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FOCUS ON: ROBOTICS

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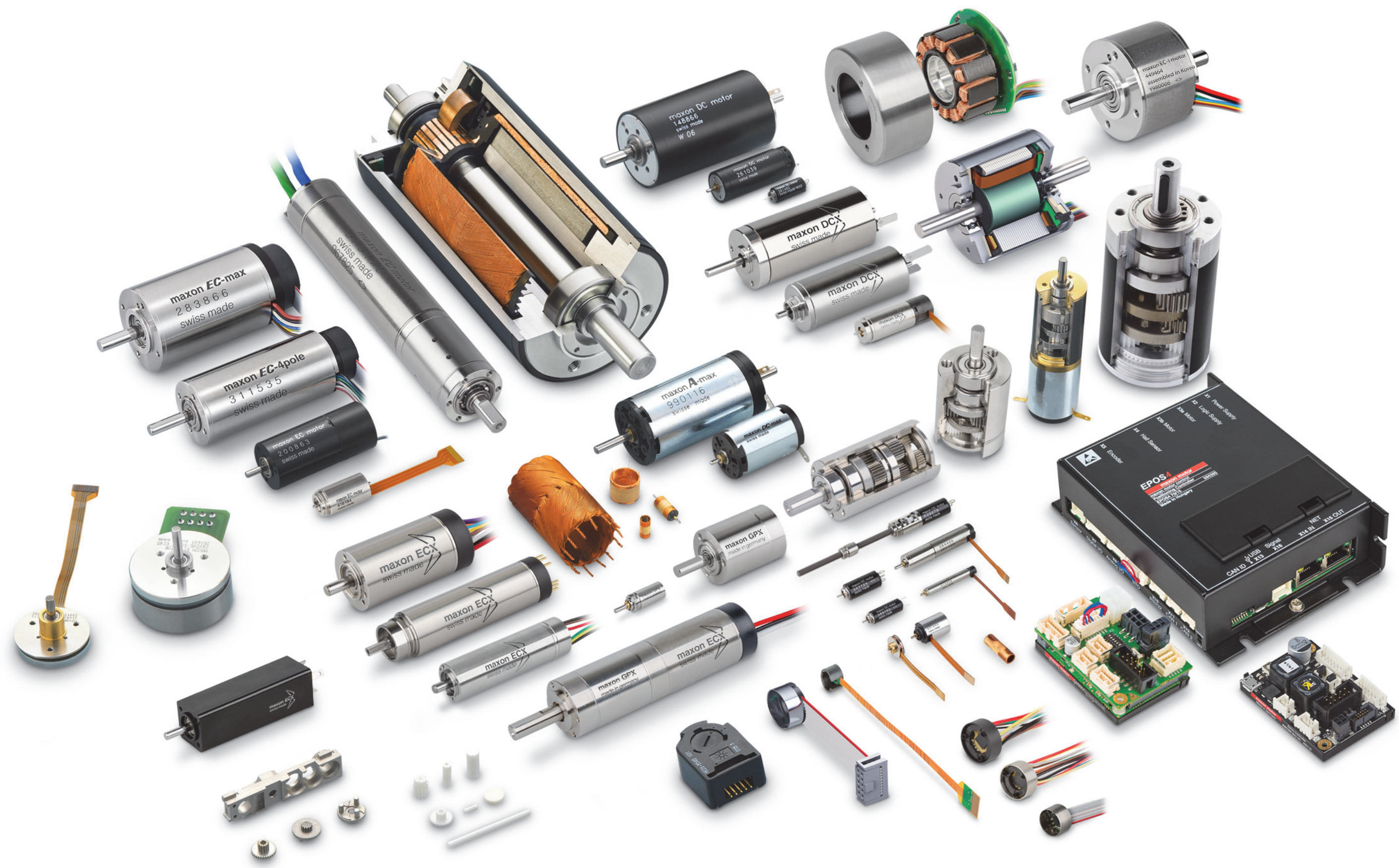

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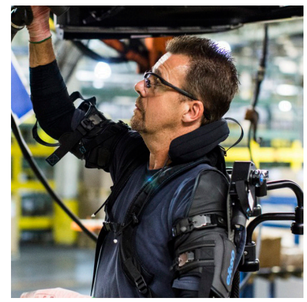
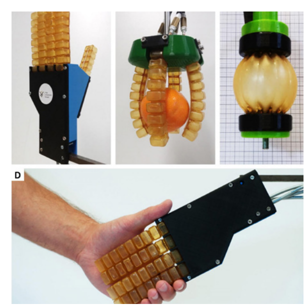


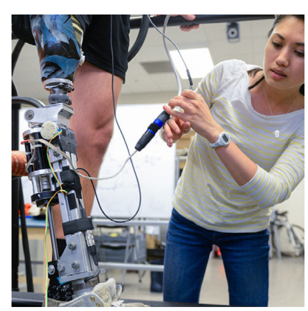
CARLOS GONZALEZ
Technology Editor
Machine Design

INTRODUCTION

THE ROBOTICS WORLD HAS GONE MEDICAL. With the aid of smaller, more efficient, and high performing components, engineers and researchers have been able to design new medical equipment for human robotic aid. Advances in others of technology such as 3D printing and artificial intelligence, have opened the doors for robots to become the medical tool of tomorrow. The following eBook will discuss what the role of robots will look like in years to come, how robots will influence medical innovation, and how to use new technology for future medical robotic design.

TABLE OF CONTENTS





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CARLOS GONZALEZ, Technology Editor

CHAPTER 1:

WHAT'S THE FUTURE ROLE FOR HUMANOID ROBOTS?

The robotic industry will see an increase in humanoid robots—but do these robots have a future in the engineering industrial space, or are they just a gimmick?

It has been well documented that there will be increase in the number of robots over the next decade. According to the Boston Consulting Group, by 2025, robots will perform 25% of all labor tasks. This is due to improvements in performance and reduction in costs. The United States, along with Canada, Japan, South Korea, and the United Kingdom, will be leading the way in robot adoption. The four industries leading the charge are computer and electronic products; electrical equipment and appliances; transportation equipment; and machinery. They will account for 75% of all robotic installations by 2025.

The growth of robotics will also affect the service industry. In a recent report from Berg Insight, the service robot base is expected to install 264.3 million units by 2026. In 2016, 29.6 million service robots were installed worldwide. *The robots in the service industry broke down into the following groups:*

- Floor cleaning robots accounted for 80% of total service robots, with 23.8 million units
- Unmanned aerial vehicles accounted for 4 million units
- Automated lawnmower units tallied 1.6 million units
- Automated guided vehicles installed 0.1 million units
- Milking robotic units tallied to 0.05 million units

The remaining segments included humanoid robots (including assistant/companion robots), telepresence robots, powered human exoskeletons, surgical robots, and autonomous mobile robots. Combined, they were estimated to have had less than 50,000 units installed.

Shown is the planning and control of multi-contact movements by humanoid robots.

Humanoid robots, while being one of the smallest groups of service robots in the current market, have the greatest potential to

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become the industrial tool of the future. Companies like Softbank Robotics have created human-looking robots to be used as medical assistants and teaching aids. Currently, humanoid robots are excelling in the medical industry, especially as companion robots.

University of Southern California Professor Maja Matarić has been pairing robots with patients since 2014. Her robots helped children with autism copy the motions of socially assistive robots and, in 2015, the robots assisted stroke recovery victims with upper extremity exercises. The patients were more responsive to the exercises when promoted and motivated by the robot.

Joint Robotics Laboratory

However, companies are now using humanoid robots to fill engineering tasks. A four-year joint research project was conducted by Joint Robotics Laboratory and Airbus Group to use humanoid robotic technology in aircraft manufacturing facilities. By using humanoid robots on aircraft assembly lines, Airbus looks to relieve human operators of some of the more laborious and dangerous tasks. The human employers could then concentrate on higher value tasks. The primary difficulty is the confined spaces these robots have to work in and being able to move without colliding with the surrounding objects.

The Joint Robotics Laboratory developed the new HRP-2 and HRP-4 robot models with a new robotic movement technology known as multi-contact locomotion. By making use of its entire body to make contact with its environment, and not just its feet, this type of robot can climb ladders and enter confined spaces. The multiple points of contact on the robot help to increase a robot's stability and offers better force control when executing a task. Lastly, the anthropomorphic form of these robots offers greater flexible for operating in different environments.

NASA

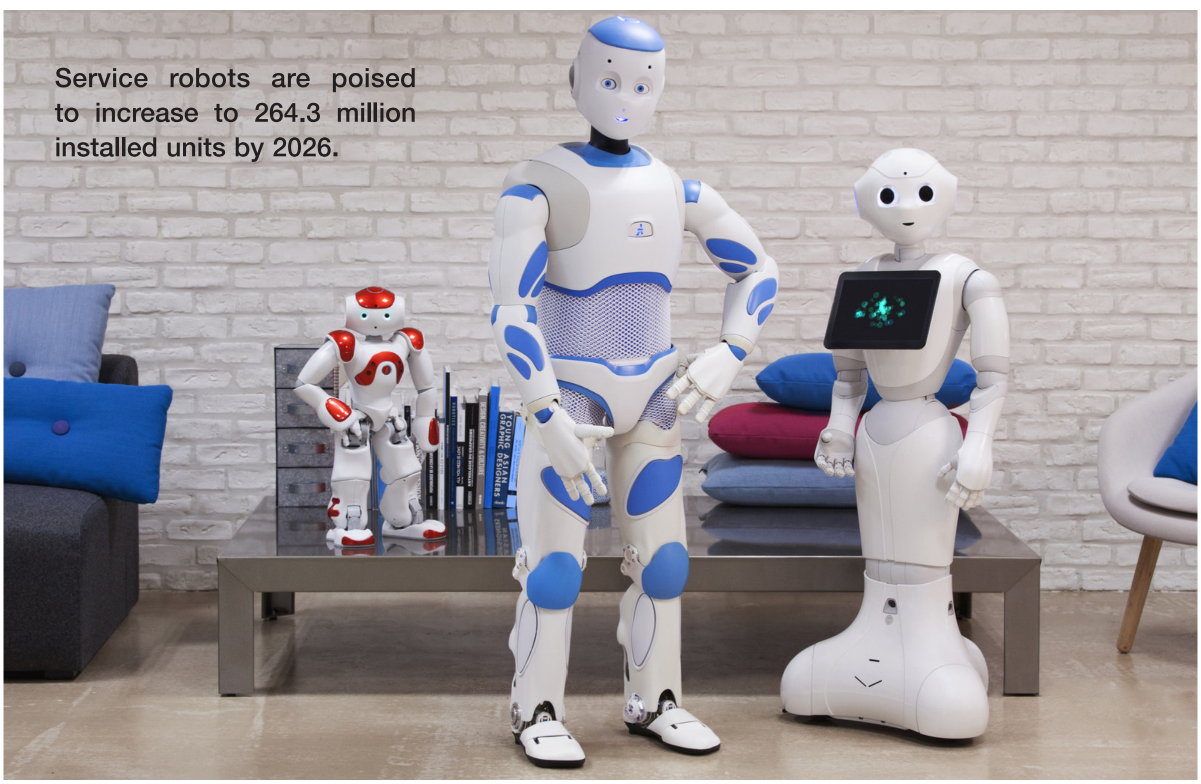
NASA is using its Valkyrie robot for similar tasks, albeit on future missions to Mars. Valkyrie is a 6-2 humanoid robot weighing 300 lb. The robot's brain is powered by two Intel Core i7 computers, and the head houses lidar sensors, cameras, and a Multisense SL camera to continually scan the surrounding objects and environments. The Multisense camera combines laser, 3D stereo, and video to sense the environment. Hazard cameras look ahead and behind from the torso to detect possible dangers.

But the real value of Valkyrie is in its hands. Professor Taskin Padir from Northeastern University and his research team have been in charge of creating human like flexibility to the robot's hands. "NASA's Valkyrie has three fingers and a thumb on each hand," says Padir. "Each digit has knuckle-like joints, and each hand has a wrist that can rotate easily. We're working on creating motions—combinations of arm, wrist, finger, and thumb movements that collectively accomplish a task, like moving a wrench in a circle to tighten a bolt, or pulling a cart from one place to another."

The ultimate goal of a robots like Valkyrie is to man the future mission to Mars. They can be sent on scouting missions to the planet and used to set up living compounds, maintaining power and life support systems for future manned missions.

So what is missing for these robots to become more present in all sectors of engineering? Two features: adaptability and force control. Currently, robots require specific programming for each object they come in contact with. This limits the robots to only one task until they are reprogrammed and re-tasked. Researchers are working on methods on how to take one robots programming and apply it to another robot.

The new machine learning technique from MIT's Computer Science and Artificial Intelligence Laboratory is called C-Learn. The "C" stands for constraints. C-Learn allows non-coders to teach robots movements and tasks by providing some basic information on the objects be-



Service robots are poised to increase to 264.3 million installed units by 2026.

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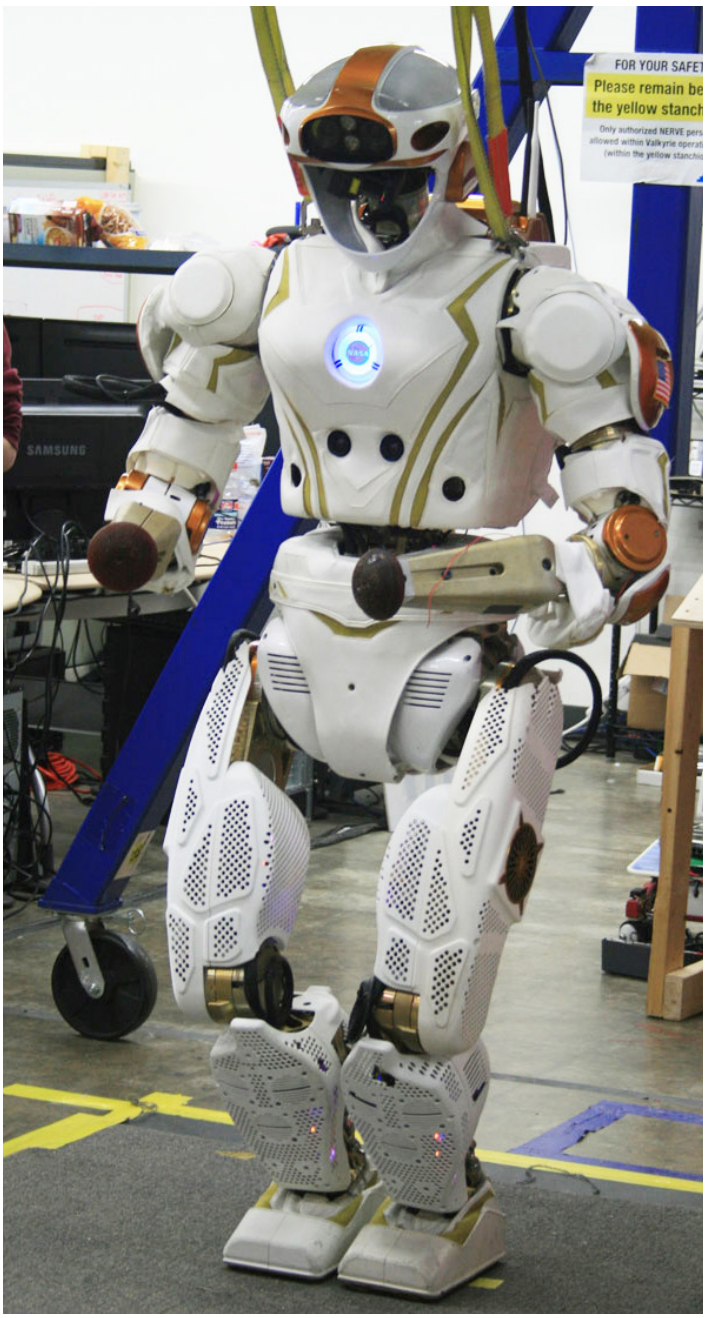
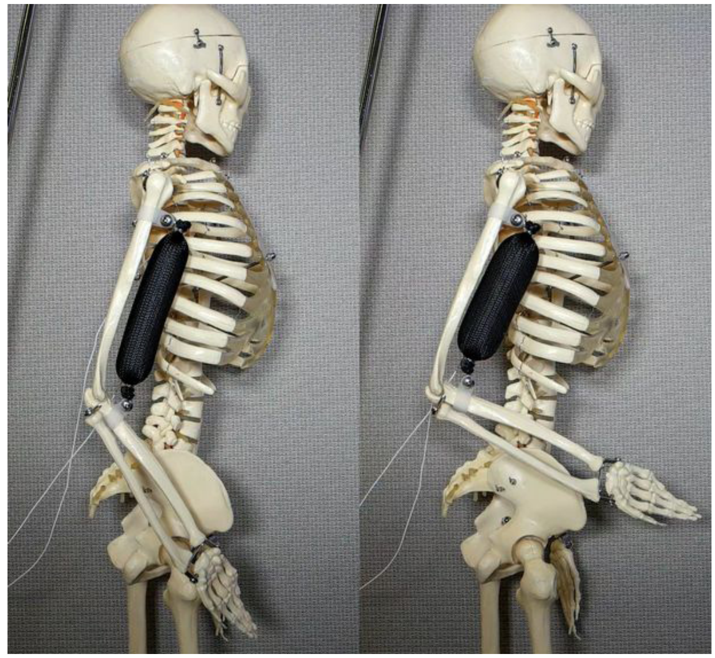
ing manipulated, then showing the robot a single demo on how to perform the task. "By combining the intuitiveness of learning from demonstration with the precision of motion-planning algorithms," says Claudia Pérez-D'Arpino, a Ph.D. student working on the C-Learn research, "robots do new types of tasks that they haven't been able to learn before."

Columbia Engineering

At Columbia University, engineers are finding new ways to replicate human muscle. They have created a synthetic muscle that can lift a thousand times its own weight, push, pull, bend, and twist.



The Valkyrie robot will help NASA explore Mars as humanoid robotic assistants.



The artificial muscle in shown in use as a bicep lifts a skeleton's arm to a 90-deg. Position.

The muscle is a 3D printed mixture of silicone rubber matrix with ethanol distributed throughout in micro-bubbles, and does not require an external compressor or high voltage electrical equipment to operate. The muscle is electrically moved by using a thin resistive wire and is low-power (only 8 V).

Professor Hod Lipson, the team's leader, says soft material robotics hold "great promise" for areas where a softer touch is required. Unlike rigid robots, soft robots can replicate natural motion, including grasping and manipulation of objects. These new muscles can be used to provide medical and other types of assistance, perform delicate tasks, or pick up soft objects.

"Rather than making each robot a custom machine tailored for a very specific task, we need to design multi-use robots—or even such capable machines that they might be called "general purpose"-good for almost any task," says Padir. "Achieving this goal also involves inventing new designs that incorporate hard and soft elements —the way human bone gives strength to a grip, with skin spreading the pressure so [even] a wine glass doesn't shatter." ■

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☞ **BACK TO TABLE OF CONTENTS**

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CARLOS GONZALEZ, Technology Editor

CHAPTER 2:

MORE THAN MEETS THE EYE: THE FUTURE OF BIO-ROBOTICS

Integrating man with machine is nothing new, as motorized prosthetics have existed for years. However, advances in robotics have created a new wave of technology, pushing the mechanical human body to new limits.

For those in need of a limb, replacement organ, or internal repair, prosthetics and transplants have been the go-to technology for many years. The inherent problem with both of these technologies is the price and availability. Prosthetics are a costly product and unfortunately, insurances only offer to cover a portion of the price tag. Many patients are left to pay out of pocket for these devices. And even if they could afford the prosthesis, the percentage of increased mobility is minimal. Transplants of organs are always subject to availability. Many patients are left waiting on transplants list for months to years, depending on the match. And even once received, the body's potential rejection of the organ is a serious concern.

The world of robotics is looking to close the gaps by bring innovation to these fields of medicine. These innovations rely on new technology to help create opportunities in the medical field that were not there before. Some companies are using 3D printing to aid in the creation of prosthetics. Others are using the advances in motion to create more efficient, lightweight robotics. Lastly, robots are being used at the nano level to fight cancer more aggressively than ever.

Advanced Prosthetics and Robotics

Advanced prosthetics are essential to people recovering from lost limbs and limited mobility. Robotic prosthetics not only replace the lost limbs, giving functionality back to the patient, but also mentally help the patient feel complete. The main problem with these prosthetics is the high cost, which may not be covered by insurance. This is where a company like Unlimited Tomorrow steps in.

Unlimited Tomorrow has created a low-cost process

The advanced prosthetic arms from Unlimited Tomorrow are 3D printed and based off of scans of the patient's still-intact arm. Each arm has force feedback and is muscle operated.

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The exoskeleton designed by a joint research effort from scientists at Harvard, the Wyss Institute, and Boston University anchors to the stroke patient's ankle to offer gait-restoring forces by transferring mechanical power via a cable-based transmission from battery-powered actuators.

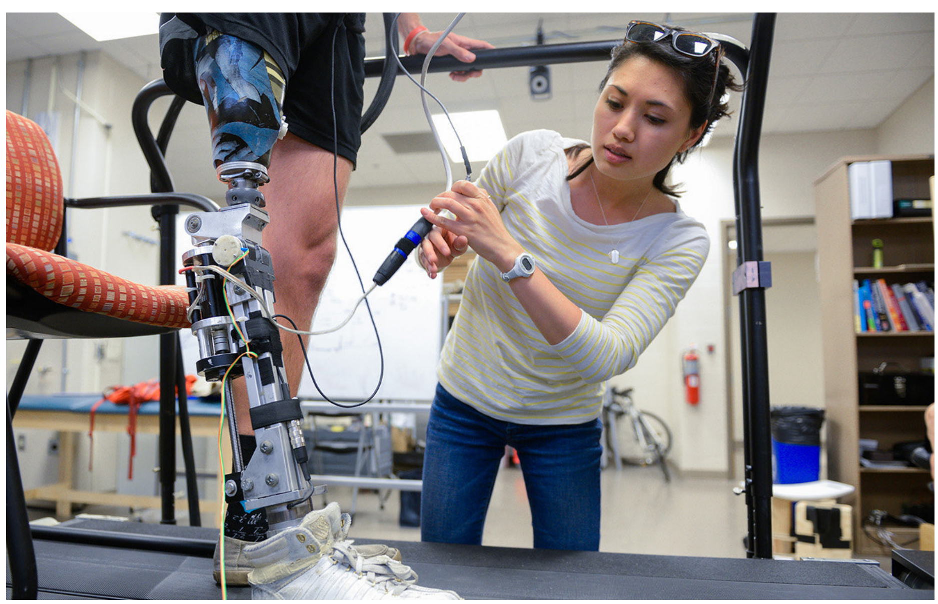
of creating prosthetic arms for individuals. By using scans of the missing limb and the still-intact arm, they 3D-print a prosthetic arm that matches the patient's skin tone and provide realistic-like features such as paintable fingernails. The average arm weighs around one pound, and with regular use, the battery life is three to four days. The arm has advanced sensing and learning features. Haptics is incorporated into the arm to provide force feedback to the patient. It's muscle-operated, and is equipped with machine learning for advanced control.

A joint research effort from The Wyss Institute for Biologically Inspired Engineering, the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS), and Boston University's College of Health & Rehabilitation Sciences: Sargent College have developed a lightweight, soft, wearable ankle-assisting exosuit to aid stroke victims. Some 80% of patients who experience a stroke lose functionality in one limb, known clinically as hemiparesis. The exosuit is to help reinforce normal gait or manner of walking in people with hemiparesis after a stroke.

Exoskeletons are being used to help stroke patients regain the ability to walk. Prior to the use of exoskeletons, patients' exercises were restricted to treadmills or walking rails. Though providing some return of their former mobility, these rehab methods retain abnormality in their gait. This hinders them from normal activities, creates risks of falling, and can lead to secondary health problems due to a sedentary lifestyle.

Patients recovering from a stroke figure out alternative methods to walk and clear the ground with their handicapped limp to push off at the ankle during forward movement. Typically, they lift their hips or turn their foot in an outward circle forward rather than in straight line. One current treatment to correct this is to wear plastic braces around the ankle. However, this does not help overcome these abnormal gait patterns, and 85% of stroke patients retain these gait abnormalities.

The exosuit designed by the research team anchors the affected limb to the suit via functional apparel. It provides gait-restoring



Andrea Brandt, a Ph.D. student in the NC State and University of North Carolina-Chapel Hill Joint Department of Biomedical Engineering, has been conducting research on a powered knee prosthesis. The device has a motor to actuate the kneed and a fixed ankle joint to help patients with missing legs walk.

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forces to the ankle by transferring mechanical power via a cable-based transmission from battery-powered actuators located on the hip belt or on a cart nearby. This helps the stroke patient walk in a straight line by preventing the foot from turning outward.

"Current approaches to rehabilitation fall short and do not restore the mobility that is required for normal life," said BU faculty member Terry Ellis. "In an ideal future, patients post-stroke would be wearing flexible adjusting exosuits from the get-go to prevent them from developing inefficient gait behaviors in the first place,"

Andrea Brandt, a Ph.D. student in the NC State and University of North Carolina-Chapel Hill Joint Department of Biomedical Engineering, has been conducting research on how powered devices can help provide motion to lower-limb amputees. While there are several published papers on how powered artificial limbs could aid in mobility for amputees, there is very little research to support their findings.

Brandt wanted to test how these devices would work in real-world situations—e.g., in load bearing conditions or interaction with the environment. "We wanted to first understand how load affects amputees walking with normal prosthesis settings that are typically prescribed in the clinic, and then to what degree different settings could benefit them," Brandt explained.

The device tested by Brandt was a powered knee prosthesis. The device has a motor to actuate the kneed and a fixed ankle joint. They programmed multiple settings that provided unique mechanical movement for load bearing and non-load bearing conditions. The settings were evaluated on how the participants would adjust their gait and their exertion rates.

Five different patients of varied ages and physical attributes used the device and were tested on a treadmill with and without carrying a backpack. When the device was set to its load bearing setting, the patients sensed a reduction in exertion and hyperextension of their intact limb.

According to Brandt, these devices will have a significant impact on the lives of amputees: "Imagine if the device was smart enough to automatically change the prosthesis parameters to fit any situation where we interact with the environment—carrying different amounts of load, walking on sand or grass—and how much more amputees might be able to rely on their prosthesis in their everyday life. This is the next stage of work in our lab."

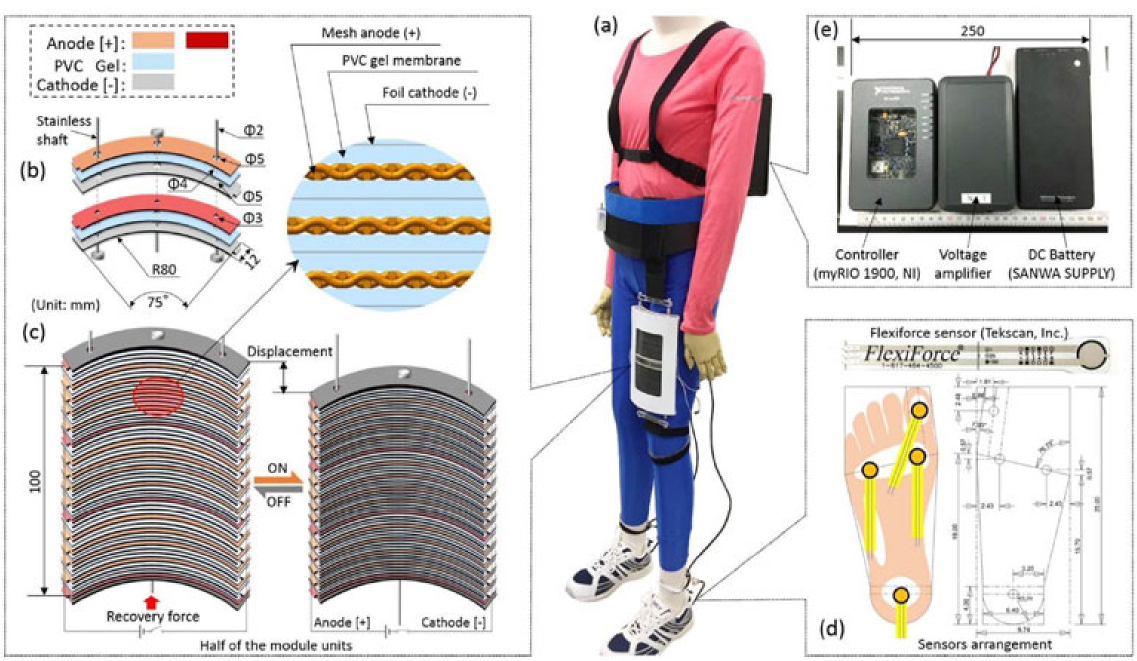
Creating Mechanical Muscles

The next phase of mechanics and human integration is to recreate human organs and function with robotics. At Shinshu University in Japan, scientists are a step closer to creating artificial muscles. A collaborative research team, led by Minoru Hashimoto, a professor of textile science and technology at the Shinshu University in Japan, has designed a wearable robot to support a person's hip joint while walking. The wearable system is a plasticized polyvinyl chloride (PVC) gel with mesh electrodes and an applied voltage. The mesh electrodes sandwich the gel and as the voltage is applied, the gel flexes and contracts just like a muscle would. Essentially the robotic system is a wearable actuator that creates movement.

"We thought that the electrical mechanical properties of the PVC gel could be used for robotic artificial muscles, so we started researching the PVC gel," said Hashimoto. "The ability to add voltage to PVC gel is especially attractive for high speed movement, and the gel moves with high speed with just a few hundred volts."

The preliminary evaluations have been performed on stroke patients with some paralysis. With the robotic wear system, the patients were able to move more naturally, increasing step length and decreasing muscular activity while walking. The suit can adjust the level of contraction to vary the mechanical assistance as patients improve during rehab.

Hashimoto articulates that several modern assisted walking devices are cumbersome and difficult to use. According to Hashimo-



Minoru Hashimoto, a professor at the Shinshu University in Japan, has designed a wearable robot to support a person's hip joint while walking. The wearable system is a plasticized polyvinyl chloride (PVC) gel with mesh electrodes and an applied voltage that contracts like muscle.

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to, "In our current study, we sought to develop a lightweight, soft, wearable assist wear for supporting activities of daily life for older people with weakened muscles and those with mobility issues. With a rapidly aging society, an increasing number of elderly people require care after suffering from stroke, and other-age related disabilities."

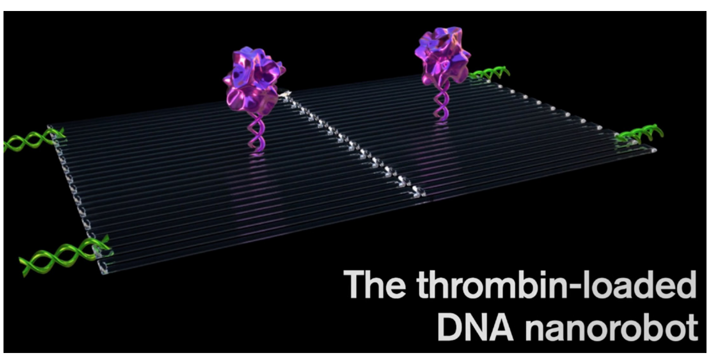
The robotic system earned first place in demonstration at the "24th International Symposium on Smart Structures and Materials & Nondestructive Evaluation and Health Monitoring" for SPIE, the international society for optics and photonics. The next phase of research is to create a string of actuators using PVC gel that could result in the creation of a fabric capable of providing external muscular support.

Cancer-Fighting Robots

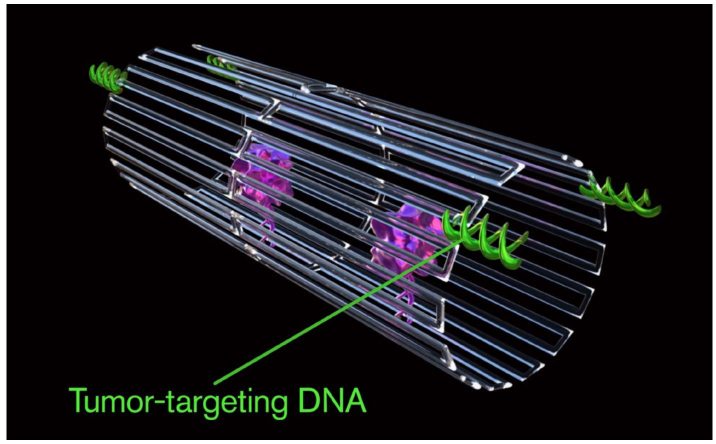
Robots are also not aiding the exterior of the human body but also on the inside. Robotic innovation is now occurring at the nanoscale. Researches from Arizona State University scientists, in collaboration with researchers from the National Center for Nanoscience and Technology (NCNST), of the Chinese Academy of Sciences, have programmed nanorobots to shrink tumors by cutting off their blood supply.

Nanomedicine is a branch of medicine that combines nanotechnology to make minuscule, molecule-sized nanoparticles to diagnose and treat difficult diseases like cancer. Hao Yan, director of the ASU Biodesign Institute's Center for Molecular Design and Biomimetic and the Milton Glick Professor in the School of Molecular Sciences, is an expert in the field of DNA origami and in the last two decades has developed atomic-scale manufacturing to build complex nanostructures.

The nanostructures can fold themselves into all sorts of shapes in sizes at a scale of one thousand times smaller than the width of a human hair. "We have developed the first fully autonomous, DNA robotic system for a very precise drug design and targeted cancer therapy," said Yan. "Moreover, this technology is a strategy that can be used for many types of cancer, since all solid tumor-feeding blood vessels are essentially the same."



Researches from Arizona State University (ASU) scientists, in collaboration with researchers from the National Center for Nanoscience and Technology (NCNST) of the Chinese Academy of Sciences, have programmed nanorobots to shrink tumors by cutting off their blood supply.



Each nanorobot is made from a flat, rectangular DNA origami sheet, 90 nanometers by 60 nanometers in size and containing a key blood-clotting enzyme called thrombin. Thrombin can block tumor blood flow by clotting the blood within the vessels that feed tumor growth.

The plan was to use these nanostructures to cut off the blood supply by inducing blood coagulation with high therapeutic efficacy and safety profiles in multiple solid tumors using DNA-based nanocarriers. Yan upgraded the nanomedicine to be an autonomous robotic system, one able to complete the task on its own. Each nanorobot is made from a flat, rectangular DNA origami sheet 90 nanometers by 60 nanometers in size and containing a key blood-clotting enzyme called thrombin. Thrombin can block tumor blood flow by clotting the blood within the vessels that feed tumor growth, leading to tumor tissue death.

An average of four thrombin molecules were attached to a flat DNA scaffold, and the sheet was folded in on itself like a sheet of paper into a circle to create a hollow tube. A special payload known as a DNA aptamer was included to ensure that only the specific protein nucleoli was targeted so that only the cancer cell was attacked. Once bounded with the rumor blood vessel surface, the nanorobots deliver the drug to the tumor's bloodstream and the thrombin begins the blood clotting. Within 24 hours, there was tumor tissue damage, and after two weeks of treatment, the tumor began to shrink.

Robots, whether they be large industrial arms, prosthetics, or exoskeletons, look to enhance the manufacturing environment through automation. The advancements in robotics will lead to not only to an automated future, but also to one where human beings could potentially be cured of serious medical conditions, rebuilt to their former selves, and enhanced with new abilities.

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☞ **BACK TO TABLE OF CONTENTS**

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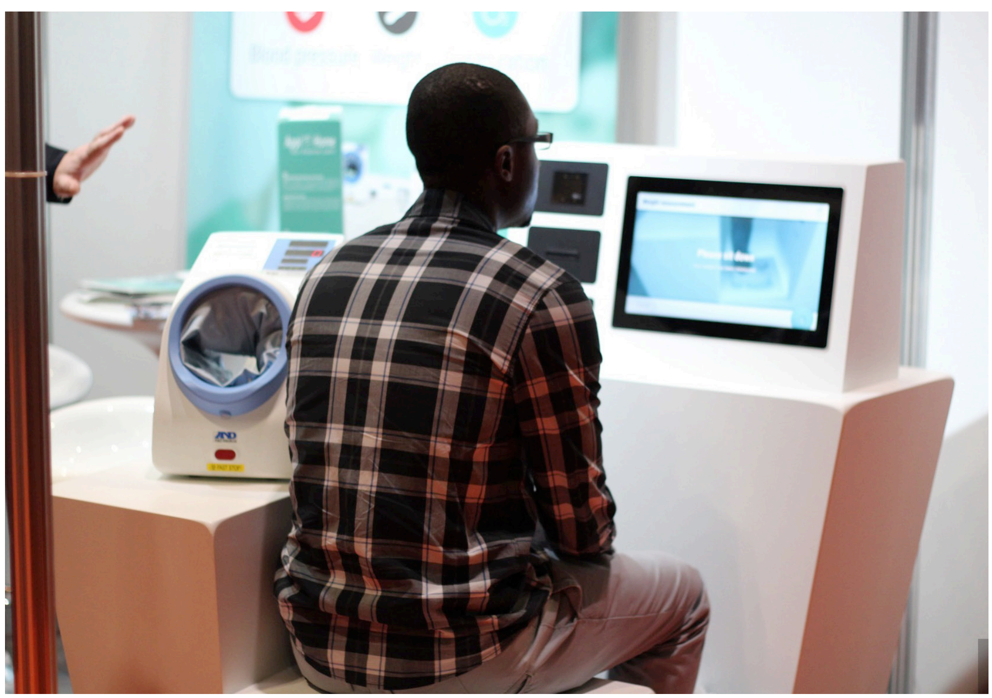
CHAPTER 3:

6 WAYS ROBOTS WILL BE THE MEDICAL ASSISTANTS OF TOMORROW

The world of robotics will find growth potential in the medical field as robotic surgery and robot assistants lead to more accurate results and better care.

Robotics is an exponentially growing industry and as we know, automation is coming to become our everyday helpers. This is especially true in the medical field. According to research conducted by Tractica, the market for healthcare robots, which includes surgical robots, hospital robots, and rehabilitation robots, will increase in revenue from $1.7 billion in 2016 to $2.8 billion by 2021, at a compound annual growth rate (CAGR) of 9.7%. Tractica predicts that healthcare robot shipments will increase from approximately 3,400 units per year in 2016 to more than 10,500 units per year by 2021. Here are six ways that robots are currently changing the medical field:



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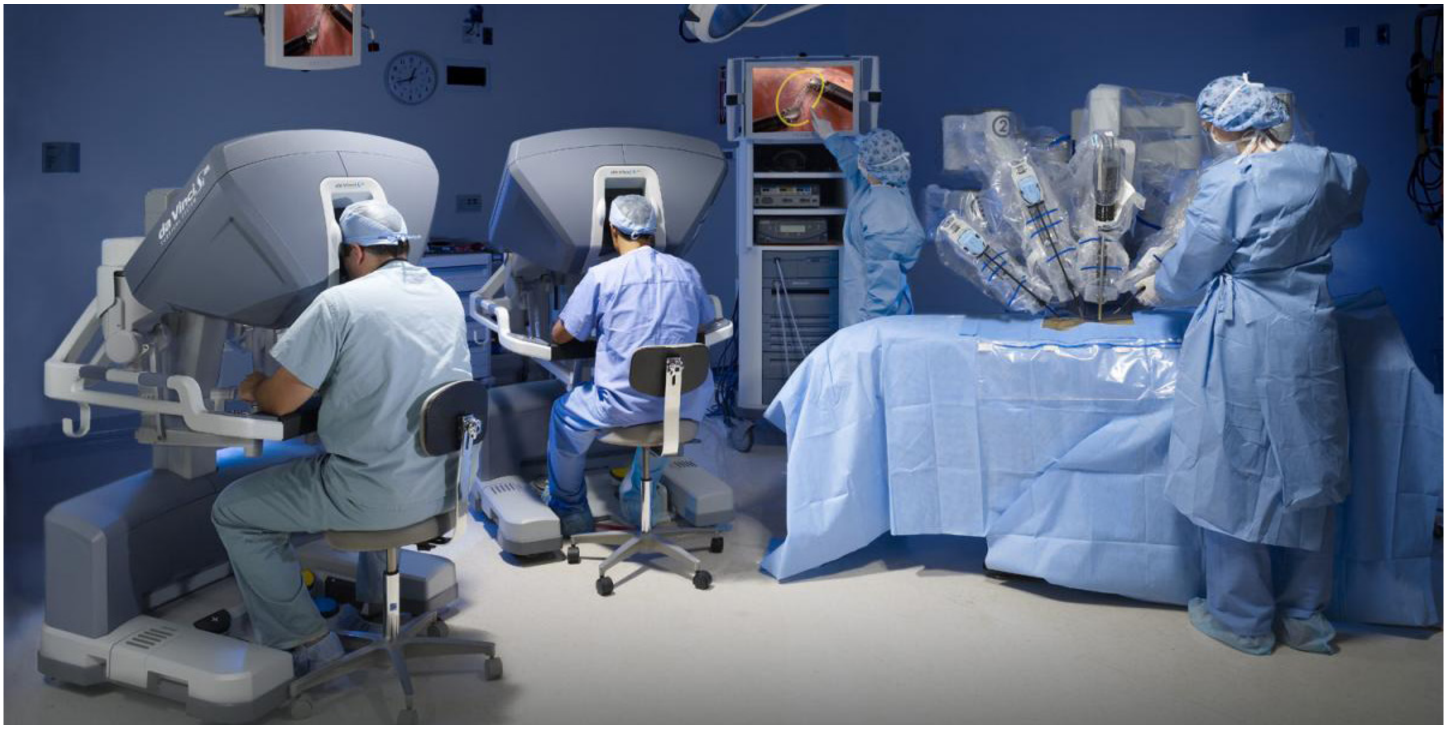

BeWell's Vital Sign Robot Terminal

The Wellpoint System is a robotic point-of-care self-testing kiosk designed to help hospitals in admitting patients. The patient sits at the kiosk and walks the patient through a self-testing protocol. The kiosk can read blood pressure, weight with the embedded seat sensor, pulse oximetry, height measurement, blood analysis, urine analysis, cardiovascular risk analysis, and Accu-Check glucose meter. The vitals are uploaded into the medical record system of the hospital at a rate four times faster than manual input. This gives the medical staff more time to attend the patient's needs.

The Da Vinci Surgical System

The Da Vinci Surgical System has been aiding surgeons since 2000. It has been used in various procedures including cardiac, thoracic, urologic, hysterectomies, prostatectomies, and gynecological surgeries. The console controls the four robotic arms. The surgeon can sit down at the control console and view the surgery from the integrated camera system. The camera provides a 3D high definition view inside the patient's body. The jointed wrist design of each of the robot arms provides greater flexibility and reaches allowing for smaller incisions and movement that is more precise. Between the years of 2007 to 2009, the use of Da Vinci Surgical Systems increased by 75%.

Corindus Vascular Robots

Corindus Vascular Robotics is another robot surgical-assist tool use for cardiac procedures. The CorPath GRX is a robotic system used in percutaneous coronary intervention (PCI) procedures such as coronary stenting and ballooning. Manual PCIs were introduced over 40 years and have had a long line of complications including trial and error navigation, deflation of stents when de-

Surgeon at Core Path Console w/Patient

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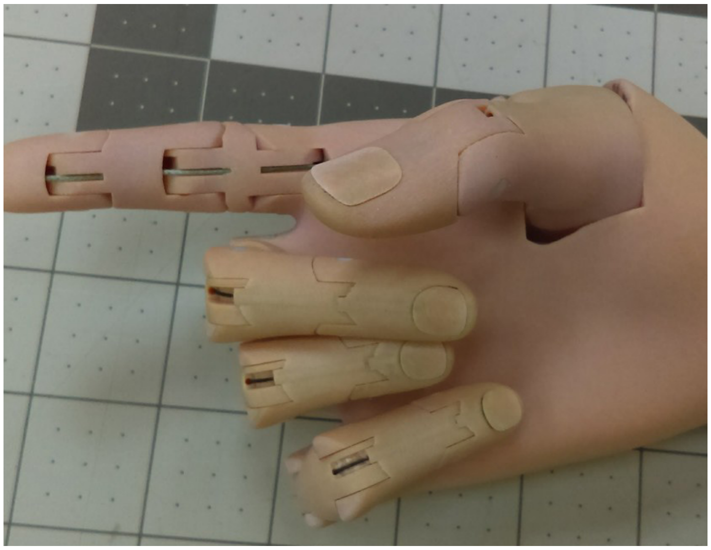

ployed, misalignment of stent position, and eyeball estimation of stent placement. Robot-guided PCI procedures can provide precise point and short placement, precision positioning within 1 mm of accuracy, and stents are held in place when inflated as to not lose position. The main advantage is that it allows the operator to stand outside of the radiation field and may reduce the number of stents used per procedure.

Unlimited Tomorrow Prosthetics

Advanced prosthetics are essential to people recovering from lost limbs and limited mobility. Robotic prosthetics not only replace the lost limbs, giving the patient back their functionality, but also mentally help the patient feel complete. The main problem with these prosthetics is the high cost, which may not be covered by insurance. Here is where Unlimited Tomorrow steps in. Easton LaChappelle founded Unlimited Tomorrow in 2014 when he was 18 years old to help assist people in their everyday lives with realistic 3D-printed robotic arms. LaChappelle has been working with robotics since he was 14 starting with a LEGO-inspired robotic hand, leading to him designing mind-controlled prosthetics and working on NASA's Robonaut. Recently, LaChappelle used low-cost 3D scanners to digitally map a young girl's residual limb and opposite full arm to create a realistic robotic replacement limb. Momo's robotic arm weighs only 1 pound, has individual finger movement, force monitor feedback through haptic sensors, a 3- to 4-day battery life, and is muscle-controlled. The mission of Unlimited Tomorrow "is to empower amputees by an intuitive scalable model to create custom devices from start to finish. We are using the newest technologies such as 3D scans, 3D printing, and machine learning to make the next generation of artificial limbs at the lowest cost possible." The project, www.TheRoboArm.com, is open-source and accessible to all.

Xenex Disinfecting Robots

Hospital-acquired infections (HAIs) are among the biggest threats to current patients. The same number of people die from HAIs as from AIDS, breast cancer, and auto accidents combined. According to the CDC, 1 out of every 25 patients will contract an HAI and 1 out of every 9 patients will die from the contracted HAI. HAIs cost the healthcare industry about $30 billion annually. Xenex's LightStrike Germ Zapping Robot is the only pulsed ultraviolet light disinfection system on the robotic market. High-intensity UV light is produced from the xenon flash lamps, which passes through the cell walls of bacteria, viruses, and bacterial spores. The DNA, RNA, and proteins inside the microorganisms become damaged by absorbing the UV light. Damage is caused in three ways: photo-hydration (pulling water molecules into the DNA that prevents transcription), photo-splitting (breaking the backbone of the DNA), and photo-dimerization (improper fusing of DNA bases). The robot has Wi-Fi and cellular connectivity providing live reporting of data including which rooms are clean and has instant monitoring and diagnostic sensors. The robot operates independently, and will detect people entering the room via its triple motion sensor detector and stop the disinfection process for operator safety.

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Robot Companions

Humanoid robotic assistants will soon offer patients companionship, in home care, and assist with rehabilitation efforts. According to the American Psychological Association, one of the key factors causing depression is loneliness. Depression affects 300 million people globally and one of the newer solutions is to pair patients with robots. University of Southern California Professor Maja Matarić has been pairing robots with patients since 2014 and has seen incredible results. Her robots helped children with autism copy the motions of socially assistive robots and in 2015, the robots assisted stroke recovery victims with upper extremity exercises. The patients were more responsive to the exercises when promoted and motivated by the robot. The trio of robots seen above—from left to right, NAO, Romeo, and Pepper from Softbank Robotics—are prime examples of what is to come from the world of assistive robots. ■

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☞ **BACK TO TABLE OF CONTENTS**

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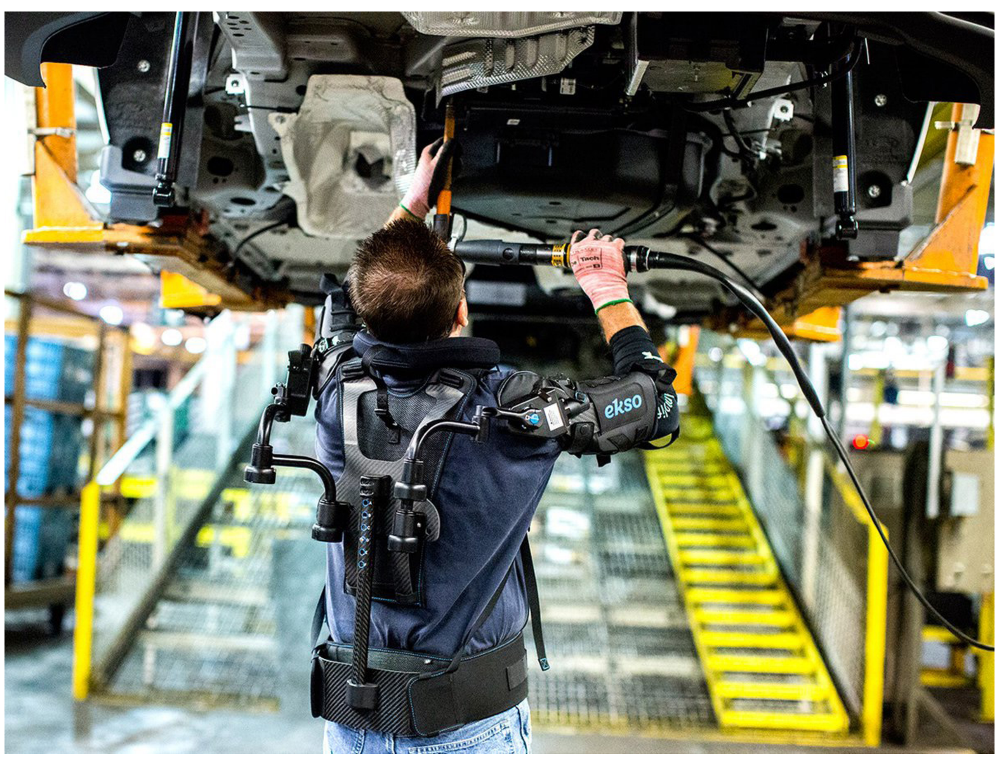
CHAPTER 4:

MANUFACTURING WORKERS BECOME MORE THAN HUMAN WITH EXOSKELETONS

Exoskeletons look to redefine the limits of manufacturing workers by providing extra strength and stability to help eliminate fatigue and injuries.

Exoskeleton research for industrial applications is a one of the fastest growing fields when it comes to wearable technologies. Exoskeletons can be used on construction sites, for factory labor, in warehouses, and even for medical applications.

According to Dr. Joseph Hitt from the Wearable Robotics Association,



Dr. Joseph Hitt from the Wearable Robotics Association believes exoskeletons for manufacturing is the most accessible avenue for the exoskeleton market. For the manufacturing industry, they offer three main advantages: a reduction in work related injuries, lower work fatigue, and the ability to retain experienced personnel.

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The EksoVest is an upper body exoskeleton that elevates and supports a worker's arms to assist them with tasks ranging from chest height to overhead.

exoskeletons for manufacturing are the most accessible and "low-hanging fruit" of the exoskeleton market. For the manufacturing industry, they offer three main advantages: a reduction in work related injuries, saving money in medical expenses and sick leave; lower work fatigue, resulting in increased alertness, productivity, and work quality; and the ability to retain experienced personnel past their physical prime in the workforce.

Exoskeletons fall into six separate categories:

Tool-holding exoskeletons. Exoskeletons consist of a spring-loaded arm, such as the zeroG mechanical arm that supports a heavy tool on one end and is connected to a lower body exoskeleton and a counterweight. The heavy tool weight is transmitted to the ground. These exoskeletons are typically passive, but some prototypes have motors in the lower half of the exoskeleton.

Chairless chairs. These are lightweight exoskeletons worn on top of work clothes, which can stiffen and lock in place. They help to decrease fatigue while crouching or standing in the same position for extended periods.

Back support. Exoskeletons can maintain the correct posture of the back while bending down to perform a lift. They reduce the load on the back muscles while bending down.

Powered gloves. These are mechanized gloves that can help workers gain a stronger grasp on tools, or else operate in reverse to help workers who have trouble opening some fingers on their hands to grasp tools.

Full-body powered suits. These provide both body support and extra strength. In recent years, developers have focused on smaller, more specialized exoskeleton projects that target a particular body part. However, there are still special projects that use a full body suit, like the new humanoid robot controller from Toyota.

Additional/supernumerary robotics. These exoskeletons provide a second pair of hands. They have two or more additional powered arms controlled by the wearer that are used to hold tools or materials in place. These exoskeletons differ from tool-holding exoskeletons in that they are powered, whereas tool-holding exoskeletons are passive.

Regardless of their category, exoskeletons can offer several add benefits to the industrial space. Let us explore two case studies that illustrate how they're being used today.

Exoskeleton at Ford's Manufacturing Plant

The EksoVest is currently being used on the Ford assembly line. The upper-body exoskeletal tool is designed by a partnership between Ford and California-based Ekso Bionics. The wearable technology is an example of a tool-handling exoskeleton. The EksoVest is an upper body exoskeleton that elevates and supports a worker's arms to assist them with tasks ranging from chest height to overhead. It is lightweight and low profile, making it comfortable to wear in all conditions while enabling freedom of motion. Each arm can provide between 5 to 15 lb. of support per arm.

The United Auto Workers and Ford support the product. It is being implemented in two U.S. plants while Ford plans how to expand the tool to other plants in South America and Europe. The project is part of Ford's effort to reduce the physical toll on their workers during manufacturing. On a typical day, assembly line workers can perform up to 4,600 times per day. "Our goal has always been to keep the work environment safe and productive for the hardworking men and women," said Bruce Hettle, Ford Group's VP of Manufacturing and Labor Affairs. "Investing in the latest ergonomics research, assembly improvements, and lift-assist technologies has helped us design efficient and safe assembly lines, while maintaining high vehicle quality for our customers."

The preliminary feedback from Ford employees is high. Paul Collins, an assembly worker at Ford's Michigan Assembly Plant, had nothing but positive marks on his experience with the tool. "My job entails working over my head, so when I get home my back, neck, and shoulders usually hurt," he explained. "Since I started using the vest, I'm not as sore, and I have more energy."

Levitate Airframe to Relieve Arm Fatigue

The Airframe exoskeleton was created by Levitate Technologies, Inc. Like the EksoVest, the Airframe supports the arms of professionals and skilled trade workers who are required to perform

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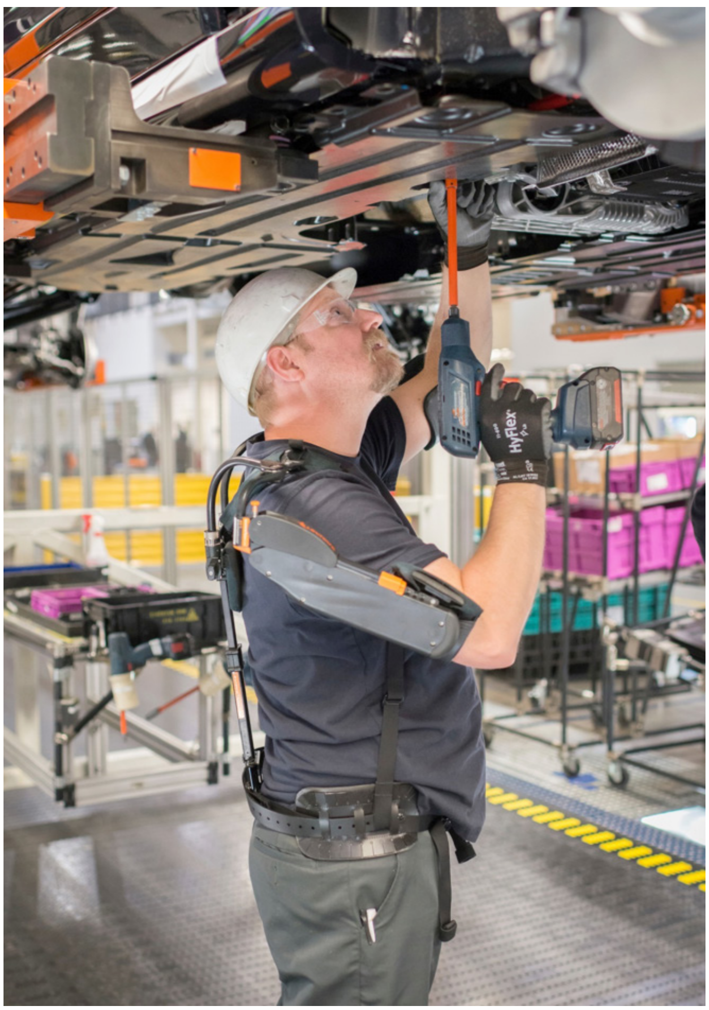
repetitive arm motions and/or stationary arm elevation. Engineer Mark Doyle, who also founded Levitate Technologies in 2013, developed the product. Pathway, a design company, works with Levitate to enhance the Airframe's optimization.

The exoskeleton works by transferring the weight of the arms from the shoulders, neck, and upper back to the core musculature through pads that rest on the outside of the hips. This helps by relieving muscle and joint strain. Since it is transferring body weight, the device helps sustain high-quality performance, protects the user, and improves work conditions.

The Airframe has a backpack-like design so it can be adjusted to almost any body size with the adjustable straps. The Airframe's design is light so as not add any extra weight for the user. It is designed to achieve about one million movement cycles in its working mode. It uses igus cylindrical plain bearings with and without flange and thrust washers.

In order to adapt to different movements of the wearer and not impede the workflow, Levitate needed the exoskeleton to be not just light and durable, but also compact and able to handle high axial loads of up to 220 lb. The use of plastic bearings such as the iglide G300 and T500 M250, along with special polymer Z materials from igus, helped to achieve all the requirements.



The Levitate Airframe exoskeleton works by transferring weight of the arms from the shoulders, neck, and upper back to the core through pads that rest on the outside of the hips.

Making a Difference, from Cars to Agricultural

Large companies in industries ranging from automotive to agricultural are already testing and using the Airframe. BMW was an early adopter of the Airframe. In their factory in Spartanburg, where their SUV X-series vehicles are produced, BMW used 66 Airframe exoskeletons. "During the initial testing and review period at BMW, I observed very positive feedback from the users," said Joseph Zawaideh, vice president of marketing and business development at Levitate Technologies. "They embraced the Airframe quickly and [the workers] even mentioned that they do not want to go back to not using it…they appreciated that the Airframe was very low profile, lightweight, and did not restrict motion." BMW announced that the Airframe has outperformed other systems, providing workers a great deal of relief in their U.S.-based factories.

Other adopters of Airframe are companies in the agricultural industry. Tests were carried out at an international agricultural manufacturer to study the efficiency of painters and welders using the Airframe. The results showed that Airframe counteracted muscle fatigue, and by using the exoskeleton, the number of painted parts increased by more than 50% and the number of welded joints increased by 86%. In addition to the amount of work, the quality of the work was also significantly better. Both painters and welders were able to carry out their work thoroughly and precisely over longer periods of time. ■

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CARLOS GONZALEZ, Technology Editor

CHAPTER 5:

THE SOFTER SIDE OF ROBOTS

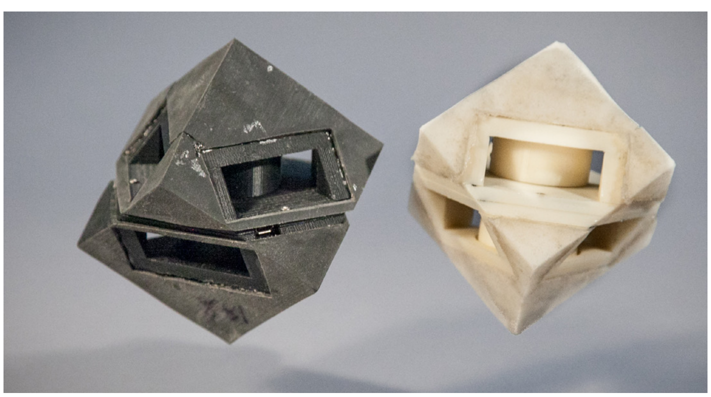
Today's engineers are developing robots with soft skin features, creating new possibilities in the collaborative human-robot workspace.

Robots are usually hard-headed—not just because their programming is a fixed option of subroutines, but also because they are almost always made out of metal and hard plastics. And for durability purposes, these robots need to have a hard exterior. It helps protect them from physical damage, environmental hazards, and helps provide strength for carrying large loads.

Nevertheless, engineers and researchers have increasly focused on developing soft skin robots to expand their use into other applications. Soft skins provide robots with the ability to handle shock loads, exhibit improved sensing, and even self-heal. In short, they create a better collaborative work environment with humans.

Shock-Absorbing Skin

The Massachusetts Institute of Technology has developed robotic skin that can absorb shock impacts, making it more durable. The Computer Science and Artificial Intelligence Laboratory have developed a 3D printed soft material that will allow robots to be more precise with their movements and provide improved durability. The team's programmable viscoelastic material (PVM) technique allows users to program every single part of a 3D printed object to the desired levels of stiffness and elasticity needed for the task.



MIT researchers designed the cube robot on the left with shock-absorbing "skins" that transfer less than half of the energy that would normally be transferred to the ground.

The PVM technique allowed researchers to 3D print a cube robot that moves by bouncing. The cube robot consists of the rigid body, two motors, a microcontroller, a battery, and inertial measurement unit sensors. Inside the robot, four layers of looped metal strip serve as the springs which propel the cube. The shock absorbing skin uses only 1/250 the amount of energy it transfers to ground to move.

This is possible through the use of viscoelastic material. The dampers found in viscoelastic are rubbers and plastics, which both have solid and liquid qualities too them. The viscoelastic material is cheap and compact, but only commercially available in specific sizes and damping levels. That is where the benefit of 3D printing comes in. By being able to tailor the material properties, the MIT research team could "program" the exact mixture of solid, liquid, and flexible rubber-like material called TangoBlack+. The PVMs could ultimately be used in other products such as running shoes, drones, headgear, sensors, and non-drone cameras to provide shock absorption.

Touch-Sensitive Robot

Human skin has the ability sense strain, pressure, and temperature. The research team at the University of Houston aimed to recreate the same capability in their newer robotic rubber skin. Rubber electronics and sensors are capable of normal operation even when they are stretched to 50% beyond their normal length. This would work as artificial skin on robots, providing them with flexible sensing capabilities. The rubber semiconductor starts out in liquid form and is poured into different molds, then scaled up to larger sizes or used as a rubber-based ink for 3D printing purposes.

The electronic skin is made by mixing tiny semiconducting

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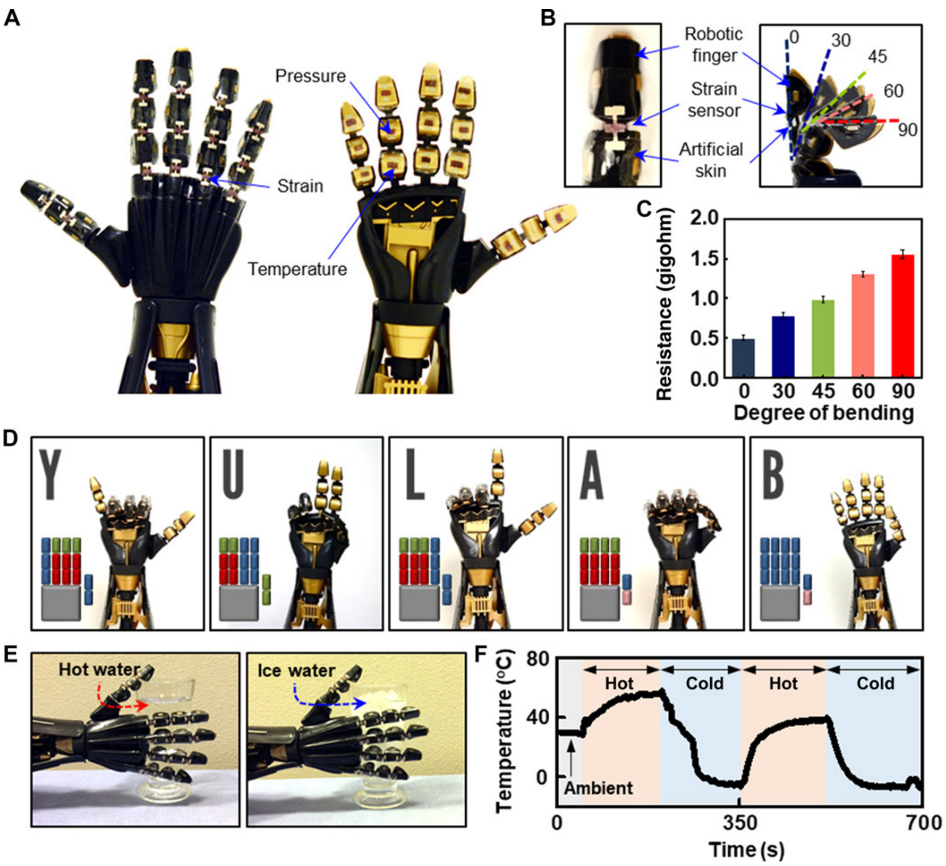


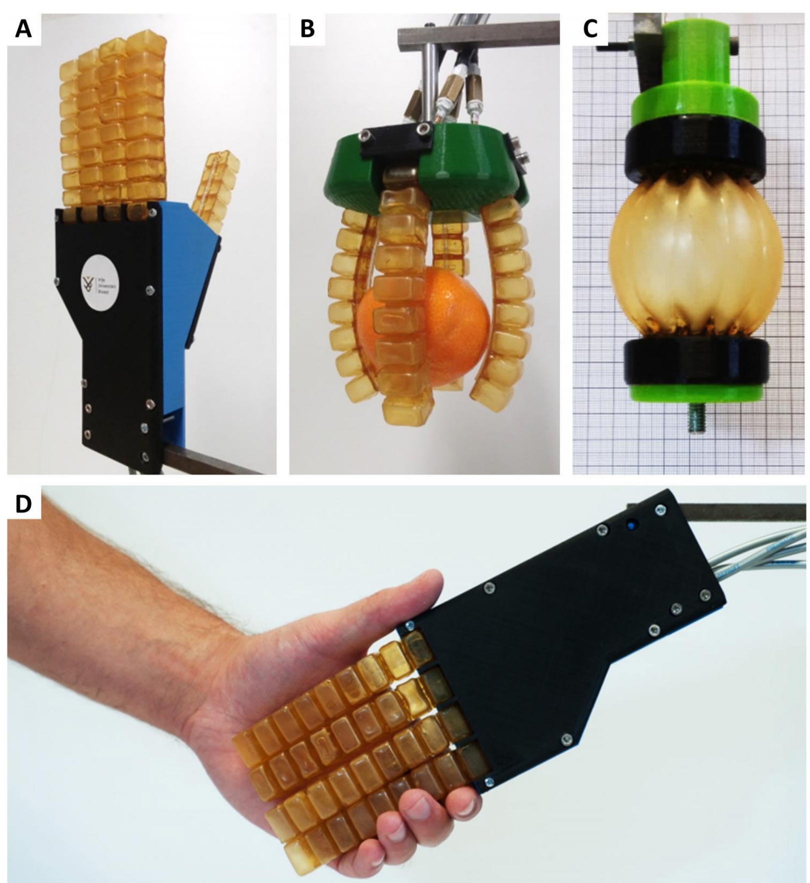
Shown here are several electronics-based robotic skins: A) a robotic hand with intrinsically stretchable rubbery sensors; B) Strain sensors located on the hinges of a robotic finger (left, top view), with an overlapped photograph of the robotic finger with different bending angles from 0 deg. to 90 deg. (right, side view); C) electrical resistance of the strain sensor under different degrees of bending; D) demonstration of using an array of strain sensors on a robotic hand to translate sign language alphabets. The inset schematics of the colored hand are electrical resistance values that correspond to C for the corresponding hand gestures; E) the robotic hand with the temperature sensors touching hot (left) and cold (right) cups; and F) the measured sensor responses while the hand with skin touched the hot and cold cups alternatively.

nanofibrils—nanowires 1,000 times thinner than human hair—into a typical silicon-based organic polymer solution called polydimethylsiloxane. It is afterward dried at 140ºF; the solution becomes a hardened stretchable material embedded with millions of tiny nanowires carrying electric currents. The team applied the strips to the robotic hand, and the electronic skin worked as a sensor that produced different electrical signals.

By using the rubber electronic skin, a robot would be able to sense everything around it and provide a better collaborative work environment. The research team performed experiments whereby the electronic skin accurately sensed temperature of hot and cold water and translated computer signal sent to the robotic hand into finger gestures in the form of the American Sign Language alphabet.

Self-Healing Robots

While robots with softer skin offer a better sensing robot, they also are more vulnerable to cuts and tears when compared to a traditional plastic or metal exterior robot.



This an overview of the self-healing (SH) soft pneumatic actuators. Images A and D show the SH soft pneumatic hand. Image B is the soft pneumatic gripper. Image C is the SH pleated pneumatic artificial muscle.

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The robotic research team at Vrije Universiteit Brussel has developed a rubber skin that can heal itself, mimicking the similar self-healing ability of human skin. The rubber developed is soft enough to provide sensitivity, yet strong enough to maintain its shape without inside support.

The rubber hand designed by the team, if cut, could be placed in an oven at 80ºC for 40 minutes, which induces the self-healing factor. The high temperature causes the wound to close. The polymer is made of a network of cross-links and the a Diels-Alder reaction occurs, creating new bonds across the damaged area. Once cooled, the new bonds firm, healing the material.

The designed soft gripper acts as an artificial muscle and has been tested on picking up various objects, as well as several variation cut tests. The healing factor behaved as expected, with the robot 98 to 99% functional after repairs. The process can be repeated as often as necessary without degrading the rubber. "Soft robots exist in several applications like grippers, crawling robots, [and] soft robot arms for endoscopy," says study co-author Bram Vanderborgh. The material can be applied today to several applications, providing a safer and self-healing robot.■

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☞ **BACK TO TABLE OF CONTENTS**

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CARSTEN HORN, Business Development Engineer
Maxon

CHAPTER 6:

DESIGN GUIDE ON HOW TO MINIATURIZE MEDICAL DEVICES

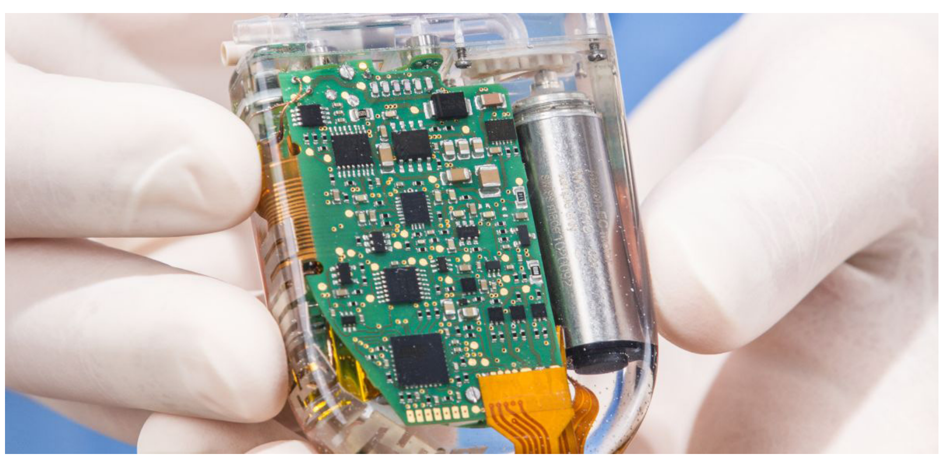
At MDTX, maxon motors presented on how medical device innovators can miniaturize their devices.

There are several benefits from miniaturizing medical devices. For the patients, small and lighter ambulatory devices offer more comfort. For example, patch like pumps offer a low-profile device that can help deliver drugs to the patient. For surgeries, miniaturization means less wounds, lower infection risk, and shorter stays in hospitals. The next generation of surgical robots and surgery tools will be smaller and lightweight. On implantable devices, further miniaturization will lead to less invasive integration such as a miniature heart support pump.

Designing a Micro Ambulatory Drug Pump

The following is an example of how maxon motors helped design a micro ambulator drug pump. This small pump drive based on a disposable double chamber pump. By oscillating a slat along the x axis, two pistons are pumping while switching two valves at the same time. maxon co-developed the drive technology and the mechanical structure of the ambulatory pump. The requirements for the device are minimal footprint and envelope, high torques, low elasticity, precision in positioning, and low noise. The unit is designed to be reusable and must undergo sterilization and cleaning processes.

When you design smaller devices, use the "inside out" concept design. With all developments, the starting point is very important. Understanding the use case precisely and extracting *(see Meghan Thorne, Medrobotis 2017)* the requirements is necessary. Learning is part of the development process—expect changes to the requirements. *In the development of a miniaturized medical device the fol-*



To control fluid that has collected in a patient's abdomen, Sequana Medical has developed an active implant. In these devices, maxon EC motors are responsible for trouble-free running and smooth pump motion. (Copyright Sequana Medical)

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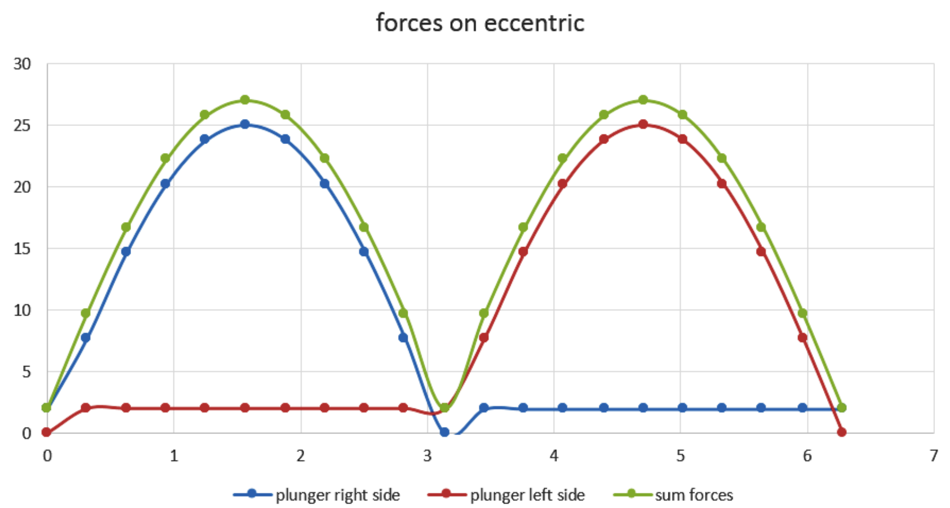
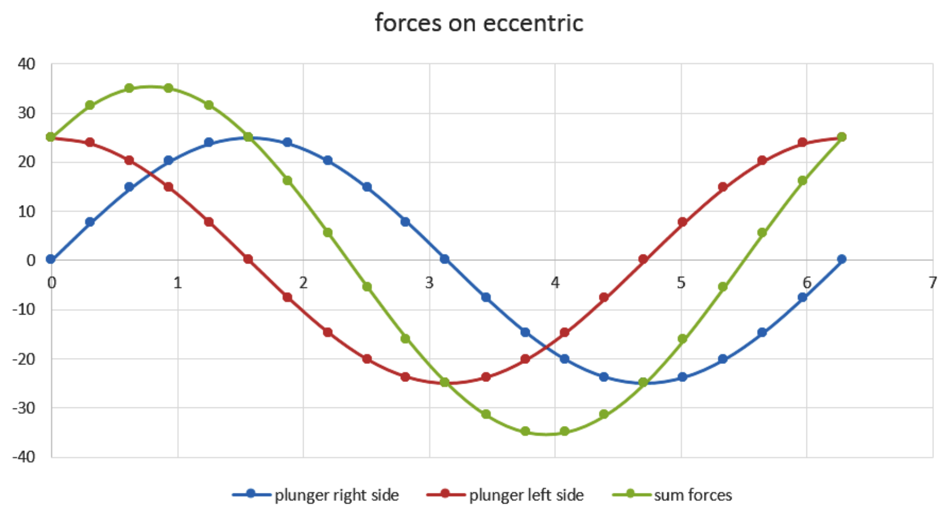




The disposable pump need on the two plungers is a changing force and for retracting a continuous force. The eccentric transfers these continuous rising forces into a sinusoidal torque form.

Generating a mathematical model helps to evaluate, if applicable, the transfer functions from the requirements to the technology you plan to use. Separate functions and solve them independently. Be sure to identify critical parameters and work with safety factors. For the micro ambulatory drug pump, the drive parameter is the pump force. The selected motor technology need to be overloaded. Understanding the duty cycle, show the RMS value of the required power is at 50%.

Step 2: Technologies

If you feel comfortable with your mathematical model, step two in the development process can follow. Assess which technology to use for which function. This step is iterative with your mathematical model. Every new technology you plan to use is a risk factor that needs to be addressed. *Technologies you should take into consideration:*

- Miniature motors with rear earth magnets (high power density)
- Epicyclical gearboxes (high power density)
- Ceramics (sintered and CIM)
- Integration of encoders on outputs (get rid of nonlinearities)
- Micro injection molding (get elasticity where needed)
- Metal injection molding and sintering
- Stamping and forming

lowing step is important:

- Generate a strong mathematical model—this mathematical model represents the outside in.
- The mathematical model represents the outside input parameters and transfer them to your inside design.
- Feasibility of changes on parameters will be much easier.

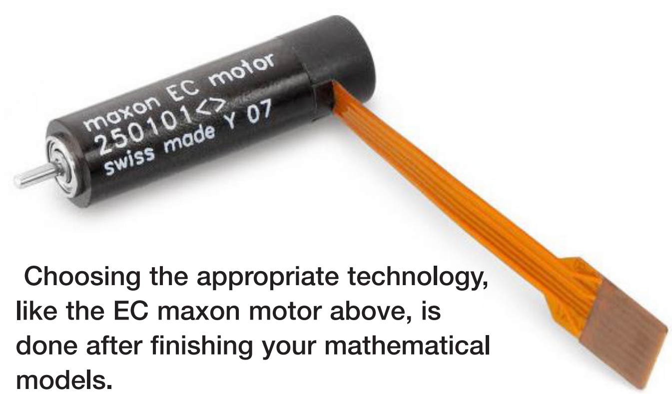
The disposable pump need on the two plungers is a changing force and for retracting a continuous force. The eccentric transfers these continuous rising forces into a sinusoidal torque form. The peek axial force is at about 25 N. An estimation on friction and load from switching of the valves is about 2 N.

Step 1: Mathematical Models

Generating a strong mathematical model help transfer functions from the requirements to the technology used in the device.

Step 3: Design Simulation and Build

Step 3 in the development process is to build up your mechanical model from the inside out. This involves modeling your design with computer-aided design software and using the



Choosing the appropriate technology, like the EC maxon motor above, is done after finishing your mathematical models.

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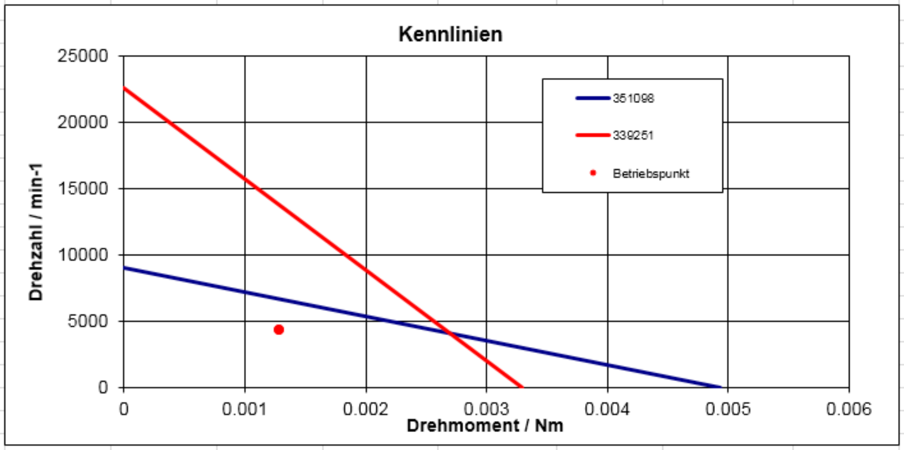
basic calculation		HOC	2/1/2011		maxon motor						
on time	90.00	[%]ED									
						EC20 flat		EC14 flat			
axial pump force	25.00	[N]				351098		339251		Betriebspunkt	
eccentric	4.00	[mm]				M	n	M	n	M	n
oscillating frequency	0.7	[Hz]				0	9072	0	22624	0.00	4340.269231
				Mn	Nm	0.0049	0	0.003295761	0	0.00	4340.27
peak load torque	100.00	[mNm]		R	Ohm	6.67		4.01			
speed	40.00	[1/min.]		U	V	5.6		5.6			
				I	A	0.84		1.40			
				Kt	mNm/A	5.88		2.36			
gear ratio	108.51			Ke	min-1V-1	1620		4040			
number of stages	4			IB	A	0.22		0.55			
efficiency per stage	0.92	[%]		Pelektr	W	1.23		3.05			
gear efficiency	0.72	[%]		Pmech	W	0.58		0.58			
torque at motor	1.29	[mNm]									
speed at motor	4340.269231	[1/min.]									
power at motir	0.58	[W]									
stall torque at output	0.38	[Nm]	EC20 flat								
stall torque at output	0.26	[Nm]	EC14 flat								



Generating a strong mathematical model help transfer functions from the requirements to the technology used in the device.

technology pieces you selected. This step is again iterative with your mathematical model. If necessary, use FEM tools to check for major parameters and optimization. It is also advisable to build up your risk analysis in parallel.

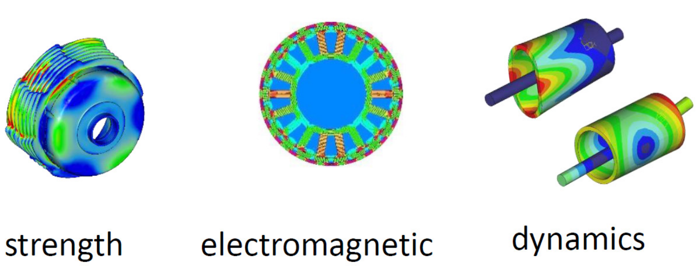
Note that tolerances do not decrease in the same ratio as the parts do. Use elasticity instead of tight tolerances and assembly processes that are tolerant to relatively large tolerances. Existing assembly technologies used should have verified capabilities and separate functions wherever possible. This can generate more parts, but gives you the opportunity to solve problems. independently and make the risk manageable. Be sure to use production technologies that fit to the parts size. *The following is an example of a milling operation for the appropriate size of the medical device.*

--Turn a 1mm shaft on a lathe

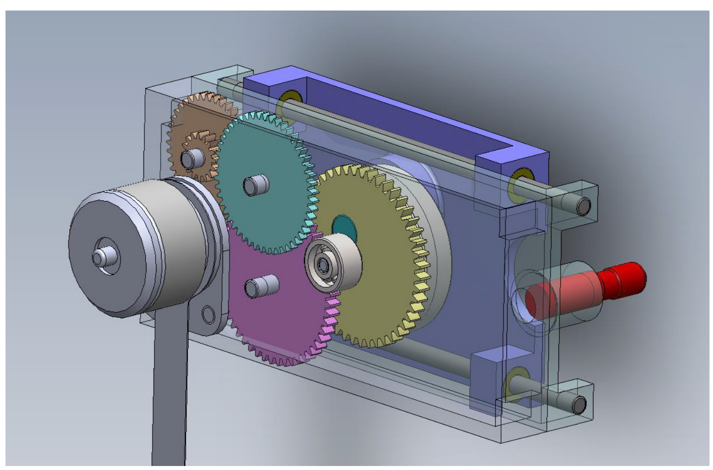
--High grade of steel with low cutting depth

--Cutting speed vk90m/min (these is normally to slow)

--The math:



The use of FEM tools checks for major parameters and optimization possibilities.



CAD models are implemented to design virtual models of the device once the technology products have been chosen.

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$$D = 1mm \rightarrow r = 12\ mm$$

$$U = 2 * \pi * r = 2 * 12 * \pi = \pi$$

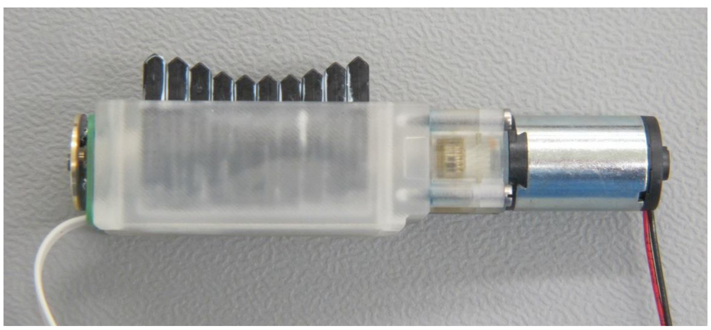
$$nL = vk\ U = 90{,}000\ mm\ 3.14\ mm\ min \approx 30{,}000\ rpm$$

Step 4: Prototypes

Step 4 in the development is to build prototypes as early as possible. Use your risk analysis, the critical requirements, and critical parameters from your math models to generate a verification plan for a proper build. Prototypes should be verified to all critical parameters. Once completed, share the porotypes and results with your customer and let them try the usability. Collect all results for a review and the next loop of optimization.

Step 5: Verification

The final step is to verify the parameters, the mathematical model, the functionality, the usability, and all processes with risks as early as possible. Check and document all assembly problems; adaptations you needed to make; and deviations from the planned geometry, function, or usability. Collect and review all data to be used as input for next iteration.



Prototypes are the final step in the process and should be verified to all critical parameters.

Miniaturization and Costs

To ensure the medical device is cost effective, build up a cost target bill of materials (BOM) for every component and a cost target route for every process. *Here are some hints to keep costs low.*

- Tolerances are expensive
- Smaller doesn't mean cheaper
- Exotic processes are more cost driving than good known standardized processes
- Processes for volume applications are often much more cost effective

Use processes for precision products that are miniaturized already. These include the clock industry, connectors, electromechanical relays, SMD technology, and optics.

Build up concomitant calculation and integrate the view for total costs of ownership. The deviation from target costs and reached costs gives you the scope of actions you still need to take. Reaching cost targets sometimes means increasing the risk. To avoid any potentially hazardous situations, be sure to always use the risk analysis in parallel. ■

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☞ BACK TO TABLE OF CONTENTS

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