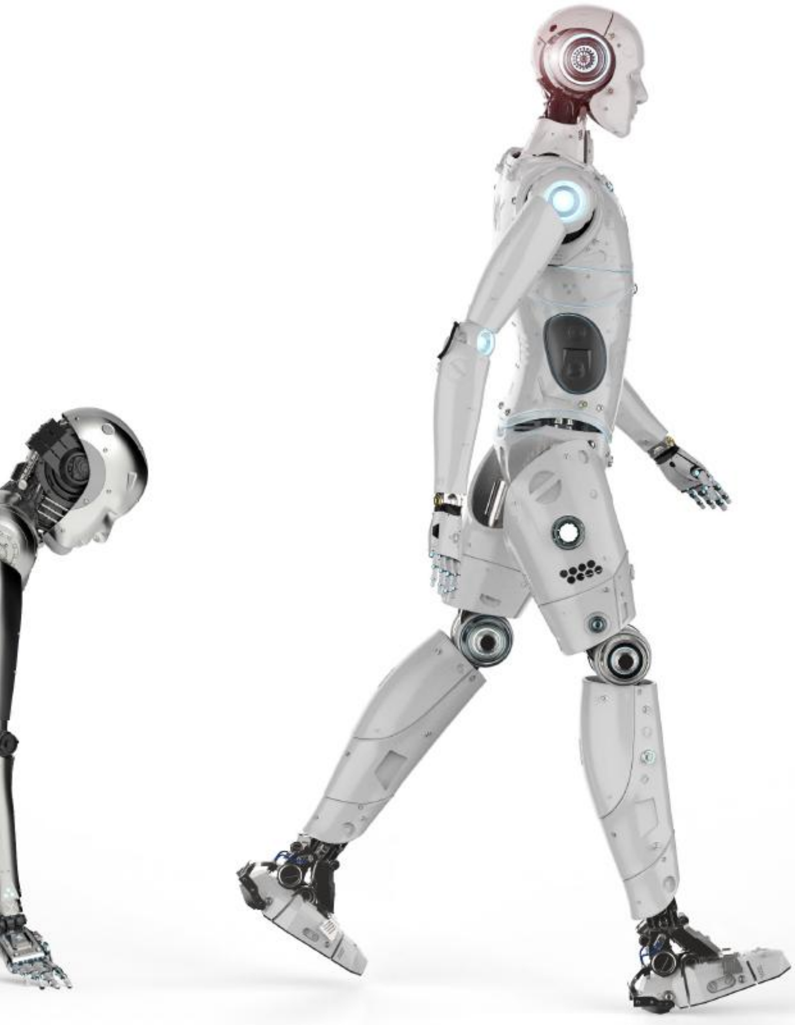
In this EIT segment, we explore service robots, which combine principles of automation with that of robotics to assist humans with tasks that are dirty, dangerous, heavy, repetitive, or just plain dull. Service robots differ from collaborative robots in that service bots require some degree of autonomy—that is, the ability to perform tasks based on current state and sensing, without human intervention. Today's service bots work in close proximity to humans, are becoming more and more autonomous, and can interpret and respond to humans and conditions.

This eBook accompanies **EIT Video #3**, which features the Henn na Hotel, the world's first hotel staffed by robots. Geared toward efficiency and customer comfort, these robots not only provide an extraordinary experience of efficiency and comfort, but also a fascinating and heart-warming experience for guests. Don't miss the accompanying blogs, which feature **"Flippy" the burger-flipping robot**, **autonomous suitcases**, **soft robotics**, and **chatbots**.

We hope you're enjoying Mouser's 2018 EIT topics, videos, eBooks, and blogs! Stay tuned…there's more to come!

Deborah S. Ray
Executive Editor

> *“Today’s service bots work in close proximity to humans, are becoming more and more autonomous, and can interpret and respond to humans and conditions.”*



EMPOWERING INNOVATION TOGETHER™

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EMPOWERING INNOVATION TOGETHER™

GENERATION ROBOT

FOREWORD

By Grant Imahara

This year, Mouser's **Empowering Innovation Together™** program has asked me to explore how robots and humans can collaborate and transform the concept of work. One specific type of robot that may make a significant contribution to that transformation is the service robot.

The International Federation of Robotics states that a service robot "performs useful tasks for humans or equipment excluding automation applications." From Rosie on *The Jetsons* cartoon to Baymax in the film *Big Hero 6*, pop culture is awash with examples of service robots. These useful and endearing robotic characters perform a wide variety of tasks from mundane jobs like cleaning to highly specialized tasks like being a "personal health care companion" (Baymax's original purpose).

In this EIT segment, I'll be traveling to Nagasaki, Japan to visit the Henn na Hotel. "Hen" in English translates as "weird, strange, or odd." And this hotel certainly fits that bill. Service robots are front and center in this oddly unique travel destination. The concierge that greets you is a multilingual dinosaur robot that checks you into the hotel. The cloakroom features a robotic arm that will store your luggage for you. Most of the remaining support staff are robots as well.

Another meaning of the Japanese word "hen" is "to change," and the hotel's slogan expresses this idea: "A commitment to evolution." The designers of this revolutionary hotel experience want to use the innovative technology of service robots not as a gimmick but as a way to fundamentally change the guest experience and learn more about human-robot interaction.

Service robots have the potential to alter every aspect of our daily lives. They can do not only the things we can't do but also the things we don't want to do. And that may be the one thing that drives this technology the most—the desire to gain more free time.

The day when the average household has a robotic maid may be closer than we think. I look forward to the day when I return home to everything clean and in perfect order, freeing me to relax, play some video games, or design more robots!

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INTRODUCTION TO SERVICE ROBOTS

By Mouser Staff

When we think of service robots, we often think of toys and novelty devices; however, with roots in engineering and automation, today's service bots are making life and work easier.

In 2018, we may not yet be jetting off to work in flying cars and have robot servants waiting at home with dinner on the table, but we don't have to look too far to see where service robots are helping us with our daily lives. Early examples of service robots were rooted in automation, which we've been using in one form or another for centuries—from when windmills helped humans pump water and process grain, to the steam engine that turns heat into an abundant—and mobile—source of energy. Nowadays, we think of automation as asking Alexa what the temperature is outside, to turn off the lights, or get a little help with navigation on the way to an appointment.

Service robots combine principles of automation with that of robotics to assist humans with tasks that are dirty, dangerous, heavy, repetitive, or just plain dull. We see these aspects in collaborative robots as well, which work side-by-side with humans, as we discussed in the **2018 EIT *Collaborative Robots* eBook**. So what makes a service robot different?

The International Organization for Standardization (ISO) defines a service robot as a robot "that performs useful tasks for humans or equipment excluding industrial automation applications" (ISO 8373). According to this specification, service robots require "a degree of autonomy," which is the "ability to perform intended tasks based on current state and sensing, without human intervention." For service robots, this ranges from partial autonomy (including human-robot interaction) to full autonomy (without active human-robot intervention). Today's service bots work in close proximity to humans, are becoming more and more autonomous, and can interpret and respond to humans and conditions.

Trending Applications

Service robots are popping up all around us, solving personal and business challenges in a wide variety of industries. Though some examples seem quirky, service bots solve real problems and are changing the way we work and live.

Personal Care Robots

Personal care robots are non-medical service robots that improve quality of life through interaction and help with tasks. The ISO identifies several types of personal care robots:

- **Mobile servant robot:** A robot that is capable of traveling to perform serving tasks in interaction with humans, such as handling objects or exchanging information
- **Physical assistant robot:** A robot that physically assists a user to perform required tasks by providing supplementation or augmentation of personal capabilities
- **Person carrier robot:** A robot designed to transport humans to an intended destination

Whereas other types of service robots work at safe distances from humans or have a physical barrier, personal care robots interact very closely with people, which poses unique design challenges. What's more, people's diverse and complex needs pose additional challenges as well (**Figure 1**).

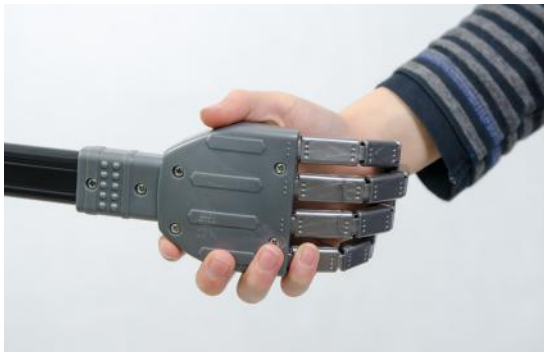

Figure 1: *Robots for children will need to be appealing to touch as well as sight. (Source: Mouser)*

Telepresence Robots

Long-distance communications that allow both parties on a call to see and hear the other person have been imagined since the early 1900s, steadily advancing to dedicated videoconferencing systems, webcams, and smartphone-based solutions. Telepresence robots take the concept one step further, allowing users to move about a room as a physical robotic representation. Your face is displayed live on a screen for others to see, along with a camera

Figure 2: Intel Telepresence robots allow cost-effective collaboration for a global workforce. (Source: Intel Free Press/CC-BY-SA-2.0)

to view an area remotely. Today, these bots normally take the form of a wheeled base for movement throughout an office, with a pedestal that affixes the camera and screen at a height high enough for interaction with humans (**Figure 2**).

While you might correctly refer to this setup as "a head on a pole," it does offer interactivity superior to traditional phone and videoconferencing options. The user can control his or her camera perspective, view people's body language, and give off visual cues that are lost in voice-only communication. Some devices include the ability to autonomously navigate to an area, showing up on time to the correct meeting. The user then simply logs on without needing to drive, fly, or otherwise commute to be in the room.

Delivery Robots

Delivery drones and rolling robots have potential to change the way products are delivered to consumers:

Drones

Delivery drones are being tested and used in various industries with some notable successes. UPS, for example, started testing delivery drones in rural areas 2017. In this use, the driver deploys the drone to visit one delivery location, while the driver moves on to deliver a second package by hand. The drone then returns to the truck to be deployed again when needed. This works especially well in sparsely-populated areas where the distance to a single stop makes things prohibitively expensive.

Rolling Robots

Small aerial delivery drones have

[CONT'D ON NEXT PAGE]

Ahead in This eBook

Ahead in this eBook, we meet a couple of very cool service robots, explore The Uncanny Valley, and take deep-dives on mimicking human gesturing and hand functions:

Sanbot: Anatomy of a Service Robot
Meet Sanbot Max. This service robot can walk, talk, carry, direct, and tell jokes. Max is 1.46m tall, has an omnidirectional four-wheel drive system, boasts arms and hands with ten degrees of freedom, can lift 400kg, and has bristles with sensors. But what's most impressive is going on inside him.

CIMON Says: Design Lessons from a Robot Assistant in Space
Designing a service bot is challenging enough, but designing one to function in microgravity that's also appealing to its fellow astronauts poses unique design challenges. Read on to see how engineers at Airbus developed the European Space Agency's first free-flying, autonomous robot assistant on the International Space Station.

[CONT'D ON NEXT PAGE]

captured the public's attention, but other delivery robots are being tested as well. An Estonian startup called Starship, for instance, manufactures delivery robots that roll on six wheels down sidewalks to deliver grocery bag-sized packages from a central hub. With capabilities to go about six kilometers, these bots use GPS and sensors, as well as cameras for navigation and obstacle avoidance. They move along at pedestrian speeds, which makes them seemingly less threatening than drones that could drop from the sky if they somehow lose power or control.

e-Palette Showroom

The e-Palette showroom concept unveiled at Consumer Electronics Show in 2018 by Toyota puts a new twist on shopping by having the store, shop, showroom, or office come to you (**Figure 3**). Using driverless vehicles that resemble something like the fusion of a modern train car and a London Black Cab, mobile showrooms could function like an on-demand kiosk, allowing customers to be able to view and even try on (or try out) available items. These vehicles could, of course, be outfitted as traditional delivery vehicles, either beckoning humans to come meet them on the street, or deploying their own minion delivery bots to go the last few meters to a doorstep. While still in the concept phase, Toyota has announced that this on-demand service will be put to use during the 2020 Olympics in Tokyo.

***Figure 3:** The Toyota Motor Corporation e-Palette concept vehicle. (Source: Nobuyuki Hayashi/CC BY 2.0)*

Farm Automation

Today, commercial farming is highly automated, with combine operators taking manual control of their machines only as needed while sitting in an air-conditioned cabin that looks more like a spaceship inside than the beaten-up tractor that urban dwellers likely still imagine. But other advancements in automation and robotics are blooming at farms as well.

Indoor Farming

Indoor farming, often called vertical farming, allows for a smaller footprint land-wise than would normally be possible, uses sensors to monitor conditions, and brings fresh produce closer to consumers. Mouser Electronics featured vertical farming as part of its 2017 Empowering Innovation Together™ series on Shaping Smarter Cities.

Farming Robots

Farm automation isn't just for gigantic combines and lettuce factories. With the FarmBot, consumers can have a robot that tends to their garden automatically (**Figure 4**). This system takes the form of a gantry-style robot that moves over a garden planned via a computer interface.

The user selects what kinds of crops are placed where in the garden, and the FarmBot does the rest, planting seeds, watering them, and even detecting and destroying weeds automatically.

***Figure 4:** The FarmBot performs gardening autonomously, removing humans from day-to-day tasks. (Source: FarmBot/CC BY 4.0)*

Figure 5: Robot vacuum cleaner. (Source: Mouser)

Robotic Cleaning

Automated vacuuming has long been imagined as something that robots could take over—think Rosie the Maid from the 1960s cartoon *The Jetsons*. Remarkably, the robotic vacuum cleaner is approaching 20 years old, with the Electrolux Trilobite making its debut in 2001 and the iRobot Roomba following in 2002. Since then, other competitors like Dyson and Samsung have joined the competition, pushing features and capabilities forward. Most floor cleaners in action today resemble gigantic hockey pucks, rather than a more complicated humanoid (**Figure 5**).

These robotic vacuums use essentially the same technologies that were used 100 years ago to suck dirt and small bits from a floor surface to a container. But unlike their human-powered predecessors, robotic vacuums use a series of sensors and physical bumpers to navigate rooms and obstacles. They also use sensors to detect large changes in elevation that they can't navigate, namely stairs. Modern vacuuming bots can power themselves for nearly an hour and can even navigate back to a charging station to recharge. They also feature scheduling so you can come home to a nice, clean house, whether or not your dog or cat enjoys the interruption.

Ahead in This eBook (cont'd)

Revisiting the Uncanny Valley

The uncanny valley describes a phenomenon that occurs as machines take on human attributes. As robots begin to collaborate with humans, work side-by-side with us, provide services for us, and augment our capabilities, addressing The uncanny valley in robotic design is an important consideration.

Robotic Gesturing Meets Sign Language

Designing robots that can perform gesture-based sign language and interpret it would provide a potentially invaluable service to the hearing impaired and those who rely on this unique language. Researchers around the world are making headway.

Robotic Hands Strive For Human Capabilities

The human hand is unmatched in its performance capabilities, but robotic hands that use soft grips and advanced algorithms are making great progress towards comparable performance in some applications.

SANBOT MAX: ANATOMY OF A SERVICE ROBOT

By Steven Keeping for Mouser Electronics

Meet Sanbot Max. This service robot can walk, talk, carry, direct, and tell jokes. Max is 1.46m tall, has an omnidirectional four-wheel drive system, boasts arms and hands with 10 degrees of freedom, can lift 400kg, and has bristles with sensors. But what's most impressive is what's going on inside of him.

Over 60,000 Sanbot service robots are going about their business in China. The majority of these are Elf and Nano models, but they are now being joined by a larger, faster, and more powerful sibling called "Max." Weighing 100kg and standing at 1.46m, Max's build is for export by Qihan, a Shenzhen-based robotics company that has been in business for over a decade. The service robot made its United States debut earlier this year at the CES® exhibition in Las Vegas, Nevada.

The high degrees of flexibility and autonomy that Max demonstrates are achievable by leveraging the latest software, electronics, electromechanical, and mechanical components. The robot is built on a four-wheel drive base with a lightweight plastic and aluminum chassis and supports a 29kW/hr Lithium-ion (Li-ion) battery power supply. It incorporates multiple sensors, arms, and hands with 10 degrees of freedom, 3D-visual simultaneous localization and mapping (vSLAM) obstacle avoidance, 5m/s walking speed, and 7kg towing capacity. All this allows Max to supervise office receptions, speak to and guide humans, and distribute documents, among other tasks.

Max is an impressive machine with an external design that incorporates mobility, strength, reliability, and visual appeal and an internal design that utilizes computing power, sensors, power supply, and motors to safely and efficiently perform a wide range of tasks. Such design forms the anatomy of a contemporary service robot.

Designed for Service

Service robots join industrial and collaborative robots in performing tedious work for humans. Service robots are not designed to take over repetitive assembly tasks or boost productivity by assisting humans in a factory environment, rather they're designed to lighten the load on humans by performing routine tasks at work, home, or in the hospital. Personal service robots handle non-commercial tasks such as domestic service or serve as personal mobility assistants while the professional type performs commercial tasks such as receptionist duties, delivering goods, or even fighting fires and assisting in rescues. Sanbot Max is a professional service robot (***Figure 1***).

Service robots are late to the party because they feature the complex design necessary to work and interact with humans. Industrial robots are relatively unsophisticated machines, segregated from humans, and designed to work at the same task for years without a break. Collaborative robots face some design complications because they cooperate to an extent with humans, but their tasks are still specialized and limited in scope. In contrast, working directly with people requires service robots to be intelligent, interact safely, and exhibit versatility and adaptability. Such specifications demand employing the best of the existing industrial-robot technologies while developing new systems suited for the unique operating environment of service.

That's what Qihan's engineers have achieved with Max. The robot melds lightweight, durable electromechanical components with IBM®-powered artificial intelligence (AI), advanced sensors, cloud connectivity, and Li-ion power. And the robot carefully negotiates the **uncanny valley** by leaning on the side of cuteness and small stature. The robot measures 1.46m (H) × 0.77m (W) × 0.62m (D), and beneath its plastic skin features clever design to make it tick.

The Friendly Robot

Service robots like Sanbot Max spend all their time moving and working among humans. Engineers have equipped the robot with features that deliver the high mobility, dexterity, and strength essential to ensure safety and productivity in its daily tasks without compromising size, weight, and battery life.

External Structure

Sanbot Max comprises five main elements: A four-wheel drive base, a torso, two arms, and a head. The four-wheel drive system uses an

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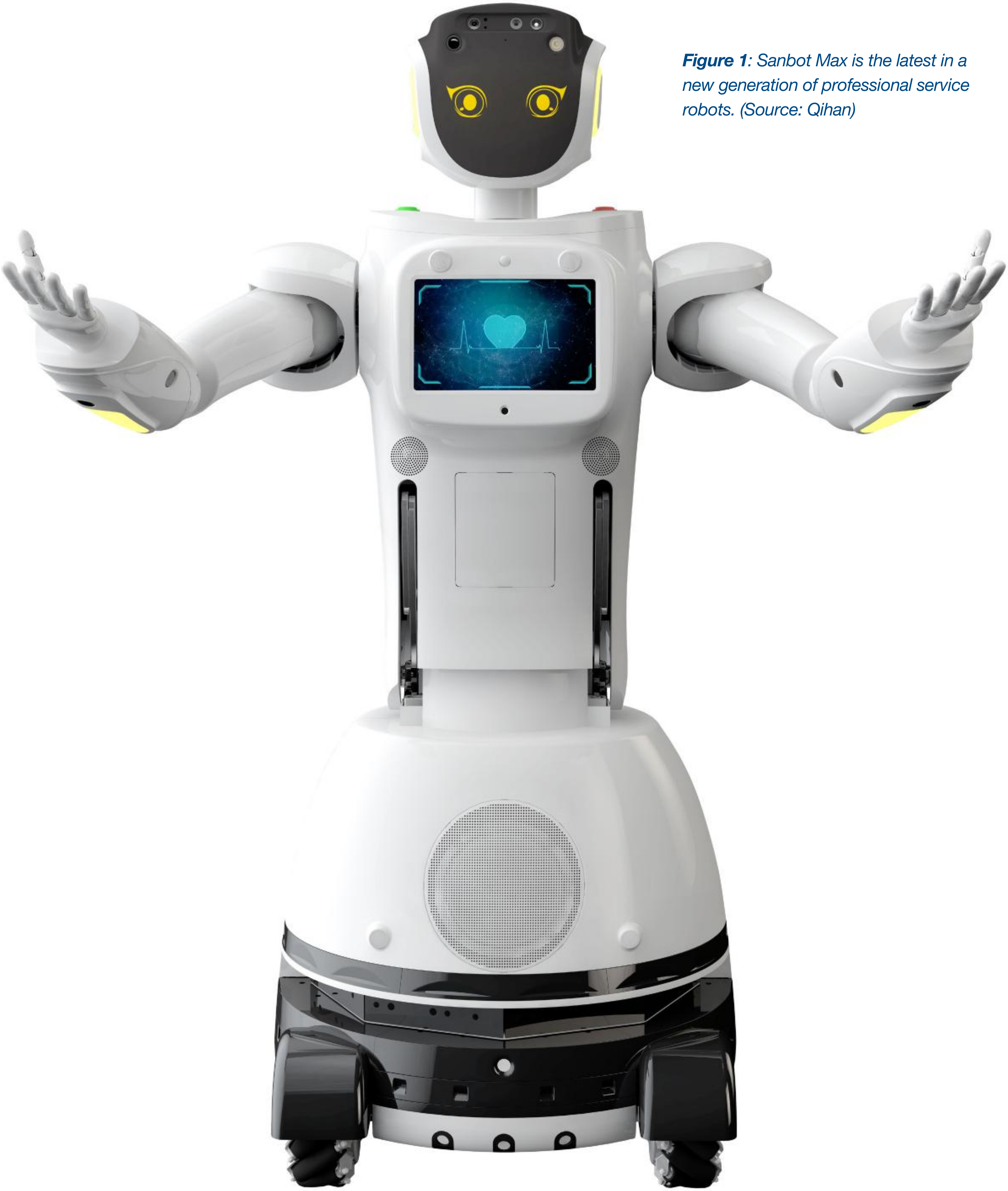

***Figure 1**: Sanbot Max is the latest in a new generation of professional service robots. (Source: Qihan)*

external motor that sits atop four Mecanum wheels. The 18cm in diameter Mecanum wheels roll in any direction, allowing Max to go forward, backward, or to the side—minimizing the space necessary to maneuver. The wheels also include a suspension to allow the robot to cope with uneven surfaces. The robot's ground clearance is 4.5cm, and its maximum speed is 5m/s (18km/hr), which is faster than most humans can move, but not so fast that it compromises safety.

Sanbot Max's small stature keeps its weight down by design to help extend battery life. Max is a little shorter than an average human—which enhances the robot's friendly appeal—but is powerful enough to carry 400kg. Unlike an industrial or collaborative robot, a service robot isn't required to perform repetitive high-precision movements with its arms or to support the objects it transports. Consequently, Max's arms are primarily designed to give the robot a welcoming posture and are used to gesture and guide. These uncomplicated requirements permit the designers to specify simpler, less power-hungry motors, reducing the complexity of their control systems. Such cost savings are essential if service robots are to increase their presence in large volumes. However, that's not to say that Max's arms are weak or unsophisticated; each has five degrees of movement with another five for each hand.

The robot's head offers three degrees of movement to allow the robot to engage with people. Such design illustrates a common approach to service robot appearance; however, functional service robots like automated vacuum cleaners are designed with fewer degrees of movement and an efficient form factor rather than with any human characteristics because its direct interaction with humans is limited. In contrast, humans prefer professional service robots to feature an identifiable face. How much this face should resemble that of a real person is a subject for further research; however, eyes, the thing that humans look at first when approaching other people, are essential. Max's eyes are purely cosmetic and made of cost-effective animated graphics that project via organic light-emitting diode (OLED) screens mounted as the face on its head. He uses other sensors for actual sight. Max also sports illuminated ears to enhance the effect of his human-like characteristics.

Freight Flexibility

Because his arms have limited carrying capacity, Max tows heavy weights on a trolley attached to a chassis on his backside. The front side of his torso incorporates a carrying frame that allows transport of items such as cool boxes, trays, or other loads up to 400kg. The frame includes a pressure transducer that estimates load weight and adjusts the robot's waist position to maintain his center of gravity and stability. An attachment system can also allow Max to push a wheelchair.

The load-carrying peripherals can be detached when not needed to lower the cost, weight, and size of the base robot. Electronics peripherals are supported via a built-in 220V interface, High-Definition Multimedia Interface (HDMI®) port, multiple Universal Serial Bus (USB) ports, power-supply ports, and switches, making it very easy to use the robot for commercial and third-party devices such as light-emitting diode (LED) screens, printers, and monitors.

Power Pack

Power for the wheels and the rest of the robot's systems comes from a Li-ion power pack. Li-ion has the highest energy density of any secondary battery technology and has allowed the Sanbot's designers to keep the power pack's size and weight down while enabling the 36V, 1.6kW (28.8kW/hr) unit to offer up to 18 hours of runtime and 50 hours of standby power. When its power is low, the Sanbot trundles off and plugs itself in for a recharge.

Obstacle Avoidance

Service robots serve in cluttered environments such as offices, retail premises, and homes. These are areas full of obstacles that first need to be detected and then avoided. That's quite a challenge for a robot that can move at up to 18km/hr. The Sanbot designers decided to overcome this problem by employing a 3D camera that acquires images at 30 frames/s (six times the industry average rate).

The scanned images provide a supplement to the robot's supplied map of his environment. If items have moved outside their position on the map, the robot uses vSLAM to learn the new positions and plan the shortest revised route to avoid obstacles.

vSLAM is a popular technique for solving the computational problem that robots and other autonomous machines face when attempting to construct or update a map of an unknown environment while simultaneously keeping track of their location within it. Several vSLAM algorithms exist, and each uses vision combined with distance and direction traveled from fixed reference points to enable navigation in cluttered and populated environments. vSLAM

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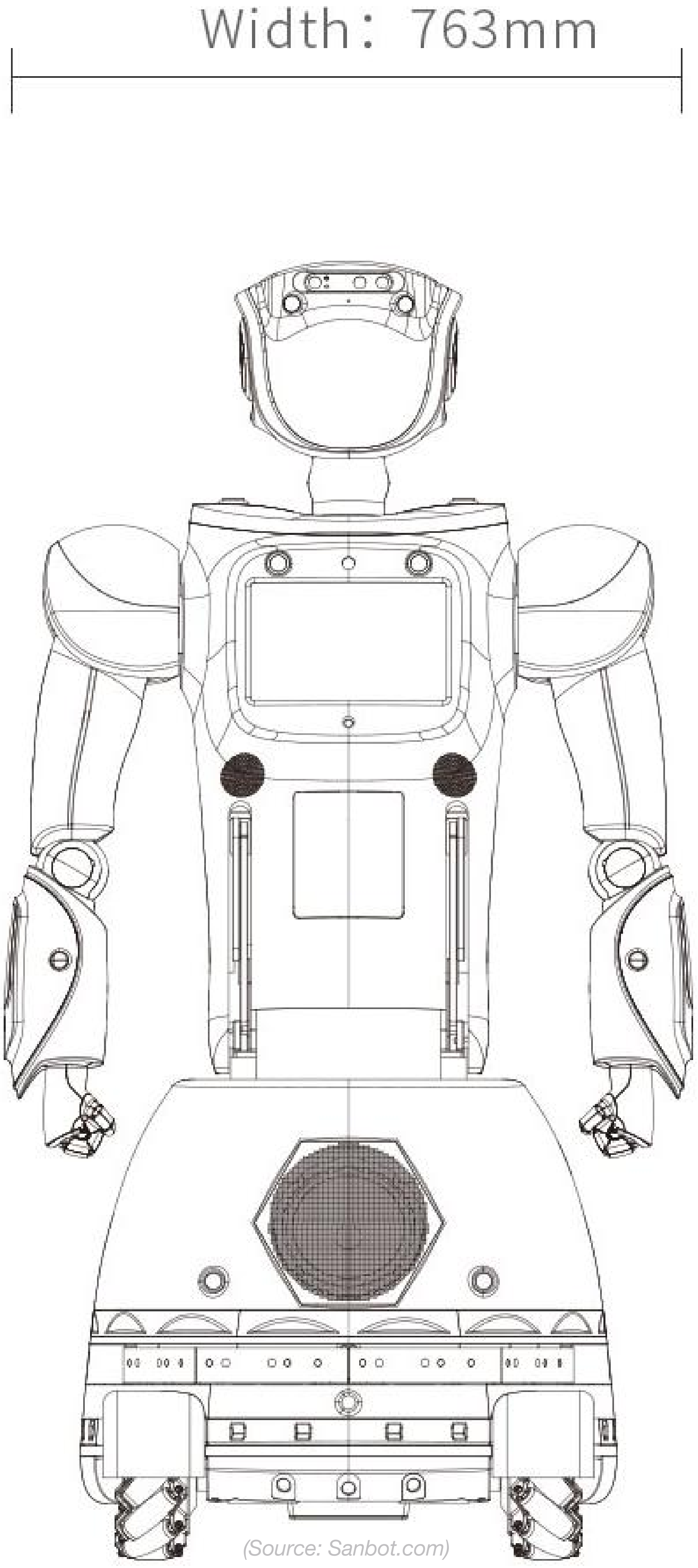

(Source: Sanbot.com)

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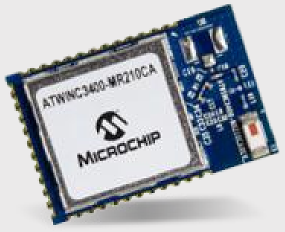

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mouser.com/microchip-r21-microcontrollers has a proven reputation for handling dynamic changes, such as varying light levels and moving objects and people, in an environment. While no initial map is required, Sanbot Max users can upload a map to the robot to accelerate the learning process. Because the vSLAM algorithms are customized to fit the available resources and operational circumstances rather than aiming at perfection, they represent a low cost yet proven option for robot navigation.

In addition to the vSLAM technology, Sanbot Max has combined infrared and ultrasonic sensors that enable it to come to a safety-rated, monitored stop when an unexpected moving object or person crosses its intended path. When traveling at a maximum speed of 5m/s, the robot can come to a halt within 1m. At normal operating speeds, the stopping distance is 20cm or less.

Interacting with People

Sensors are a key element for successful robot design. Some are there to mimic the human senses of sight, hearing, and touch (while many don't consider taste and smell as essential yet, research labs around the world are investigating how to reproduce these senses artificially for future robots). Others extend the robot's sensory capabilities beyond those of humans.

Sanbot Max incorporates an array of vision, hearing, touch, gyroscopic, and magnetic sensors to inform it about its surroundings and aid communication with people.

Vision

In addition to the vSLAM 3D camera for navigation purposes, Sanbot Max has a high-definition (HD) color camera (for facial and object recognition and recording) and a reverse black-and-white camera. Despite four decades of research, facial recognition is still a challenge for robotic systems. Today's techniques are a major improvement compared to those of a few years ago because modern computing power allows rapid comparison of many more reference points on the face than were comparable before. And these reference points are now imaged in three dimensions rather than on a flat surface to improve the differentiation between various faces even further.

Sanbot Max refines the facial recognition technique by framing the face using the HD color camera and then framing other objects in the picture that it doesn't recognize as part of a human body. It then discounts the non-human elements when performing facial recognition. This process of elimination helps in situations, for example, where the parcel a courier is delivering obscures part of his or her face.

Hearing and Speaking

Sanbot Max listens via no less than six microphones arrayed on its head, which register voice commands from up to 5m away from any direction. The robot converses in several languages through two speakers and features a projector to display videos when words aren't enough to express an instruction or idea.

Sensing

The head, torso, and arms feature touch sensors. Infrared and ultrasonic sensors supplement these sensors, primarily to allow the robot to be aware of its distance from moving and stationary objects. Because it also works so closely with humans, Sanbot Max contains software algorithms that help the robot learn from its interactions and modify movements and reactions to enhance safety.

Graphical User Interface

In addition to talking directly to the robot, a person can enter information and instructions on a 10.1in., 1080P touchscreen mounted on the robot's upper torso.

Listening and Learning

A critical element for a service robot is learning from experience. This experiential learning not only allows the robot to constantly update its map of the local environment or schedule the best time for a battery recharge but also enables the optimization of its service by remembering the faces of regular visitors, so they are not required to self-identify each time they visit.

Machine learning is a complex challenge that Sanbot Max's designers have addressed by combining the resources of the robot's programmers, its sensors and onboard computing power, and remote cloud services (**Figure 2**).

Figure 2: *Sanbot Max employs a three-way support system that leverages its own resources and those of a programmer and cloud-based server. (Source: Sanbot)*

Open for Developers

Sanbot supplies a software development kit (SDK) and an application programming interface (API) to allow programmers to create their own code for the robot to customize it for a specific duty. For example, configuring a robot specifically for reception duties in a confined area allows a designer to limit the allocation of resources to navigation, thereby extending battery life. Instructions to the robot can upload to a mobile device or a PC.

Onboard Computer

Sanbot Max features a powerful onboard computer that runs a real-time Linux operating system to control movement, communication, and power-autonomous operation when necessary. This operating system can also support a range of common Android applications.

Wireless Connectivity

Connectivity is one of the key enablers for contemporary service robots; previously, the robots were “on their own,” reliant solely on their internal resources to operate. Such reliance either limited the tasks the robots could perform or added weight, complexity, power consumption, and costs.

Now, wireless connectivity to the Internet allows powerful cloud servers to supplement a robot’s resources. Not only does this permit remote communication and software updates, but it also enables a streamlining of the robot’s computing systems, because the most demanding processing tasks can offload to a remote computer. Sanbot Max employs both Wi-Fi and cellular connectivity (which a third-party, 4G SIM card enables).

Artificial Intelligence

Sanbot Max’s wireless connectivity enables the robot to use Nuance® voice recognition software and IBM’s Watson artificial intelligence (AI). The Nuance voice recognition helps the robot understand a range of languages, dialects, and accents while Watson, which is an extended development from its original concept as a question/answer system to one that uses computers working in parallel to support a range of machine-learning activities, helps the robot increase its overall intelligence.

Conclusion

Sanbot Max from Qihan demonstrates how practical service robots are becoming a reality. The robot originates from earlier, smaller models that have sold in large numbers in China and are now an export beyond the country’s borders.

The robot is proving its success, as the designers have sourced proven technology from external suppliers while focusing their efforts on developing a solution that can perform in professions involving reception, delivery, or other service-related operations. The designers have also put considerable effort into ensuring that the robot’s appearance, characteristics, and movements encourage humans to interact with it. The result is a reasonably priced, practical product that performs well in commercial environments.

The designers of Sanbot Max have also demonstrated how wireless connectivity to the cloud points to the near future of service robots: These automatons will increasingly draw on external resources to power their AI rather than carry expensive, complex, and power-hungry computers and software onboard. The IBM Watson software, for example, demands the resources found in a $1 million server, like the IBM Power 750. Spreading that cost over the use of thousands of relatively inexpensive service robots empowers companies to build a sustainable business model and encourages consumer adoption (**Figure 3**).

Figure 3: *Service robots will increasingly draw on external sources such as IBM’s Watson to power their AI. (Source: Clockready/CC BY-SA 3.0)*

CIMON SAYS: DESIGN LESSONS FROM A ROBOT ASSISTANT IN SPACE

By Traci Browne for Mouser Electronics

Designing a service bot is challenging enough, but designing one to function in microgravity and that is also appealing to its fellow astronauts adds to the unique design challenges. Read on to see how engineers at Airbus developed the European Space Agency's first free-flying, autonomous robot assistant for the International Space Station.

Of the more than 220 visitors to the International Space Station (ISS) in the past 18 years, June 2018 marked the first time one of those visitors was a free-flying, autonomous service robot. CIMON, or as it is more formally known, the Crew Interactive Mobile Companion, is a 32cm in diameter, 5kg, spherical robot that can speak, hear, see, and understand. CIMON is a robot head with no body.

In fact, CIMON's design was reportedly inspired by the Professor Simon Wright's character (a flying brain) in the 1978 cartoon series, Captain Future. Much like the professor-aided Captain Future in the fictional world, CIMON was responsible for assisting astronaut Alexander Gerst in the Columbus laboratory module in the ISS.

CIMON, developed and built by Airbus on behalf of the German Aerospace Center (DLR), was assigned to assist Gerst with three different tasks, making this service robot a **collaborative robot** as well. The three tasks involved solving a Rubik's cube puzzle, conducting experiments with crystals, and carrying out a medical experiment which CIMON would film. CIMON could also serve as a complex database of all necessary information about operation and repair procedures for experiments

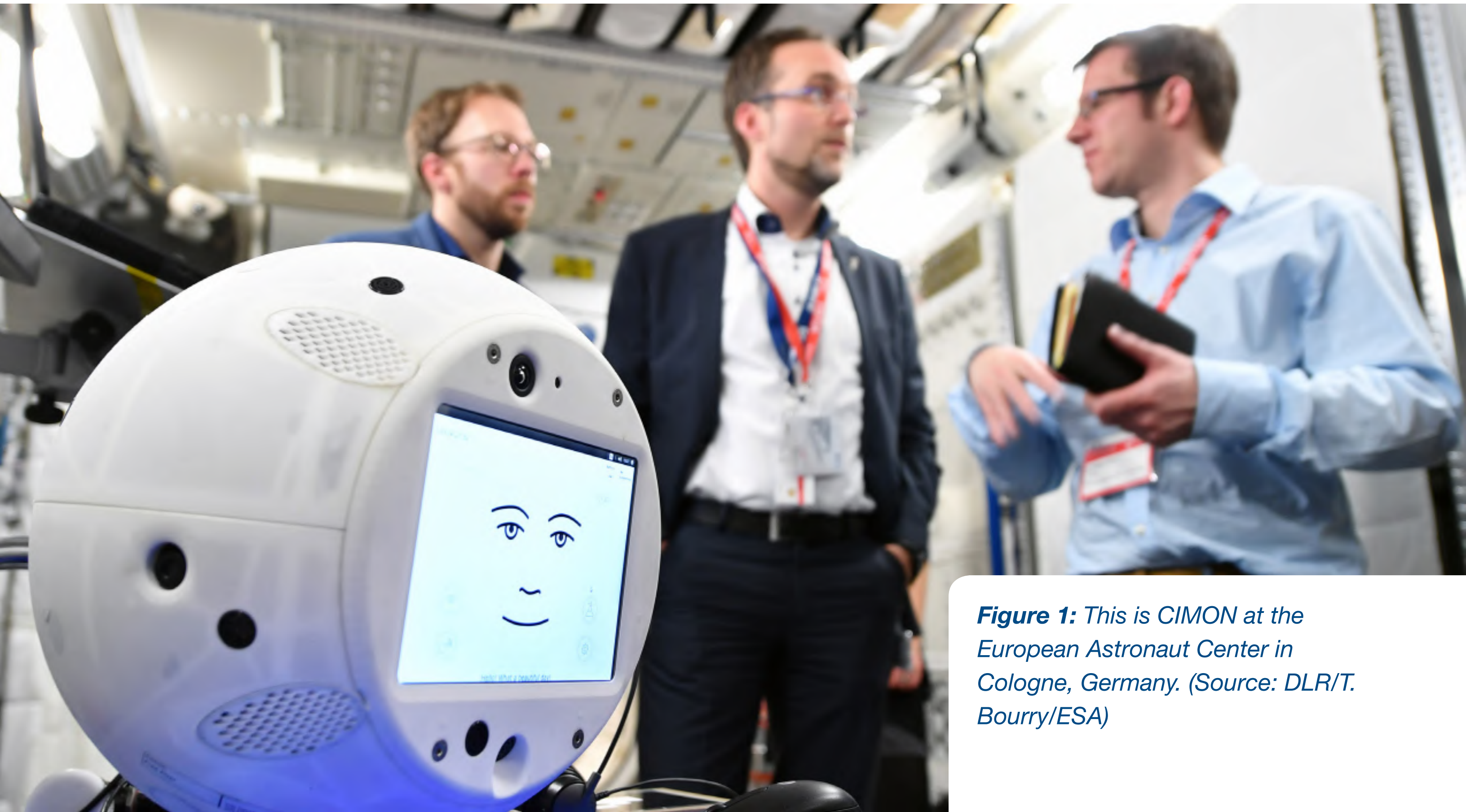

Figure 1: *This is CIMON at the European Astronaut Center in Cologne, Germany. (Source: DLR/T. Bourry/ESA)*

and equipment on the ISS, allowing astronauts to have their hands free while working. If the crew wanted to capture video for documentation purposes, CIMON could handle that as well.

Designing for Microgravity

While the design may have been inspired by science fiction, the spherical shape has a more practical application in a microgravity environment (**Figure 1**). Till Eisenberg, project manager at Airbus Friedrichshafen, said that the primary challenge was to create a robot that would be accepted by the astronauts.

“Everything in the Space Station is rectangular, and it is a very technical environment. We wanted to have a calm point of focus,” said Eisenberg.

CIMON’s service as a calm point of focus, along with its ability to make the astronaut’s job more manageable, is important. Judith-Irina Buchheim, a researcher at the Ludwig-Maximilian University Hospital in Munich, thinks that the assistance CIMON provides astronauts will reduce their exposure to stress, which researchers believe has an impact on the human immune system. The simple, spherical shape contrasts to the boxy, technical environment of the ISS, but there are other advantages as well.

Because CIMON was the first free-flyer to operate on the ISS, safety was a significant concern. Typically, the rule for a microgravity environment is that everything must be strapped down to prevent objects from floating around and getting into things and places they should not. Eisenberg said that sharp edges or corners would be a hazard as it floats around the ISS bumping against walls, equipment, or the astronauts themselves.

Even if CIMON’s shape meant it would not hurt anyone, colliding with astronauts trying to work in an already-cramped space could quickly become annoying. To avoid that situation CIMON is equipped with 12 ultrasonic sensors that enable it to detect obstacles and be aware of incoming objects. These sensors measure the distance from the obstacle or astronaut to CIMON.

Fourteen internal fans allow CIMON to move and rotate in all spatial directions. While CIMON is on the move, a dual 3D camera sensor collects information about the depth and relation from one feature to another and builds a map based on Simultaneous Localization and Mapping (SLAM) algorithms. A frontal video camera and face detection software would focus on the eyes of Gerst, allowing CIMON to orient itself to simulate eye-contact.

If Gerst wanted to get CIMON’s attention, when it was otherwise occupied, say looking out the window and enjoying the view, he could look in the robot’s direction and speak to CIMON. An array of microphones could detect the arrival direction of Gerst’s voice, and CIMON would orient himself until the speaker was in the field of view of the camera, at which point the eye gazing could happen.

For their final test, Eisenberg and CIMON boarded the Airbus A300 Zero-G for a parabolic flight test. Eisenberg described the flight as “a great experience” and “something everyone should do.” The plane flies up and down at 45° angles. The decent is where microgravity occurs, and this phase lasts about 20 seconds. A typical parabolic flight test will experience this about 30 times.

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Designing the Face and Voice

The ability to maintain eye contact and communicate are essential skills for an assistant, so the service bot needed a face. In CIMON's case, the face is a simple line drawing displayed on a front-facing screen (**Figure 2**). As mentioned earlier, acceptance by the astronauts was one of the engineers' primary challenges. The team invited Gerst to be a part of the design phase to ensure CIMON was an assistant with which the astronaut would work. Gerst was presented with several voices and faces to choose from, ensuring he would be happy with the result, while providing him with a sense of ownership and familiarity when he and the robot finally met on the ISS.

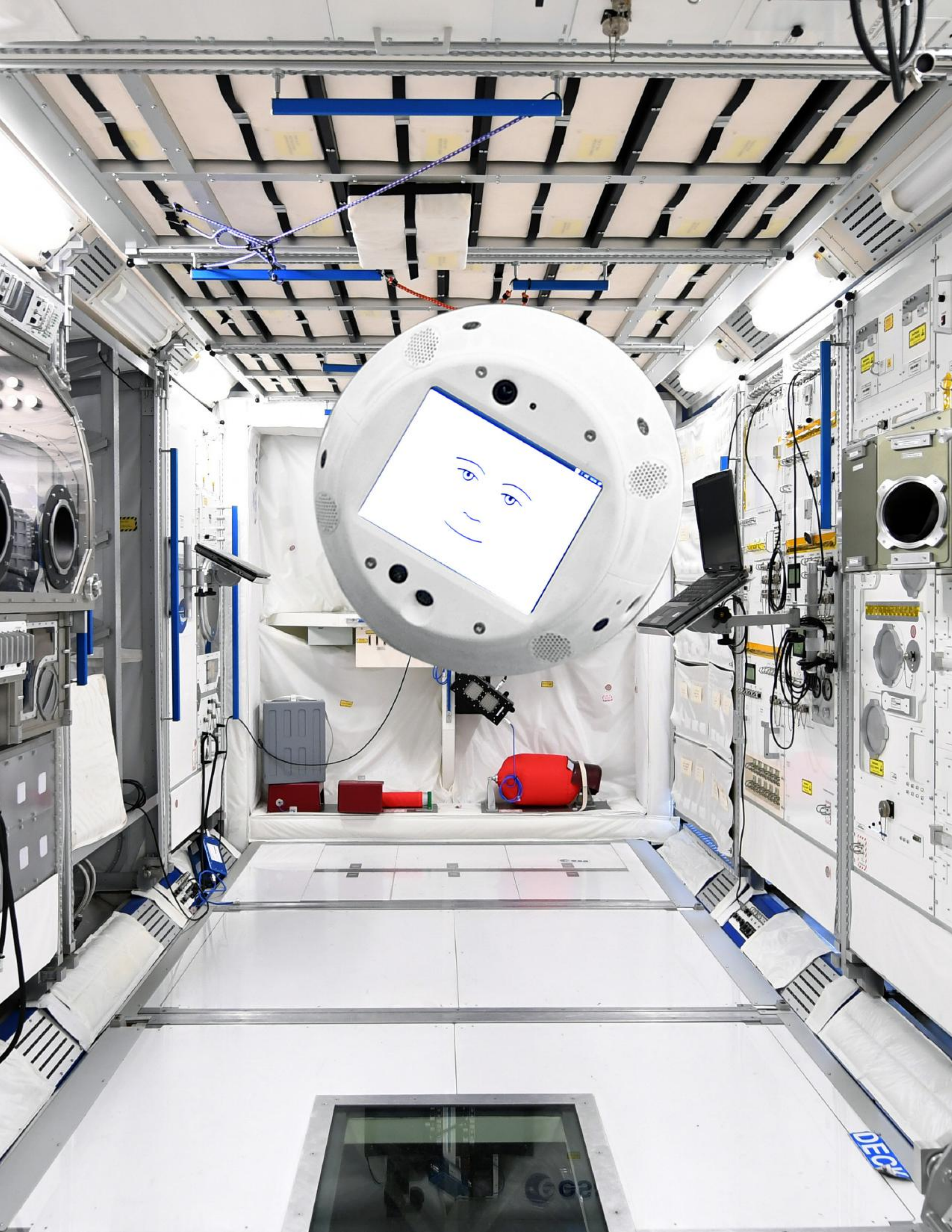
An integral part of CIMON's ability to assist astronauts is the IBM Watson artificial intelligence (AI) system, which provides the core speech comprehension element. When someone speaks a language to a robot like CIMON with an AI system, the robot's job is to identify intent. When a message arrives via audio stream, it then undergoes translation into written language so that the system can understand and interpret its meaning. Once the identification of intent is complete, the AI system generates an answer based on several keywords in one sentence.

Eisenberg said that the AI will always understand words that align with its training. That is why a system that is working fine with a small project group can react in an unexpected way when a new person tries to interact with it. Aware of this potential problem, the team had Gerst interact with the AI for two sessions. Not only did those sessions make the AI familiar with Gerst, but it acclimated him to working with AI. Much like aeronautic radio chatter, the crew on the ISS has created a specific way of talking, and they use keywords that have well-defined intentions, so CIMON should not have any trouble interacting with other crew members in the future.

Scientists are also hoping to use CIMON to observe the group effects that develop in small teams over extended periods of time, such as during extended missions to the moon and eventually Mars. They want to understand more about the social interaction between humans and machines as well. That interaction is significant because Eisenberg said that someday service robots, acting as flight attendants, could potentially play an essential role in those long missions.

All in all, CIMON is impressive for a robot created on a 3D printer and built with commercially available, off-the-shelf sensors. Moreover, all this came about in less than two years. That timeline is impressive for just about any application, but for the space industry, it is epic. M

Figure 2: *This is a composite image of CIMON on the ISS. (Source: DLR/T.Bourry/ESA)*


DECK

REVISITING THE UNCANNY VALLEY

By Jon Gabay for Mouser Electronics

“The uncanny valley” describes a phenomenon that occurs as machines take on human attributes. As robots begin to collaborate with humans, work side-by-side with us, provide services for us, and augment our capabilities, addressing the uncanny valley in robotic design is an important consideration.

The concept of robots integrating into our lives is nothing new, but the challenge of creating robots that do not intimidate or make people feel threatened is proving more difficult than imagined. The phenomena called “the uncanny valley” describes the uneasiness humans experience when a robot closely mimics a human but not quite entirely (**Figure 1**). In this case, some subconscious mechanism kicks in to make us feel uneasy, fearful, and non-trusting. Yet robots that are clearly toy-like, cartoon-like, or considered “cute,” do not elicit this response.

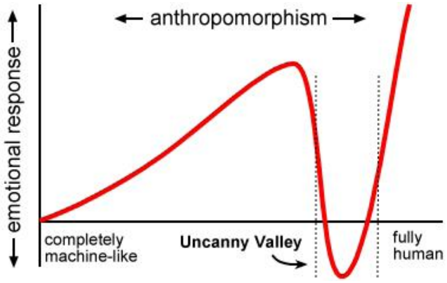


***Figure 1:** The uncanny valley describes the uneasiness humans feel when a robot has enough human characteristics to create dissonance between what looks near-human but not quite human. (Source: Wikimedia Commons)*

As robots begin to collaborate with humans, work side-by-side with us, provide services for us, and augment our capabilities, addressing the uncanny valley in robotic design is an important endeavor.

More Detailed Look

The initial discovery of the phenomena in 1970 by Dr. Masahiro Mori clearly showed that as mechanized machines take on human attributes they become more accepted until a nearly human looking robot is presented. As the machines approached a nearly human looking state, a dramatic decrease in acceptance takes place, until a real human likeness manifests. He called this effect bukimi no tani, which has become known as the uncanny valley.

He also went on to propose that motion as well as form affect realism and can deepen the valley if a motion is unnatural and mechanical in appearance. This is especially true when there is a coordinated effort to make several face muscles move in tandem to emulate a real face. Unnatural eye movement, in particular, can cause a flee response from observers.

Robots with Human-Like Features

Modern day media has been able to exploit these evolved inherent reactions toward almost human-looking machines and even dolls. The earliest mass exposure to the robotic form came from the Forbidden Planet movie, where Robbie the Robot was introduced (**Figure 2**). This mechanical bi-pedal humanoid form is far from looking like a real human and, if deemed friendly, is not intimidating. The popular Lost in Space robot looks even less intimidating (**Figure 3**) and looks even less human. But, the popular C-3PO begins that ascent to looking more human (**Figure 4**) but is still not particularly threatening, especially with the comical, jerky non-human like movements and the almost comical voice.

***Figure 2:** Forbidden Planet’s Robbie the Robot was pseudo-humanoid but not scary. (Source: Wikimedia Commons)*

Figure 3: *The Lost in Space robot is less human-looking and less intimidating. (Source: Wikimedia Commons)*

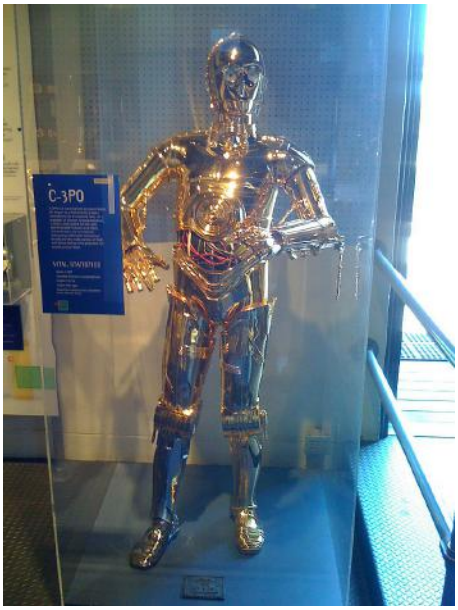


Figure 4: *C-3PO is humanoid in form, but because the facial features and movement are unlike those of humans, the droid doesn't scare us. (Source: Wikimedia Commons)*

However, even toys and dolls can be made to be intimidating, though their features are non-human. Examples here can include Chucky from the Child's Play movie series of horror movies (**Figure 5**). Facial expressions designed into a doll, puppet, or robot can certainly convey a sense of evil or foreboding. Even when a doll or puppet is not trying to be scary, it can look scarier if it takes on human capabilities, like a ventriloquist puppet.

Figure 5: *Chucky is a good example of a doll that can look intimidating by its facial expressions. (Source: Wikimedia Commons)*

And, to further the point that the engineering of scary facial expressions can occur in a mechanical robot, consider the popular Terminator robot for example (**Figure 6**). The internal Terminator robot is clearly not human but still elicits a fear response. It could be the icy cold, lifeless stare and/or the use of the skull style head that also touches a nerve.

Figure 6: *The Terminator robot is not human, but it has a cold, lifeless stare. (Source: Wikimedia Commons)*

Humans Portraying Robots

Examples of humans portraying robots can be found in popular culture and can illustrate how both emotionless and emotion-exaggerated robots can lead to acceptance, because underlying everything, their face is a real human's. For example, the TV character Data from Star Trek: The Next Generation (**Figure 7**) is very human looking, even though the facial expressions are somewhat emotionless. Conversely, the robot Kryton from the BBC series Red Dwarf (**Figure 8**) has plates and a head shape that are non-human, but his comical facial expressions and jovial personality make him comical and easily accepted.

Figure 7: *Commander Data looks human but has emotionless expression. (Source: Wikimedia Commons)*

Figure 8: *Kryton's head does not look human, but his jovial personality makes him easily accepted. (Source: Wikimedia Commons)*

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When humans play robots, the uncanny valley does not tend to appear in the same way. Perhaps we are picking up on subtle biological movements and clues that reassure us. Even our attempts to create a static-face and robotic-like form still fall short. The somewhat human-looking and emotionless robot from the movie I-Robot is an example of a human-like robot that can fall into the uncanny valley (**Figure 9**), and eye movement and voice can play a role here.

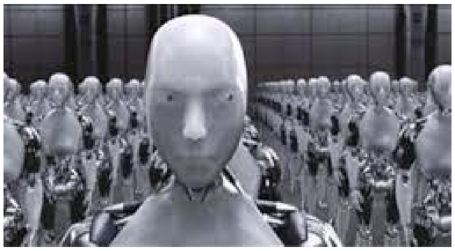

Figure 9: *Emotionless stares built into robots can eliminate the flee response toward robots that poorly emulate human facial movements, but they can also be intimidating and scary. This type of almost human face can fall squarely into the uncanny valley. (Source: Wikimedia Commons)*

The Importance of Getting it Right

Like it or not, robots are replacing humans and will continue to replace humans in the workforce and service industries: Initially to handle dangerous occupations where liability and insurance factor in and continuing to replace people at every juncture of society. Even the most abused countries with the most overworked and underpaid workforces will not be able to compete with the relentlessly working, non-complaining, will-less, and soul-less machines.

This inevitable shift is particularly true with the aging populations and the diminishing workforces. There are already fewer jobs for today's young people, and as time goes on, people will not be able to compete with robots, physically, mentally, and from a perspective of productivity. Robots will be stronger, faster, and smarter, especially as artificial intelligence (AI) integrates through society and the infrastructure humanity is building.

AI used to be simple rule-based systems and encapsulated know-how from human programmers. This standard is no longer the case. Newer deep-learning techniques have empowered AI-computer learning in ways not even the programmers understand. We are truly outside looking in, not knowing what or how a computer learns. This lack of deep insight into how an AI computer's intelligence grows and its awareness works is both dangerous and exciting: Exciting because AI machines are already outperforming humans and not just in menial tasks. Deep-learning AI computers are outperforming seasoned doctors at determining which cells from a PAP smear are cancerous or potentially cancerous. We do not know what these computers see or have discovered that empowers them to make a better determination than humans.

Designing Service Robots

For the time being, ignorance is bliss, and we are boldly engineering robots that will integrate with society. While most of our effort is going toward vacuum-cleaner robots, agricultural robots, delivery drones and bots, and even **robotic assistants in space**, we will soon take on a more human form to better fit in and serve—especially with child care, babysitting, and health care.

It is important that our children are not afraid of robots that have charge over their safety, just as it is important for elderly folks to allow robots to help them walk, dispense medications, and detect and report any life-threatening circumstances. AI robots will tirelessly watch our elderly, communicate with them at a rudimentary level, protect them, and even save lives.

So, now is the time to perfect the look and feel of our robots and solve this uncanny valley syndrome. To transform our robots and eliminate the uncanny valley, engineers are becoming the pioneers of advanced robotic systems with multiple motors, hydraulics, magnetics, and electromechanical muscles to try and make that perfect face and personality of which people are not afraid.

Some would say we are very close. Already, there are robotic newscasters, robotic receptionists, and robotic guest stars on TV shows. Social robots can hold conversations and even memorize things you have spoken about in the past for reference and context. And the list continues.

Conclusion

The uncanny valley describes the uneasiness humans feel when a robot closely mimics a human in appearance and movement but not quite fully. Pop culture has exploited these inherent reactions to robots in TV and film as well as in humans portraying robots. In designing robots that will collaborate with humans, work side-by-side with us, provide services, and extend our capabilities, designers must consider the uncanny valley and find the essential balance. M

ROBOTIC HANDS STRIVE FOR HUMAN CAPABILITIES

By Bill Schweber for Mouser Electronics

The human hand is unmatched in its performance capabilities, but robotic hands that use soft grips and advanced algorithms are making great progress toward comparable performance in some applications.

The human hand is a marvel with multiple, tightly integrated sensors and actuators. It displays amazing dexterity and does so using only "linear contraction actuators" called muscles (**Figure 1**). It can lift, move, and place tiny, ultralight objects with precision and also manage relatively heavy large ones. It can manipulate and coordinate actions, deal with the unexpected, and do all these things with apparent effortlessness.

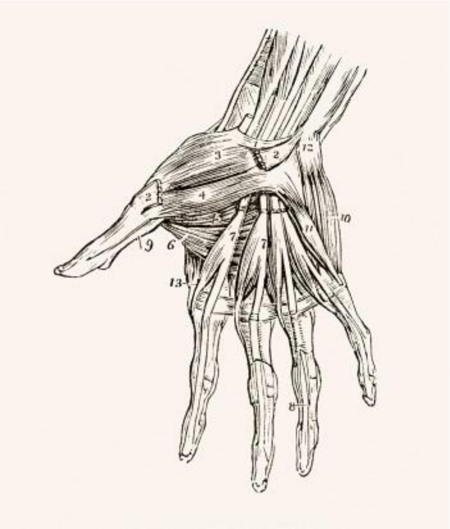

Figure 1: *The human hand with its complex array of muscles, nerves, skin, and more, is unmatched in capability and sensitivity by even the best robotic hand available today. (Source: Mouser)*

Yet the hand is much more than a grabber, manipulator, and lifter with skillfully controlled muscles. It has a huge array of dispersed yet coordinated sensors: Pressure, temperature, vibration, sliding, roughness, and even pain. Despite the number of sensor points and the constant flow of information it provides, it is somehow all handled by the body and the brain in real time without noticeable delay.

Many robotics-related efforts have strived to emulate the human hand, with good reason. A smart, electromechanical hand that could, at least in principle, perform the same tasks with the same skills, dexterity, and self-awareness would be more than an amazing technical accomplishment. It would be a major boon to the advancement and adoption of robots in consumer, industrial, professional, and other applications. There has been major progress, but there is also a very long way to go. Full replication of the human hand seems to be a long way off, despite the ones we see in futuristic movies.

Still, the lack of full human-hand emulation has not stopped strides which have made robotic hands into useful systems. At present, robotic hands that focus on actions such as lifting, turning, picking, and placing for a constrained and fairly well-defined task are already in widespread use in manufacturing, auto assembly, warehouses, research and development (R&D) drug testing, circuit-board assembly, and many more situations.

Getting Closer to "The Hand"

Despite the challenges, the quest for a universal hand continues, with many projects advancing to more sophisticated "fingers" and with better tactile sensing. After all, the ability of the hand to sense its activity, and the mind to discern intentions versus results and direct reaction via feedback, is a major factor in the versatility and success of the human hand. Robotic hands now sense pressure and strain to emulate sensing by nerves and may even sense position, orientation, and motion via gyroscopes and accelerometers. While such position and motion sensors were historically costly, large, and cumbersome, they are now available as low-cost, reasonably accurate, low-power devices.

One other thing that the human hand and mind do well is correlate multiple sensed inputs. For example, if you lightly touch the handle of a hot pan, the sensed temperature will be lower compared to grabbing that handle tightly. The human brain is good at integrating these disparate data types and extrapolating correct inferences. Working to add this capability is an area of intense research in the use of smart vision to assess situations and surroundings, provide data for a solution using adaptive learning and artificial intelligence (AI), and to assist in implementing the solution while overcoming impediments.

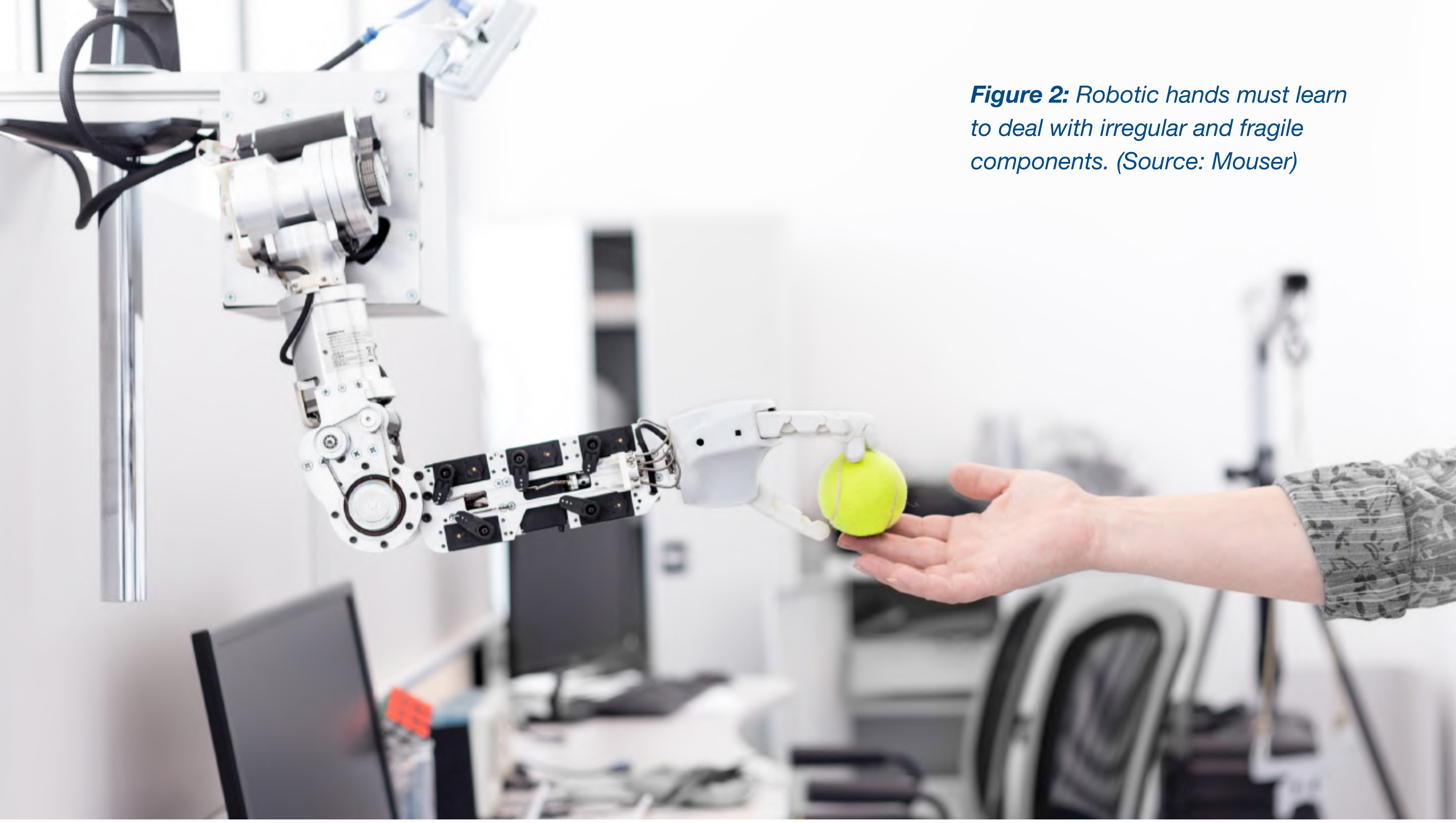

***Figure 2:** Robotic hands must learn to deal with irregular and fragile components. (Source: Mouser)*

One of the interesting things about hand-like robotic research is the diversity of the efforts and proposed solutions. If you look at designs, you'll be struck not only by their general similarities but also by the major differences. The reason is that no one—except perhaps for some very leading-edge groups—is trying to recreate the human hand with all its attributes and capabilities. Instead, each team is picking a select subset of capabilities and striving to come close to that objective of focus.

One common factor to nearly all approaches to emulating the human hand is the use of "soft robotics." Hard-surface, fixed-path grippers, which are essentially powered clamps, are well-suited to manipulating firm objects of known configuration, such as a car door. But in the real world of hands and activities, the skin and underlying tissues are relatively soft and therefore can conform to the diverse and unknown shapes of objects. They can also gently handle soft, irregular, and fragile objects, which is another key requirement (**Figure 2**).

However, soft robotics brings a new set of issues. In general, the versatile robotic controller needs to know a great deal about what it is grasping. In many cases, but not all, the human hand identifies what it is grasping using skin pressure sensors of various types and is often, but not always, aided by vision.

Effective Solutions Require Vision AI

The basic challenges of developing a viable hand-like design are formidable. Engineering considerations cut across multiple technologies and through many functional levels. The hardware stages that are the system's foundation require new and unique sensing approaches. The acquired data must be useful in comparing a planned action to the model of what should happen, and then adjusts must transpire as needed (and adjusts are always needed, given the unknowns of different situations in the real world).

Making sense of the tactile and vision sensor data is an arduous task. A significant amount of computation and data-processing capability is necessary to support advanced algorithms, and they must operate in real time with the robot-hand action.

As more and better sensors are added (which is a good thing in many ways), the volume and type of data sets and what they represent also rapidly increase. Just "making sense" of it all requires significant programming skill and resources. Further, the multiple types of data (e.g., pressure, motion, position, image) must be integrated, correlated, and coordinated to calculate and create a set of specific, viable instructions for what do to next.

Even that may not be enough, however. Today's systems are exponentially adding advanced

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algorithms to embed ongoing self-learning and self-improvement. These essential advances to the processing portion are the results of leveraging mistakes and experience with various forms of AI including inference, interpolation, and extrapolation from the huge data sets.

Universities Show the Way

Another interesting aspect of the robotics/hand technological development efforts is who is doing the research: In short, almost everyone, from universities to commercial start-ups (of which there are many) to established vendors who already support customers and installation. It's a huge potential market with truly countless applications, and a design that is superior for a large fraction of these can be both a major academic achievement as well as a commercial success.

Furthermore, from an academic perspective, the topic is interesting; it is a great focus of research for publishable papers, and there are so many feasible approaches for robotic hand development that there are opportunities for each research center to pursue a different, non-overlapping solution. Also, any robotics effort requires a diverse set of technical talents encompassing mechanical design, electronic engineering, power and motor systems, sensors, and lots of software and algorithms, so there are many roles for many students. Finally, it is a tangible, demonstrable topic that easily attracts attention, and with that comes the grant opportunities that academic institutions need and seek.

A look at a few recent and fascinating examples shows the creativity of the breadth of solutions evolving to enhance the touch-and-grasp performance of robotic arms. They also show that widely different solutions are viable candidates to pursue.

Massachusetts Institute of Technology

A team at MIT is focusing on the common problem of packing and unpacking varied items, such as groceries, where objects of random sizes, shapes, and firmness must be picked and placed. Their solution uses suction cups on inflatable grippers controlled by a sophisticated, vision-driven grasping algorithm (**Figure 3**). This enables the robot to assess a bin of unknown objects and determine the best way to grip or suction onto an item amid the clutter without having to know anything about the object before picking it up.

***Figure 3:** This robotic arm uses a vision-driven grasping algorithm to navigate gripping items of various sizes, shapes, and firmness. (Source: MIT)*

The system's algorithm employs multiple grasping tactics: Using suction to grab the object vertically or from the side; gripping the object vertically, like a claw in an arcade game; and for objects that lie flush against a wall, first gripping vertically then using a flexible spatula to slide between the object and the wall. These tactics combine with learning what works and what does not to improve the next performance as well as modify performance on a given pass if the attempt is unsuccessful.

University of Washington and UCLA

The human hand is adept at sensing shear—a sideways motion with pressure variations and subtle vibrations—to sense slippage, grasp integrity, and also accomplish various tasks. Recognizing this, a team at the University of Washington (in conjunction with the University of California, Los Angeles, or UCLA) has developed shear-sensing fingers for robot hands as well as for prosthetics.

The design is based on a stretchable electronic skin, made from silicone rubber laced with tiny serpentine channels—each roughly half the width of a human hair—and then filled with electrically conductive liquid metal that won't crack or fatigue when the skin is stretched (unlike solid wires). This skin is wrapped around the selected "end-effecter" (finger) implementation, that is, on either side of where a human fingernail would be (**Figure 4**).

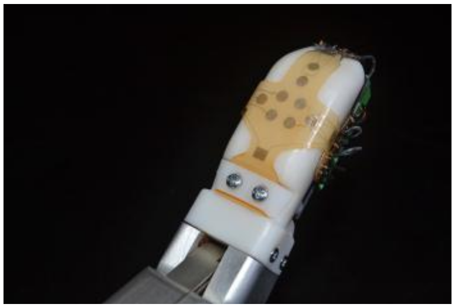


***Figure 4:** The "skin" in the fingertips of this hand uses a sophisticated network of fluid-filled, hair-thin channels to measure grip pressure. (Source: UCLA Engineering)*

When shearing action occurs, the microfluidic channels on one side compress while the ones on the other side stretch out. This, in turn, changes the electrical resistance of the fluid path in the various channels. This change undergoes measurement and then correlation with the shear forces and vibrations which caused them.

University of California, San Diego

A team at the Jacobs School of Engineering at the University of California, San Diego is using a trio of inflatable silicone-rubber fingers which can sense pressure during operation. The gripper brings together three different capabilities: It can twist objects; it can sense objects; and it can build 3D simulations or models of the objects it is manipulating.

The pressure-sensing skin that covers the fingers measures pressure by using embedded, conducting carbon nanotubes. The conductivity of the nanotubes changes with flexing and pressure, and this data is integrates to determine what the object is and how it is being held. This is done by using sensor outputs from finger-like grippers to create a 3D model of the object, a computationally intensive process.

This implantation, using inflatable fingers, gives the grippers multiple degrees of freedom, so they can pick up and manipulate objects. For example, a gripper can turn screwdrivers, pick up and screw in lightbulbs, and even pick up and hold pieces of paper, which are considerably challenging tasks for a robotic hand.

Summary

The present state of robotic hands is quite impressive, as is the rate and type of progress. While no such hand comes close to the incredible human hand, these hands are beginning to approach what has been, until recently, only in the realm of science fiction.

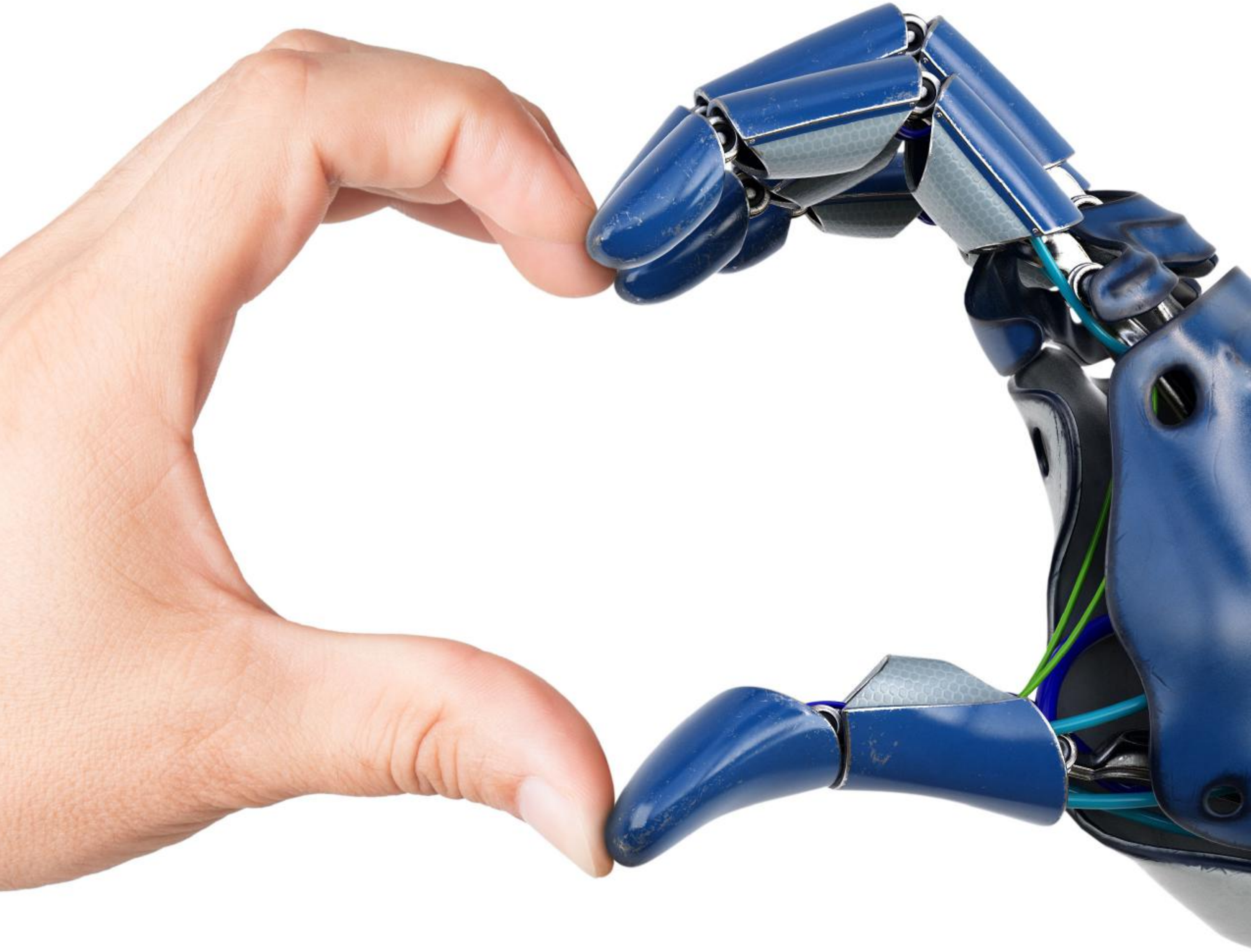
Instead of hard clamp-like grippers doing predefined tasks in well-controlled environments, today’s designs often have softer, finger-like appendages supporting multiple data acquisition and control channels. Many of them do not use conventional rotary motors but prefer linear motion actuators or inflatable, finger-like structures with sensing built into their skin-like surface.

But as with the human hand, a capable and advanced robotic hand alone is not enough. Helping these robotic hands realize their potential of being as flexible in function and versatility as the human hand are the advanced algorithms, seamless integration, AI, and more that often come with the aid of vision systems and real-time image analysis. ◼

ROBOTIC GESTURING MEETS SIGN LANGUAGE

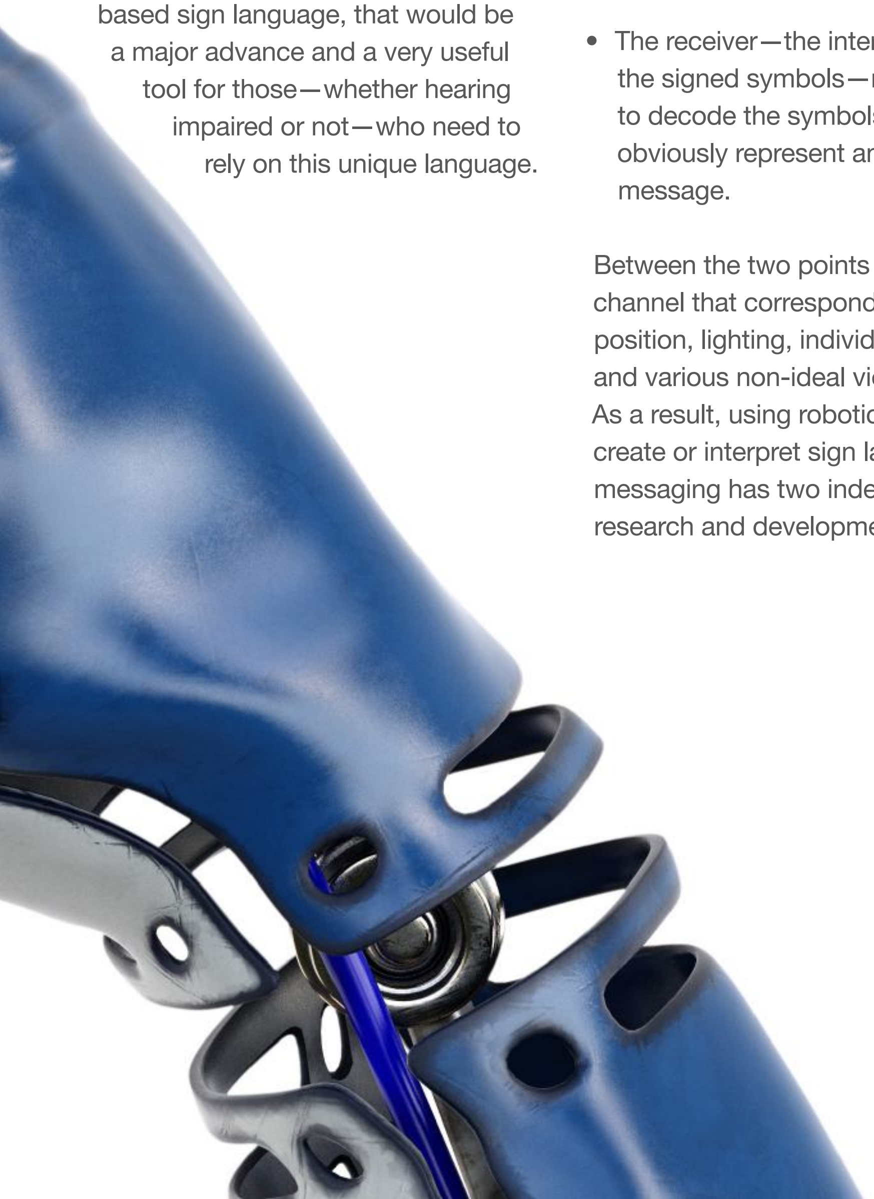
By Bill Schweber for Mouser Electronics

Designing robots that can perform gesture-based sign language and interpret it would provide a potentially invaluable service to the hearing impaired and those who rely on this unique language. Researchers around the world are making headway.



The gestures that humans routinely and effortlessly make when speaking are important parts of conversation. They supplement the spoken words by conveying meaning, intent, attitude, and much more. That's why a face-to-face or even video meeting has much more impact, as nuances and subtleties are added by the gesturing. Adding appropriate gestures may be a key factor for robots to become accepted as companions and helpers.

But there's an area where gestures are not only a nice enhancement but essential to the robotic function of sign language to communicate with the hearing impaired. If a robotic system were developed that could substitute for a human intermediary to both initiate and interpret hand-based sign language, that would be a major advance and a very useful tool for those—whether hearing impaired or not—who need to rely on this unique language.



Though estimates vary widely, a credible 2005 study by Gallaudet University puts the number in the U.S. at roughly 500,000 individuals, albeit with a large potential error band.

Challenges of Robotic Sign Language

Using robotics and computing power for generating and interpreting sign language is really a dual problem, corresponding to the transmitter, channel, and receiver problem of a communications link:

- The transmitter—the signing hand, arm, and body—has the relatively easier role, because it's encoding a known message (letters, words, and phrases) using standard symbols in a fully defined format.
- The receiver—the interpreter of the signed symbols—must try to decode the symbols, which obviously represent an unknown message.

Between the two points is the noisy channel that corresponds to shifts in position, lighting, individual "accents," and various non-ideal viewing angles. As a result, using robotics to either create or interpret sign language messaging has two independent research and development objectives:

- For creating the sign language gestures
- For interpreting the signs

As with communication transmitters and receivers, these are very different problems with different approaches, architectures, and technologies. According to Professor Han-Pang Huang, who heads the robotics laboratory at National Taiwan University (NTU), "Sign language has a high degree of difficulty, requiring the use of both arms, hands, and fingers as well as facial expressions."

Signing is deterministic and thus easier than interpreting, at least in principle, and much effort has been devoted to it. Still, signing has huge challenges in the electromechanical aspects. It may seem that effective signing is just a matter of a making a series of finger positions, each representing a letter, to spell out each word using what is known as fingerspelling (**Figure 1**), but fingerspelling is only a small subset of the total sign language environment.

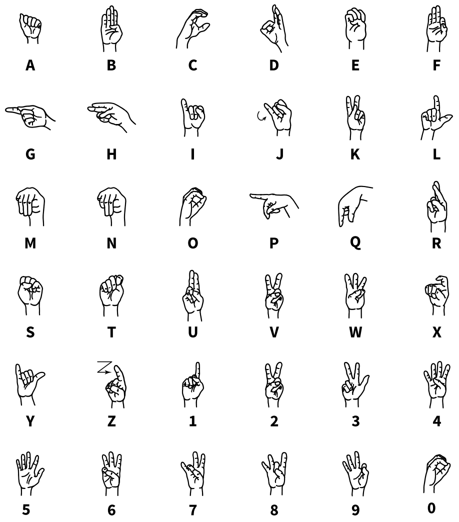


Figure 1: *American Sign Language provides a standard hand and finger-based representation for each letter and also includes many common words and phrases. (Source: Mouser)*

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The full sign language repertoire includes many single signs for common words and phrases, with four manual parameters:

- **Handshape:** Arrangement of fingers to form a specific shape
- **Movement:** Characteristic movements of the hands
- **Orientation:** Direction of the palms
- **Location:** Place of articulation, which can refer to the positions of the hands (relative to each other) or positions of markers (i.e., fingertips) relative to other places (e.g., chin, other wrist)

A website called Signing Savvy includes short video clips of American Sign Language (ASL) fingerspelling, word, and phrase gestures in action. Signing is more than hands, as there are also the non-manual components of facial expressions. These consist of two components:

- The upper part (eyes and eyebrows)
- The lower part (mouth and cheeks)

Adding to the challenge is that manual and non-manual actions must be done in a smooth and fluid manner, with synchronized finger motions.

Present robotic efforts almost entirely focus on replicating the basic finger signing motions, in some cases with the supplementation of some broader gestures, while minimizing or avoiding the broader gestures and non-manual effects. The objective is to use a text-to-hand gesture approach and eventually supplement this with a speech-to-gesture design where the originator must merely talk and the words will be translated into fingerspelling and then more complex phrases and signing.

In the fingerspelling text-to-gesture design, most of the effort focuses on the electromechanical aspects. The person types in the desired text, then letter parsing occurs, and the corresponding instructions for finger and hand motions come up and take action. The design challenge is in the creation and control of a human-like hand.

Note that a major difference between robotic hands used for fingerspelling and other robotic hands is that the signing hand needs five fully articulated fingers plus a wrist, whereas robots for picking and placing objects usually have some version of a much simpler three-fingered actuator with fewer and different degrees of motion. That pick-and-place design is clearly inadequate here. However, unlike pick-and-place robotic hands that need some sort of force and pressure sensor to provide feedback from the fingers or grippers for better control, a signing hand does not need that additional feature.

One example of a fingerspelling robotic arm is from NTU's Robotics Laboratory. This hand has six degrees of freedom in the robot arm alone, plus finger control. It uses six brushed DC motors with harmonic drive to reduce the speed of the motors. The resulting angular rate of motion is up to 110 degrees per second, and the weight of the arm is about 5kg.

A more ambitious project from the same organization is the Nino robot, which attempts to be more life-like. This nearly full-sized humanoid, which is 1.45m tall and weighs 68kg, has demonstrated basic sign language functions via some of its 52 degrees of freedom, including individual finger joints. It's not an easy task, as noted by Professor Han-Pang Huang.

Not all robotic gesturing efforts are highly complex and backed by a large organization, yet some still show significant innovation. Antwerp's Sign Language Actuating Node (ASLAN), from the University of Antwerp, Netherlands, and sponsored by the European Institute for Otorhinolaryngology, is a 3D-printed robotic arm with the ability to convert speech into basic sign language (**Figure 2**).

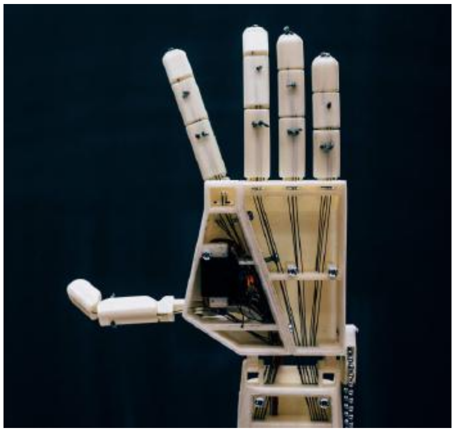

Figure 2: *ASLAN, developed by the University of Antwerp, is a 3D-printed robotic arm with the ability to convert speech into basic sign language. (Source: University of Antwerp)*

A three-person team built ASLAN using 25 3D-printed parts, 16 servo motors, and three motor controllers, plus other components and an Arduino® board as the system controller. The first prototype took 139 hours to print. The rationale for the 3D printing approach was to lower costs and also enable anyone with access to an appropriate 3D printer to make their own, considering the unique mechanical parts were no longer special, long-lead items.

Making Gestures Interpretable

For the more difficult problem of interpreting signed language, there are two basic, non-overlapping approaches: Gloved and video. In the gloved method, the person signing wears a special glove with embedded sensors, and the movements of the

[CONT'D ON PAGE 33]

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glove and fingers undergo tracking and interpretation by a processor. In the video method, an imaging system observes the person signing, and then attempts to recognize the signs using feature extraction algorithms.

Gloved Approaches

Even the glove approach has different implementations. One design, from a team led by Roozbeh Jafari, associate professor in the Department of Biomedical Engineering and researcher at the Center for Remote Health Technologies and Systems at Texas A&M, uses a glove-like unit which is instrumented with two distinct sensors. First, there are inertial sensors (i.e., accelerometer and gyroscope sensors) that respond to motion and measures the accelerations and angular velocities of a hand and arm. This sensor pair captures the user's hand orientations along with hand and arm movements during a gesture.

However, this sensing by itself is not sufficient, as certain signs in ASL are similar in terms of the gestures required to convey the word. Although the overall movement of the hand may be the same for two different signs, the movement of individual fingers may be different. To address this problem, the Texas A&M system adds an electromyographic (EMG) sensor to non-invasively measure the electrical potential of muscle activities. This enables the system to distinguish among various hand and finger movements based on different muscle activities. The data it provides works in tandem with the motion sensor to provide a more accurate interpretation of the gesture being signed.

Despite its sophistication, the sensor arrangement is actually a simpler aspect of the system. The harder task is developing and executing complex algorithms to interpret the sign and display the correct letters and word for the gesture once the sensed data is sent (via a Bluetooth® link) to an external PC.

A very different glove approach is used in a setup at University of California, San Diego. There the glove is enhanced with commercially available, easy-to-assemble stretchable and printable electronics (**Figure 3**). It uses a leather athletic glove with nine stretchable sensors adhered to the back at the knuckles—two on each finger and one on the thumb. The sensors are made of thin strips of a silicon-based polymer coated with a conductive carbon paint and secured onto the glove with copper tape. Stainless steel thread connects each of the sensors to a low-power, custom-made printed circuit board that is attached to the back of the wrist.

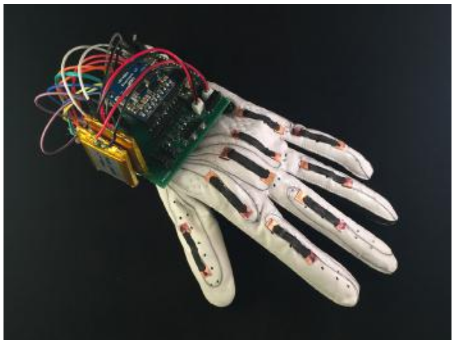

Figure 3: *"The Smart Glove," developed at University of California, San Diego, translates the ASL alphabet into text and mimics sign language gestures. (Source: University of California, San Diego)*

The sensors change their electrical resistance when stretched or bent, which in turn creates a different binary (1 or 0) code for each sensor point. This allows the sensors to directly create a unique code for different letters of the ASL alphabet based on the positions of all nine knuckles, producing a nine-digit binary word that maps to a matching letter. Similar to the Texas A&M glove, this glove is also fitted with an accelerometer and pressure sensor to help distinguish between letters with gestures that generate the same nine-digit code.

The data from the glove transmits to a smartphone or nearby PC using a Bluetooth link. The algorithms that attempt to map the data from the glove's gestures into actual letters must implement complex pattern matching, corrections of various known types of distortions and variations, and much more.

Video Approaches

While the glove approach is low cost and direct, it requires that the signer wear that glove and so limits widespread use in more general real-world situations. The alternative is to use one or more cameras to capture the signing process, perform feature extraction and pattern recognition on the image, and then decide which character was signed.

Single-Camera Approaches

One such system was developed and refined by a multinational team from the Institute of Information Technology at the University of Dhaka, Bangladesh; Chalmers University of Technology, Gothenburg, Sweden; and Sookmyung Women's University, Seoul, South Korea. This system uses a single camera and extracts and classifies features with a two-phase approach consisting of a feature extraction phase and the classification phase. Resizing of the image samples occurs, and then they convert from the camera's red, green, and blue (RGB) color map to the luminance, in-phase quadrature (YIQ) color space to improve image fidelity and clarity. The images are then segmented to detect and digitize the sign image.

In the classification stage, the algorithm constructs a three-layer, feed-forward, back-propagation neural network consisting of 40 by 30 neurons in the input layer, with 768 (70 percent of input) neurons for the hidden layer, and 30 (total number of ASL images for the classification network) for the neurons in the output layer. While this neural network may seem straightforward, the reality is that the actual network topology and construction involve many sub-arrays, multiple data-manipulation blocks, and dynamically calculated weightings.

Another team based at the University of Surrey (Guildford, UK) uses a more detailed model of the three types of sub-unit extractions and multiple sign-level classifiers. The team's structural diagram elaborates on multiple parallel paths of feature extraction and classification that are necessary.

Feature extraction begins with the captured image, then edge filtering of the image, followed by generation of a token of the image. Next, the token is used in a matching process versus existing test-reference images to determine a best-case match. This overall procedure is not a trivial process, of course, and has many areas of potential issues and errors in both feature extraction and matching.

There are tradeoffs when choosing to use a single camera versus multiple cameras. With a single camera, the volume of real-time data for analysis is less, and the feature-extraction task is more focused and defined. However, the images from a single camera lack depth and are subject to shadows, blocking, and other shortcomings. Thus, some aspects of the algorithms in a single-camera system are more complicated and prone to errors.

Multiple-Camera Approaches

For this reason, some groups use a multi-camera system, especially as the video equipment is now relatively low in cost and easy to interface. SignAll, based in Hungary, has developed what they claim is the first commercially available system for the automated translation of sign language. Their system is based on computer vision and natural language processing (NLP) of data streams from three cameras and one distance sensor. The depth sensor is placed in front of the sign language user at chest height, and the cameras are placed around him or her to allow continuous tracking of the shape and the path of the hands and gestures.

The system processes the images taken from the different angles in real time. Once the signs are identified from the images, an NLP module transforms the signs into grammatically correct, fully formed sentences. SignAll also maintains that their algorithms can decode prosody, which is the elusive aspect of languages that subtly shapes the way we say what we say. Prosody incorporates the setting of rhythmic and intonational features so the SignAll system can perceive the various combinations of the linguistic units. When signing in ASL, this involves head and body movements, eye squints, eyebrow and mouth movements, the speed and formation of signs, pacing, and pausing.

Conclusion

There is no doubt that signing systems that can replace human signers and interpreters would provide tangible benefits to a large group of people with hearing impairments as well as their companions. Many research projects are underway, primarily at universities, and there has been significant progress to overcome problems in robotic signing and interpreting. Nonetheless, there also is a huge amount of work still to be done in both hardware and data analysis.

In stepping back to view the amount of effort it takes to develop robotic sign language capabilities, it makes you truly appreciate the amazing capacity of a human being, who can (with some practice) learn to sign and interpret letters, words, phrases, and more using only eyes, body language, and an embedded processor (the brain) that weighs about 1.5kg and dissipates only about 50–75W. Will automated systems ever be that good? Well, for the answer, you'll need to check back in 10 or 20 years. M