MECHANICAL
ENGINEERING
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DYNAMIC SYSTEMS & CONTROL
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SPECIAL REPORT

SOLAR SURGE

In the late afternoon, utilities must add power—and fast.

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KEEPING UP WITH STARTUPS
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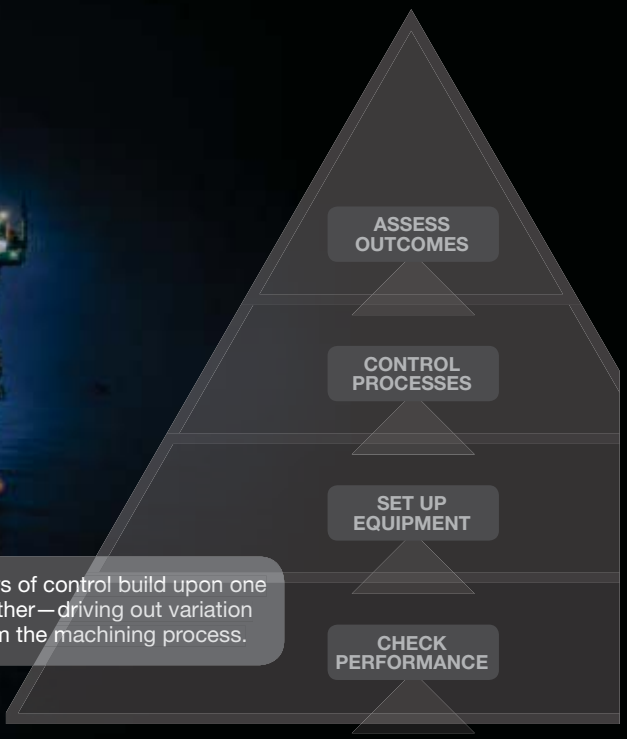

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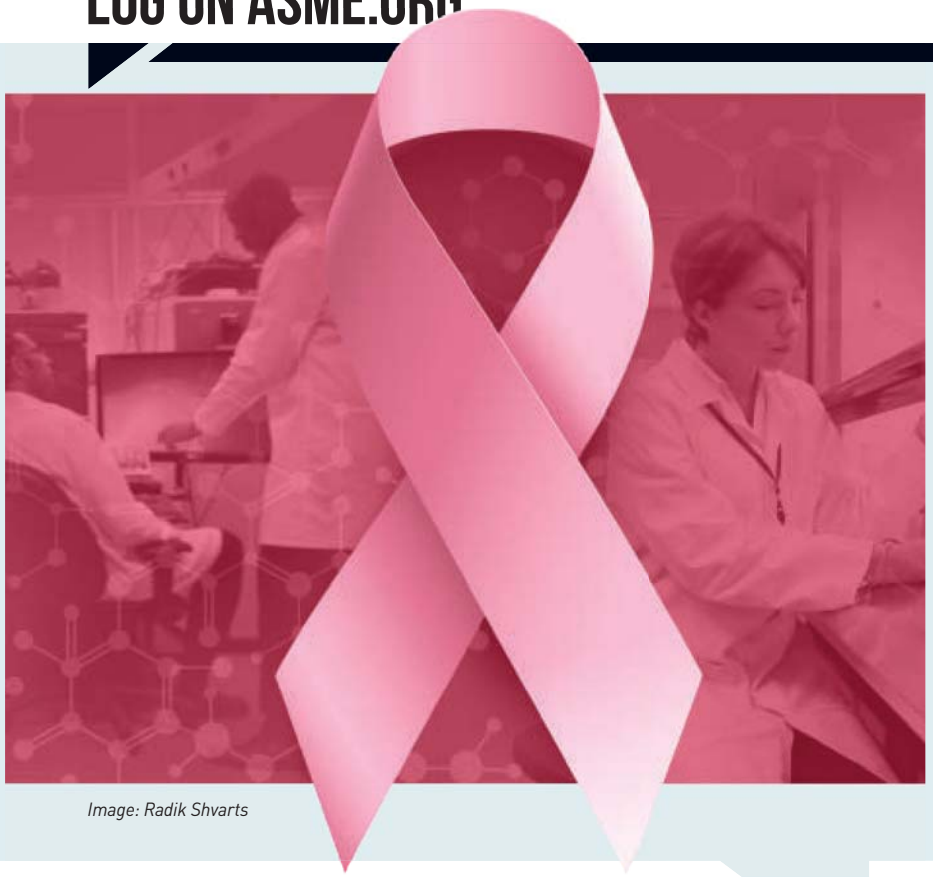

Image: Radik Shvarts

MECHANICAL ENGINEERS FIGHT BREAST CANCER

TWO DECADES OF RESEARCH SHOW CANCER EXHIBITS MECHANICAL PROPERTIES. Ovijit Chaudhuri, a Stanford University assistant professor of mechanical engineering, and his team are looking at the way breast cancer's mechanical properties interact. By understanding those interactions, the researchers could one day develop treatments for women most at risk of cancer's spread while allowing women with less invasive cancer to forgo some forms of treatment.

INTERVIEWING BASICS FOR ENGINEERS

Hiring managers and industry experts give advice on how young engineers seeking a new job can successfully tackle the interview process. Among other items, they note nontechnical managerial skills are becoming more important.

For these articles and other content, visit asme.org.

AN ENGINEER'S GUIDE TO GETTING PUBLISHED

FOR GENERATIONS, THE MANTRA IN ACADEMIA has been "publish or perish." It is no different for engineers in fields like mechanical and biomedical engineering, where academic work is common and new developments happen frequently. As a result, the concept of academic and business-to-business publishing, while foreign to many outside of the institutions, has emerged as a critical part of the modern engineer's toolkit.

Image: Radik Shvarts

CREATING ENERGY WITH EVERY STEP YOU TAKE

LAURENCE KEMBALL-COOK HAS BEEN LOOKING for ways to generate power and energy in open spaces away from the grid for a long time. The solution he came up with revolved around the very steps we take. He developed a pavement tile that converts the force of a person's footstep into rotational energy and stores it within a flywheel. Set within the tile, the flywheel rotates and interacts with magnets and copper coils to generate power.

NEXT MONTH ON ASME.ORG

LEARNING ENGINEERING SKILLS VIA PLAY
Kids sign up for the fun of classes teaching how to build various projects with Legos, but they come away with much more. Legos can be used to draw in students in a way that few other teaching tools can and also help engage them in STEM learning.

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A designer turns basic mechanical concepts into a safer chopping tool.

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—Archimedes

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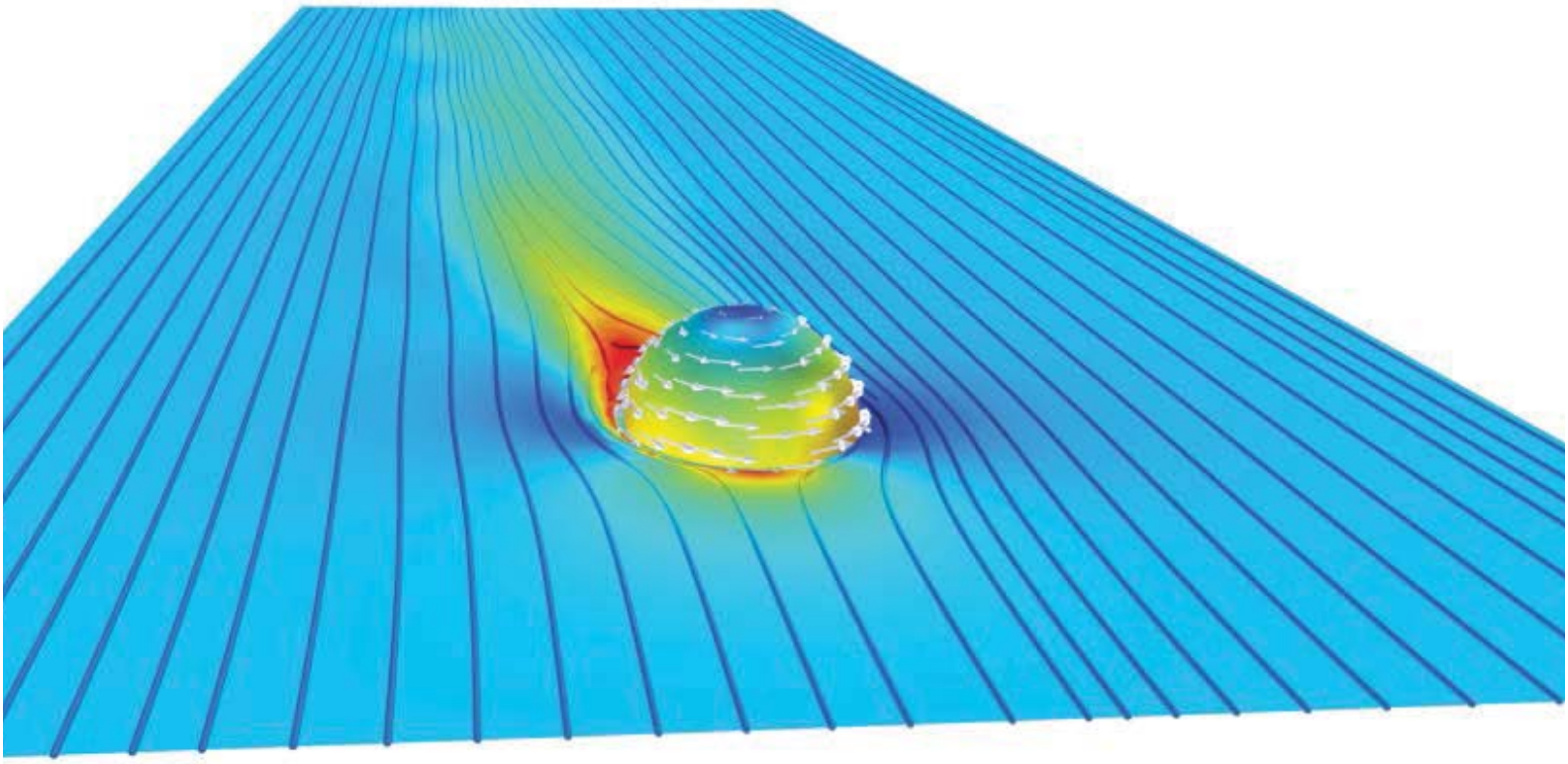
Bend it like...Magnus?



Visualization of the velocity field around a rotating forward-moving soccer ball.

He kicks the ball, sending it into a straight line. There's no way it will go into the net — the ball is headed for the stands. The goalie relaxes, a ball boy ducks. Then suddenly, the soccer ball bends inward and flies directly into the goal. How is this possible? Turbulence and the Magnus effect. To learn more about the physics at play, you can use CFD simulation.

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John G. Falcioni
Editor-in-Chief

FIRST IS STILL NUMBER ONE AMONG STUDENTS

Victoria is a senior high school student from southern Michigan who plans to attend a two-year biblical college in the fall. Afterwards, she is looking forward to raising a family, she said. Christine is a sophomore from northern Virginia. She is not yet sure what college she will enroll in, but is certain that her future is in technology.

Victoria is friendly but reserved. Christine is outgoing and talkative. On paper, they do not have a lot in common. Yet the indefatigable passion they share for FIRST brought them together as friends.

Victoria and Christine were ambassadors at the FIRST Championship event held in Detroit, Mich., during April, where they spent almost two hours giving me a personal tour. As we walked past showcases, the competition floor, and pit areas, they enthusiastically described the nuances of the various competitions, where more than 20,000 came to test their robots or cheer for their teams.

FIRST (For Inspiration and Recognition of Science and Technology), is an organization founded in 1989 by Dean Kamen to promote science, technology, engineering and math (STEM) education.

Since then it has grown into a movement of impressive scope and influence. In the 2017-2018 season, 533,000 students on 61,000 teams participated from 86 countries. It drew 250,000 volunteers, including mentors, coaches, and judges. And it awarded more than $70 million in scholarships from 200 donors.

FIRST calls its program, "The hardest fun you'll ever have." Student participants have six weeks to turn a kit of supplies into an industrial-size robot that performs a specific challenge, like balancing on a beam or flinging discs into a goal. The competition celebrates its participants while raising the profile of engineering as a profession and a powerful way of thinking.

ASME has supported FIRST since the competitions began. Hundreds of ASME members throughout the world serve as volunteer mentors and judges, and even sit on FIRST's board.

Behind it all is Kamen, an ASME member and recipient of the ASME Medal and the Hoover Medal, which ASME administers. Kamen is best known as the inventor and entrepreneur who commercialized the first drug infusion pump, the Segway self-balancing human transporter, and the iBOT mobility system. With FIRST, he describes himself as a "shameless beggar" of support. It's working.

I had not attended the FIRST finals since the program's early years. It was impressive then, but the energy and excitement on the floor now are overwhelming. (I encourage you to learn more at www.firstinspires.org.)

Yet, while the competitions take center stage, FIRST's real focus remains on bringing students together through team building and community. By engaging K–12 students in exciting, mentor-guided programs, FIRST nurtures STEM skills, inspires innovation, and fosters the social skills needed for a well-rounded life.

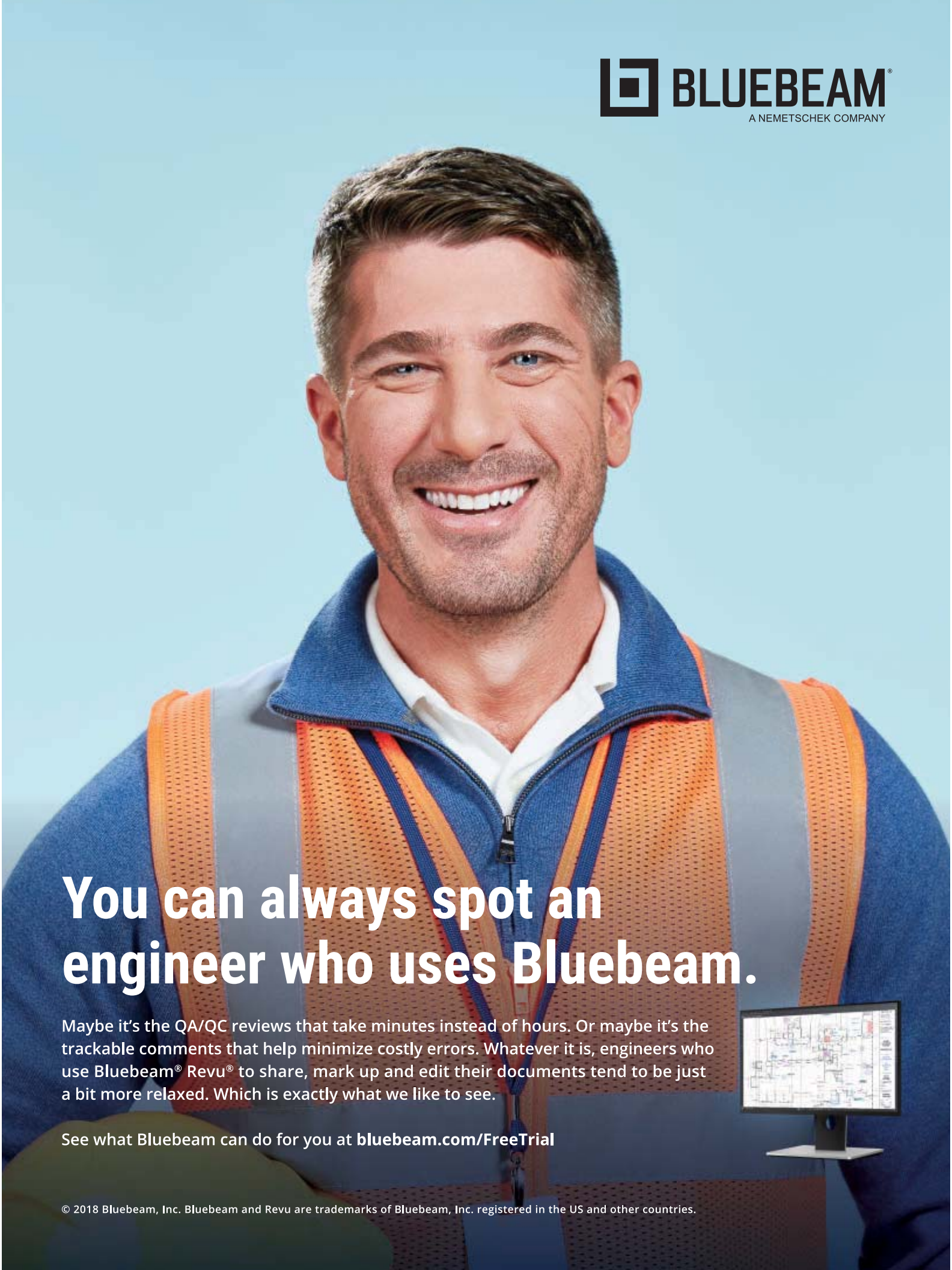
It also builds relationships between people who might not otherwise meet, like Victoria and Christine, or like the teams in the pit who help their competitors repair their robots. These friendships, forged through a common interest in technology, make FIRST an important movement that's worthy of praise.

All those relationships may not last forever, but what will last a lifetime is the experience we all share being part of the energizing FIRST community. ME

FEEDBACK

If you're involved in FIRST, tell me about your experience. Email me

falcionij@asme.org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LETTERS & COMMENTS

FEBRUARY 2018

Reader Jensen is intrigued by the prospect of electric-powered trucking.

« One reader was won over by the case for shale gas. Another would like more information on electric trucks. And we get evidence of our reach to young readers.

POINT CHARGE

To the Editor: I'd like to make two additional points in regard to reader replies in the March 2018 issue to the November 2017 feature, "Rekindling the Spark."

First, hydrogen can be produced by electrolyzing water using solar power. Second, as for the lithium challenge, graphene batteries using carbon are on the horizon.

Paul F. Penko, *Berea, Ohio*

CROSSED ROADS

To the Editor: I was interested in reading about the electrification of the trucking industry in the January 2018 Trending column. As a lean sigma practitioner, I am always excited about the adoption of new technology that enables efficiency goals—in this case, overall fuel efficiency.

However, in the February 2018 issue, I read about a proposal to reinvest in the national rail system ("A New Age of Rail" by Michael E. Webber). This article also discusses an alternative to conventional, diesel-fueled long-haul trucking but offers a resuscitated rail system an alternative solution.

Both of these articles present ideas on how to reduce trucking on the nation's highways and take an economic and fuel-efficiency approach to their arguments.

It is unlikely that they have accounted for each other considering they arrive in back-to-back magazine issues.

The interfering effects of revitalizing national railways and replacing long-haul trucking with electric vehicles would be difficult to predict at best. However, I would be intrigued to see someone take a stab at it. After all, predicting the interaction of a complex system goes to the very soul of what we do as engineers, and coming up with a multi-faceted solution to our nation's transportation infrastructure problems may help overcome the inertia that is currently paralyzing most efforts to resolve this pressing issue.

Jared Jensen, Life Member, *Houston*

To the Editor: We wanted to share this photo of our six-month-old enjoying "story time" with daddy, Danny Cheng, who recently made a career change into mechanical engineering. Baby Caleb is an M.E. in the making!

Thank you for your wonderful publication.

Jenny Cheng, *Fremont, Calif.*

MAKE THE CASE

To the Editor: Michael E. Webber's column in the April 2018 issue ("Renaissance and Revolution") was very informative. The article clearly pointed out the factors that pushed shale gas forward in the energy market, while also describing shale's collateral benefits as an energy source.

In light of the seemingly effective argument for shale, why is there an appeal for nuclear energy in the final paragraph? By the time I got to the end of the article, I wondered, "Who needs nuclear energy?"

I would love to hear the answer to that last question, but if I don't, it was still a great article.

Stewart McLaughlin, P.E., *Portland, Ore.*

THANKS

To the Editor: The April 2018 issue was an excellent magazine. Thank you!

Dudley Jones, Life Member, *Princeton, N.J.*

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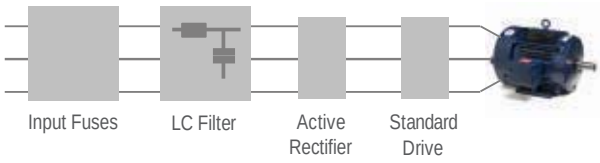

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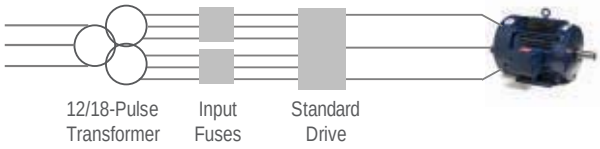

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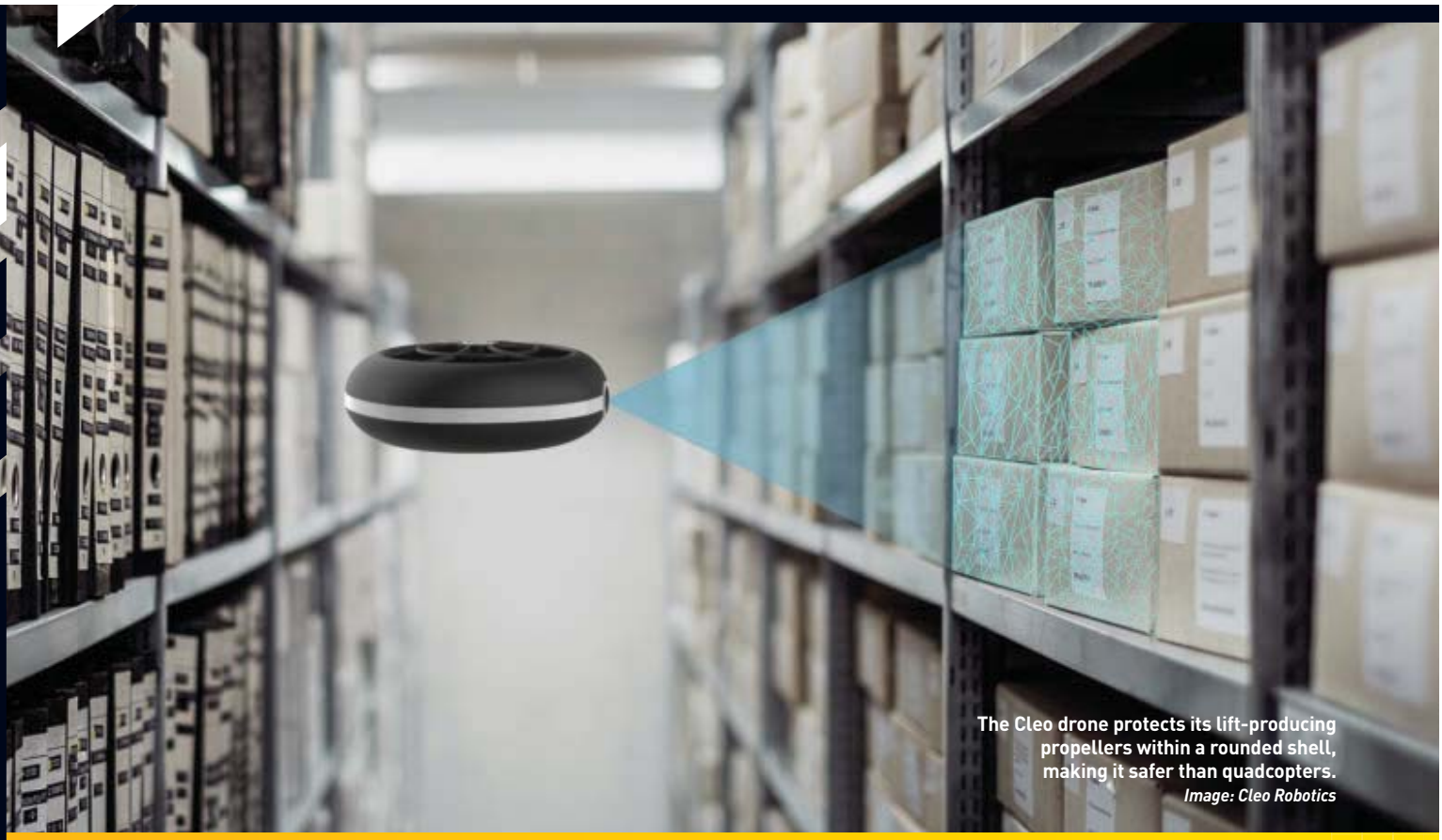

The Cleo drone protects its lift-producing propellers within a rounded shell, making it safer than quadcopters.
Image: Cleo Robotics

DRONUT FILES

CLEO IS BUILDING A HANDHELD DRONE THAT CAN FLY INDOORS.

From a young age, Omar Eleryan was fascinated by flight. But Eleryan sees weaknesses in current drone designs—propellers protruding out of quadcopters or tricopters for instance could be a source of anxiety and frustration.

"What if I lose control of the drone and hit a dog," Eleryan said. "It could cause some serious injury to someone."

He's now the CEO of Cleo Robotics. His rethought drone design, Cleo, is a fat disk small enough to fit in the palm of a hand and fly indoors. Hidden inside Cleo are two propellers—one moving clockwise, the other counterclockwise—reducing the threat of injury and making it safer than quadcopters.

The original idea was to develop something like a flying saucer, but many have called it the "dronut" for its resemblance to an oversized doughnut, Eleryan said. The drone's size is scalable and could be larger with bigger internal propellers. It's as agile as a quadcopter in navigation.

Another goal behind Cleo was to make a human-friendly drone that can also roam at street level. That idea has been pursued with algorithms like the University of Zurich's DroNet that would navigate a drone away from humans, but Eleryan says it's important to keep the propellers hidden to make home and street-level drones a reality.

"Quadcopters are not meant for indoor applications. That's where we come in and fill the gap," Eleryan said. Also, one bump in the wall could cause quadcopters to break, and that would be a big investment lost.

Cleo, which is controlled via a smartphone app, could have many uses in residences, industries, warehouses, law enforcement, or with first responders. One potential use is security—the drone could be connected to smart home security systems and fly to check out a spot in a home or warehouse if a sensor is triggered. Cleo can broadcast live images to a security company from blind spots that security cameras could miss, Eleryan said.

The drone's development started with mashups of off-the-shelf parts from hacked quadcopters and tricopters, but the challenge of making a handheld drone soon became evident. The propellers in the initial designs were either too big, or too small and inefficient to lift anything. After months of prototyping,

The drone feels less like a robot and more like a doughnut.
Image: Cleo Robotics

the Cleo designers hit the right size with custom 3-D printed propellers, which allowed the drone to lift more. Finding the right parts, 3-D printers, and materials were a big challenge, Eleryan said. The 3-D printed material used for prototyping was the MJP VisiJet Crystal, a translucent plastic used in prototyping of tooling and medical-grade equipment.

The electronics in Cleo are still being finalized, but it'll need a beefy processor. In addition to high-definition computer vision, the makers want Cleo to handle artificial intelligence tasks like image recognition and pack enough processing power to make smarter navigation decisions. Algorithms for computer vision and other tasks will be loaded based on a specific application. Cleo has multiple cameras, LIDAR, GPS, and Wi-Fi. It has a battery life of 12 to 15 minutes under normal flying conditions.

The final Cleo models will be manufactured, and materials of Cleo could vary depending on the application—sturdy materials could be used in more rugged applications. The plan to go to business and government organizations first may be a financially smart decision, given consumer drone companies are struggling. For instance, GoPro shut down its drone operations in January. **ME**

AGAM SHAH

A SILVER LINING

Researchers find a reliable way to print silver nanowires on flexible circuit boards.

Silver is an amazingly versatile metal, and well-suited for electronic devices. It is highly flexible and conductive. Had silver not been so valuable, it could've been used instead of copper on circuit boards.

Silver nanoparticles—which are popular in research—are being used on flexible circuit boards. However, researchers at North Carolina State University in Raleigh believe silver nanowires are more durable and reliable than silver nanoparticles.

The researchers have introduced a breakthrough technique to 3-D print silver nanowires on flexible substrates, which was so far considered a challenge. That would lead to more durable flexible printed circuit boards in which wiring doesn't break down easily, which is key to building reliable electronics.

"Silver nanowires have high aspect ratio, with typical lengths over 20 micrometer. Compared to silver nanoparticles, silver nanowires are more conductive especially under bending or stretching, so they are emerging as a promising material for flexible and stretchable electronics," said Yong Zhu, professor at NCSU's department of mechanical and aerospace engineering.

Most 3-D printing projects have focused on silver nanoparticles, which are easier to implement than silver nanowires. Microsoft has shown a technique to print silver nanoparticles from conventional inkjet printers to make flexible circuit boards, including one made on paper. Flexible circuit boards are also playing a key role in miniaturization of devices.

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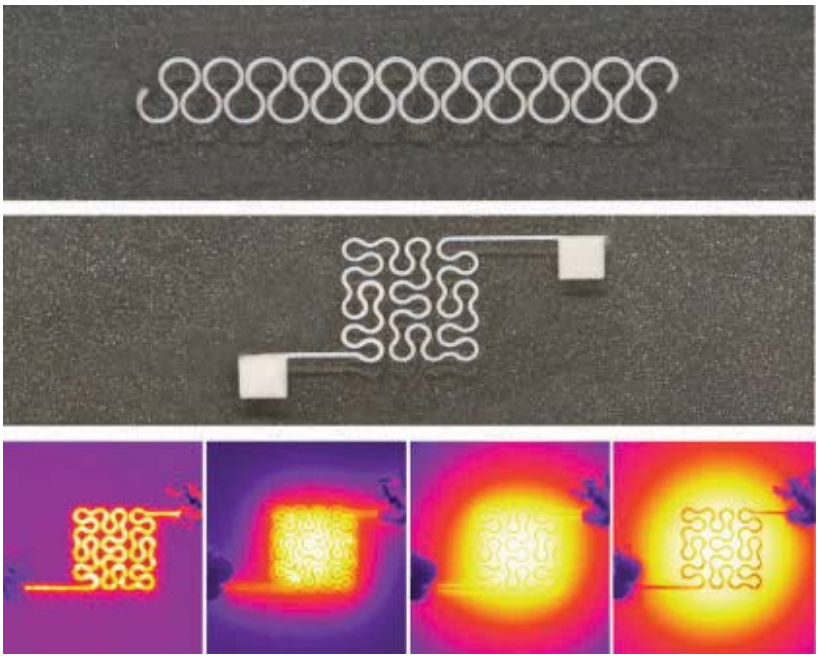
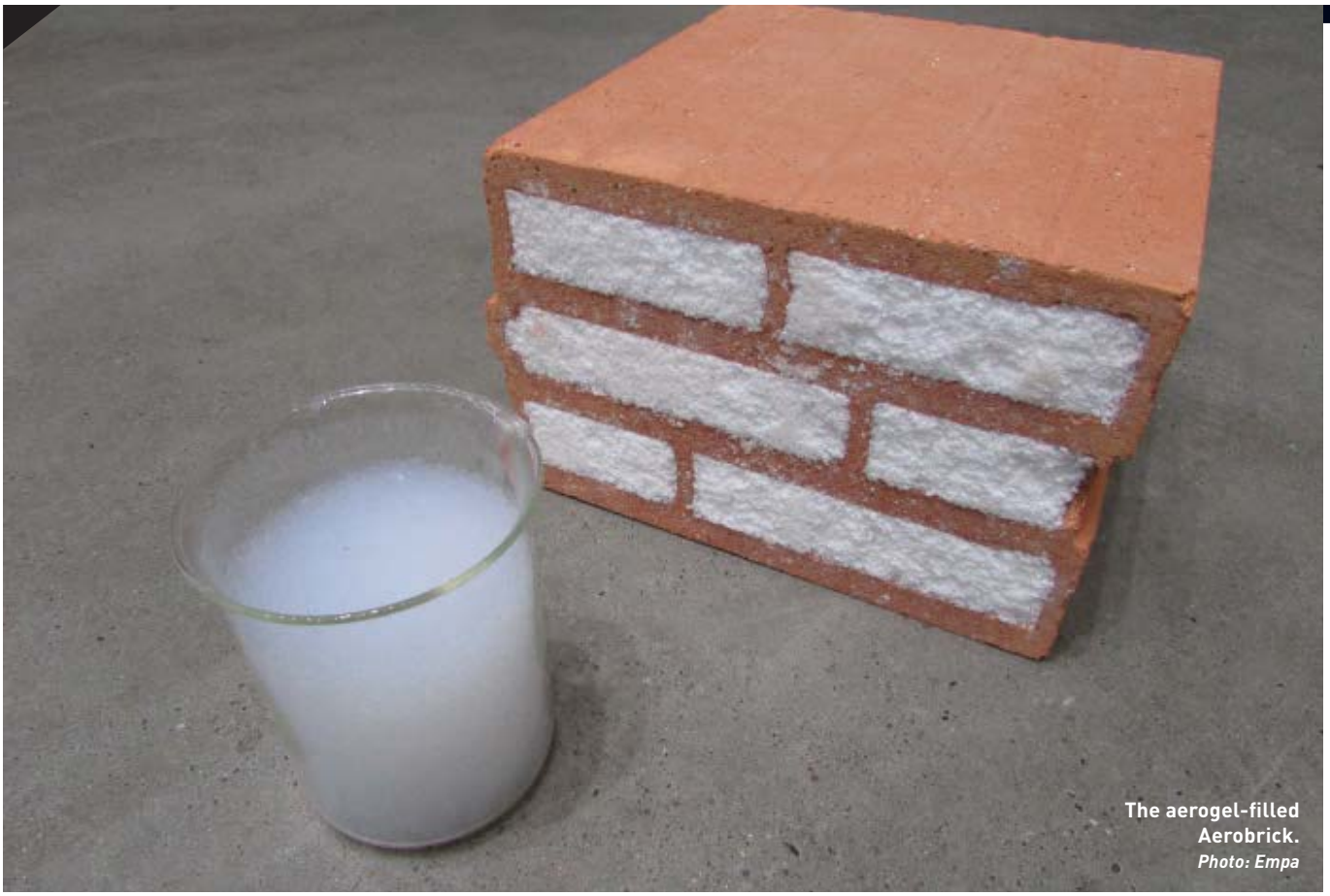


Silver nanowires could be the next hot thing in printed electronics.
Image: NCSU



The aerogel-filled Aerobrick.
Photo: Empa

A NEW BRICK COULD ELIMINATE INSULATION

Most homeowners looking to lower heating or cooling costs know the drill. First thing to do is ensure the house is properly insulated, typically by rolling down a layer of the pink fiberglass stuff or having a fluffy version blown into their home's walls.

But here's a relatively new idea: Instead of adding insulation, build the structure from bricks already stuffed with a material known for its thermal conductivity. The bricks do away with extra layers of insulation and decrease the thickness of a wall.

Scientists at Swiss research group Empa claim they've created the best-insulating brick of the bunch. It uses a different insulating material than the rest: aerogel, says Jannis Wernery, who led the project. He's a scientist in Empa's Building Energy Materials and Components department, part of The Swiss Federal Laboratories for Materials Science and Technology.

A wall constructed from the aerobricks conducts heat up to eight times better than one made from standard clay and shale bricks, Wernery's group has shown.

The bricks offer strong insulating and building benefits. For example, a regular brick wall would need to have a depth of more than 6 feet to provide the same insulating properties as an 8-inch deep aerobrick wall. A wall made from perlite bricks would need to be about 35 percent thicker than an aerobrick wall to have the same insulating properties, Wernery says.

Aerogel is a lightweight, manufactured material made from a gel in which gas replaces the gel's otherwise liquid component. The tiny bubbles minimize the movement of the air molecules through the material, making it an ideal thermal insulation material, Wernery says.

Like similar bricks on the market, aerobricks are made from hollowed standard clay stuffed with aerogel. "The aerogel can easily be filled into the cavities and then it joins with the clay of the bricks," Wernery said. "The aerogel stays in the bricks and you can work with them as usual."

Because aerogel is expensive, Empa researcher Matthias Koebel and his team have developed a new production method they hope will bring down the costs of aerobrick production.

The aerobricks have a measured thermal conductivity of 59 watts-per-meter Kelvin. In addition to its thermal properties, aerogels absorb almost no

continued on p.25 »

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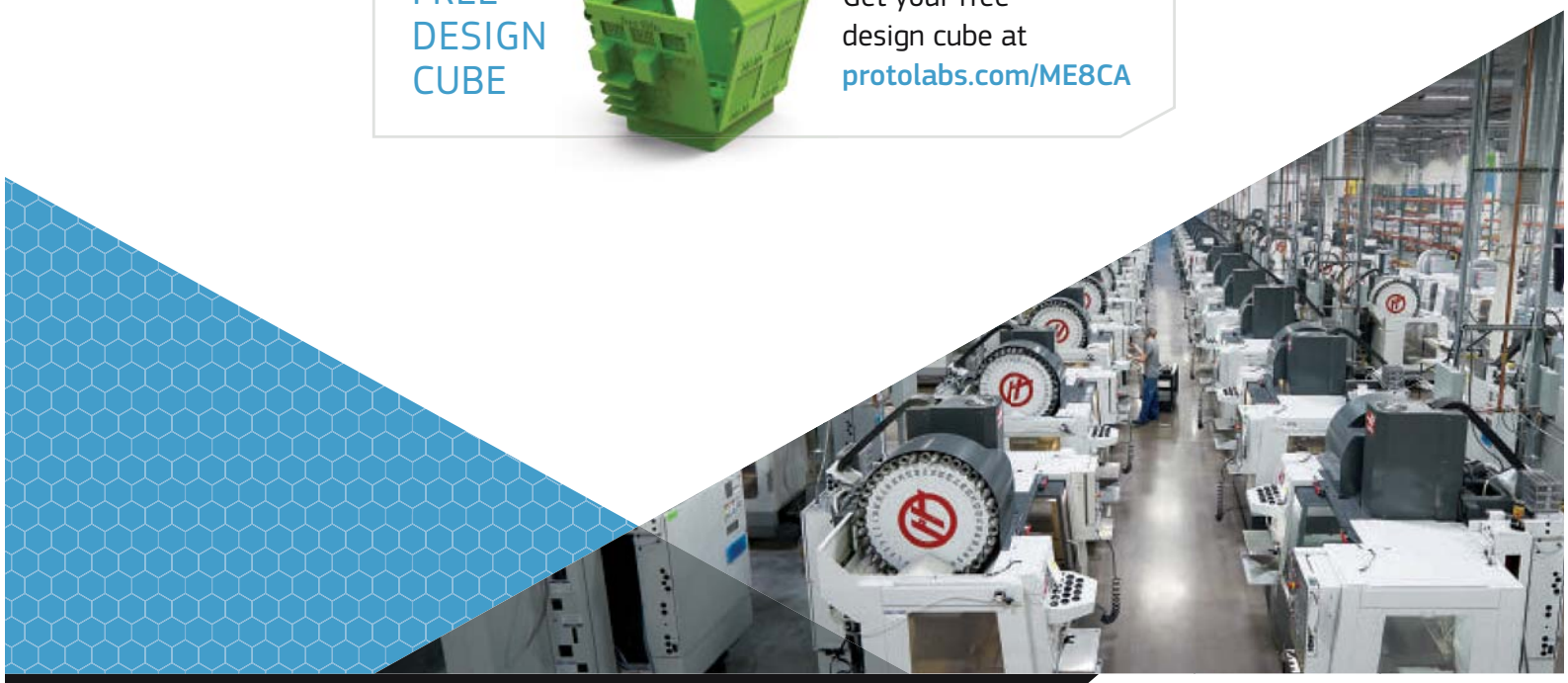

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CLEAN WATER AND NUTRITION TECHNOLOGY IN CENTRAL AMERICA

Guatemala is a Central American country with great opportunities to innovate. Despite natural resources such as rivers, lakes, and mountains, a great portion of the population lack access to sufficient water. The sources are not reliable and in most cases the water is not clean. An aggravating factor is the contamination.

Another challenge in Guatemala is nutrition. According to UNICEF, 43.4 percent of children are chronically malnourished. Chronic malnutrition strikes indigenous children hardest. These children commonly live in rural areas and account for as many 80 percent of those who suffer malnutrition.

Guatemalans have developed some technologies to address the issues of clean water access and malnutrition. These are made-in-Guatemala solutions to problems that are found all around the world, but that are acute in this lush Central American country.

Founded in 2012, Bici-Tec is a social business focused on the design and implementation of *bici-tecnología* (bike-related tech) to solve common-day problems. *Bici-tecnología* is human-powered technology that can save effort. It is used mainly in rural areas. Some of the designs include pedal-powered water pumps, corn shellers, and coffee pulpers.

Bici-máquinas (bike machines) are made to order. The most popular ones are the water pump and the corn sheller. The main advantages of *bici-máquinas* are that they work without electric power, they have a long lifetime of six or more years, and they are easy to use.

Ecofiltro is a ceramic "pot" water filter, intended mainly for homes and schools. The filter is made of clay, sawdust, and colloidal silver. Ecofiltro uses an innovative social business model where they offer different presentations of the filter from plastic to ceramic.

In the 1950's INCAP (Instituto de Nutrición de Centro América y Panamá) developed a nutritional supplement called Incaparina to address malnutrition in Guatemala. Incaparina contains corn flour and soy flour fortified with vitamin A, calcium, and riboflavin, among other vitamins and minerals. It can be found in powdered form to be prepared at home or as a liquid ready-to-drink beverage.

In 1959 INCAP presented the product and sold the license for mass production to Corporación Castillo Hermanos. A longitudinal study was conducted from 1969 to 1991 proving that children who consumed Incaparina since conception throughout their third year were taller and heavier.

continued on p.27»

POWERING UP

Virgin Galactic's VSS *Unity* reached a top speed of Mach 1.87.
Photo: Virgin Galactic

Virgin Galactic, the space tourism company, passed a major milestone in April. The company's VSS *Unity* completed its first powered flight test, reaching an altitude of 84,271 feet before returning to a Mojave Desert airstrip. *Unity* was powered by a rocket motor with nitrous oxide and hydroxyl-terminated polybutadiene as propellants and reached a top speed of Mach 1.87. The flight was the first for the company following a fatal crash of a previous spaceplane during a 2014 test. The new craft, built by The Spaceship Company for Virgin Galactic, employed the raising of its tail booms before beginning descent, a safety mechanism that was added in response to the 2014 accident. ME

CONNECTED AND VULNERABLE

Cybersecurity isn't just about computers. Sensors also have serious security deficiencies.

We are bombarded with headlines about the insecurity of online systems. For most people, cybersecurity has effectively been framed as a problem with information technology and data leaks.

But that conception is missing another channel of vulnerabilities: hardware attached to industrial systems. Process sensors, actuators, and drives have been considered to be engineering systems, so they have not been addressed from a cybersecurity perspective. But increasingly, information technology and the so-called operational technology of commercial and industrial hardware have merged. Until we invest in securing these physical systems, they will remain inherently insecure.

Many hardware systems are shipped with only the most rudimentary security in place. Often, even if sensors are shipped with password protections in place, the default password is easily guessable and users are never prompted to change that default.

Consider this analogy: Doctors take physical measurements of their patients in order to develop a sound diagnosis. That means that the measurement equipment—thermometers to take temperature, electrocardiographs to record heart rhythms, and so on—must be well maintained and procedures must be followed to obtain the correct data. If the sensors are faulty due to poor maintenance, bad design, or cyber threats, then the doctor could make a misdiagnosis.

The same theory applies to process sensors connected to control system networks. As with the doctor, the results of incomplete or incorrect data can be—and have been—disastrous.

There have been more than 1,000 actual control system cyber incidents to date worldwide in electric generation, transmission and distribution; pipelines; manufacturing; and other industries. A number of these incidents were process sensor-related. Impacts have ranged from trivial to equipment damage, to environmental releases, to widespread electric outages, to deaths.

In 2005, for instance, water-level monitoring instruments at the earthen Taum Sauk dam near Lesterville, Mo., had deteriorated, and water continued to be pumped into the reservoir beyond its capacity. Eventually, the dam collapsed.

In another instance in Buncefield, England, a malfunctioning sensor failed to stop the filling of an oil tank at a storage facility. After 250,000 liters of petroleum spilled out of the vents at the top of an oil storage tank, the oil ignited, touching off an explosion that reportedly was heard 125 miles away. More than 40 people were injured and fire at the tank farm and adjacent site burned for several days.

Most such incidents were assumed to be unintentional, though the lack of control-system forensics at the process-sensor level leaves that an open question. Existing process sensors, actuators, and drives have no cybersecurity or authentication. Because of these issues, ISA has formed a new working group to tackle security issues for sensors.

Additionally sensor protocols such as wired and wireless HART, Fieldbus, and Profibus have been demonstrated to be cyber vulnerable. Since process sensors are the starting point for all process controls and safety applications and actuators, motors, and drives are the final elements, the lack of security in these devices can affect system security and safety.

The lack of security in process sensors, actuators, drives, and similar devices affects mechanical engineering applications in almost all domains. There are a limited number of process sensor suppliers and most are international, serving multiple markets. And as more and more manufacturers embrace the melding of sensor and product through such initiatives as the industrial Internet of Things and Industry 4.0, the security vulnerabilities inherent in these technologies will become increasingly important to address.

Too often we don't know how lax we have been in our personal online security until someone has hacked our account and stolen information. Only then do we practice personal vigilance.

We should do a better job of securing our physical systems in advance of a failure rather than waiting for a disaster to become the wake-up call. ME

JOE WEISS, P.E., is managing partner at Applied Control Solutions, LLC in Cupertino, Calif.

continued from p.11 »

A SILVER LINING

NCSU's breakthrough technique tackles challenges like clogging related to 3-D printing silver nanowires. The researchers used an electrohydrdyonamic system, applying electrostatic force to eject ink from a wide nozzle, reducing the problem of silver nanowires jamming the nozzle. The ink's silver nanowire solvent is non-toxic and water soluble. The technique retains a fine printing resolution.

"This technology enables high-resolution, large-scale printing of highly conductive silver nanowires for flexible and stretchable electronics. The applications include wearable sensors for health monitoring and activity tracking, prosthetics, electronic skins, wearable displays, RFIDs, among others," Zhu said.

So far the researchers have used flexible boards with silver nanowire circuits to develop a prototype wearable heater for thermal therapy and dry electrocardiogram electrode for heart activity monitoring. "We are developing more sensors and electronics and plan to integrate them for wearable applications," Zhu said.

The electrohydrodynamic printing system was built in-house and had three sub-systems: a pneumatic dispensing system, a voltage supply system, and a precision three-axis translation stage. The NCSU researchers hold a provisional patent on the 3-D printing technique, and want to commercialize the technology.

The high price of silver is not a major concern for the researchers. What's more important is the superior environmental stability and easy printability of silver. "The silver nanowire pattern printed is a thin film with typical thickness less than 500 nm. So cost is not a major concern at this point," Zhu said. ME

AGAM SHAH

"AS MORE COMPANIES AND PEOPLE get into research and development in low Earth orbit, I think we'll get more creative ideas both about the fundamental science we can do there and about what products we can create in space."

Former astronaut ***Sandra Magnus****, who recently retired executive director of the American Institute of Aeronautics and Astronautics, on the prospects of privatizing the International Space Station. Magnus was quoted by the* Los Angeles Times *on March 2, 2018.*

Q&A
ALBERT MANERO

WHEN HE WAS A MECHANICAL engineering student at the University of Central Florida, Albert Manero stumbled upon the need for prosthetics for kids. That discovery pushed him into the field of bionics. Manero started a student-based volunteer group and the team built an Iron Man-themed arm for Alex Pring, a 7-year-old boy who was born with a partially developed limb. That group evolved into Limbitless Solutions, a non-profit organization that builds affordable, bionic, 3-D-printed arms for children. For Manero, Limbitless Solutions was a way to combine academic skills with an entrepreneurial spirit to advance the field of bionics. He believes that's it's important to take what you do in engineering and apply it in business.

ME: From a technical perspective, tell us what you mean by bionics? Are these prosthetics truly bionic or more of a hybrid?

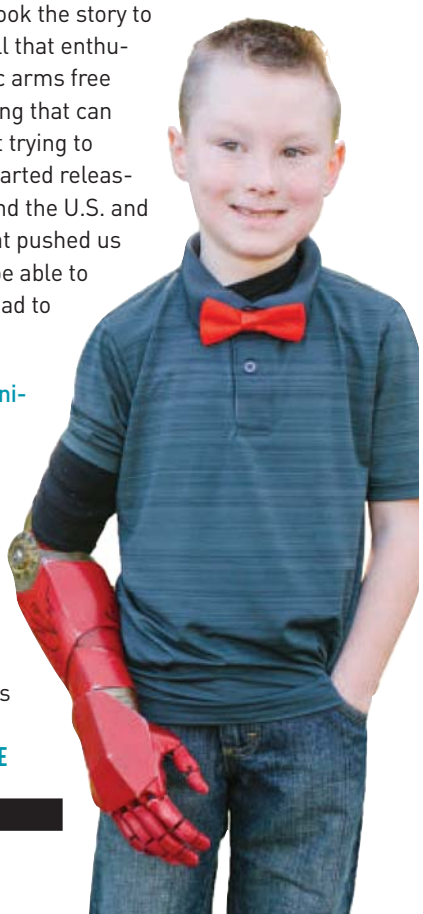
A.M: We work with electromyographical bionic limbs. That means they are able to read the muscle voltage signal, capture the intentionality, and use that to open and close the hand. The current model only does a binary open and close but we are now working on a version that will give full hand dexterity. That's how kids are able to use their arms naturally. It provides a binary grasp to the kids about the same strength you would expect a young child to have. We are looking to augment the ways to give them tools to be able to go after anything they need day to day.

ME: How have the innovations in additive manufacturing enabled you to build your products?

A.M: The use of additive manufacturing incredibly speeds up the time of prototyping. Being able to create complex features, things that would be expensive or prohibitive using traditional manufacturing—I think that's where additive really succeeds. In the case of a bionic arm, it is supposed to look organic and have different moving designs, and 3-D printing lends itself to capturing that an artistic nature. We couldn't have done this without 3-D printing as we didn't have the budget when we started and we needed to rapidly iterate with the complexity. Being able to use additive allowed us to have the right blend, the right tools, and right material that can really bring the entire device to life.

ME: One of the most high-profile projects your company has worked on was the Iron Man project. Can you tell us more about that?

A.M: It was an incredible opportunity and we are thankful Robert Downey Jr. was able to participate and make this little boy's dream come true. We took our traditional design and were able to theme it just like the movie. Microsoft had reached out to us for its Collective Project, which is a group of stories about student-led impact around the country. Robert was very receptive and it took the story to a whole other level. We are trying to use all that enthusiasm and take it forward by making bionic arms free for families and transform that to something that can really scale. When we started we were just trying to help this local family but when the story started releasing we started receiving emails from around the U.S. and the world from people asking for help. That pushed us to launch our non-profit as we wanted to be able to give the kids bionic arms for free and we had to find a way to do that.



ME: What advice would you give to mechanical engineers interested in starting their own businesses?

A.M: It's important to take what you do in engineering and apply it. In terms of entrepreneurship, you are taking the same principles and rigor and putting it behind developing out a business in the same sense. It has been challenging for us in our youth, so having great advisors and mentors can make the difference between having a great idea and making it grow and scale. ME

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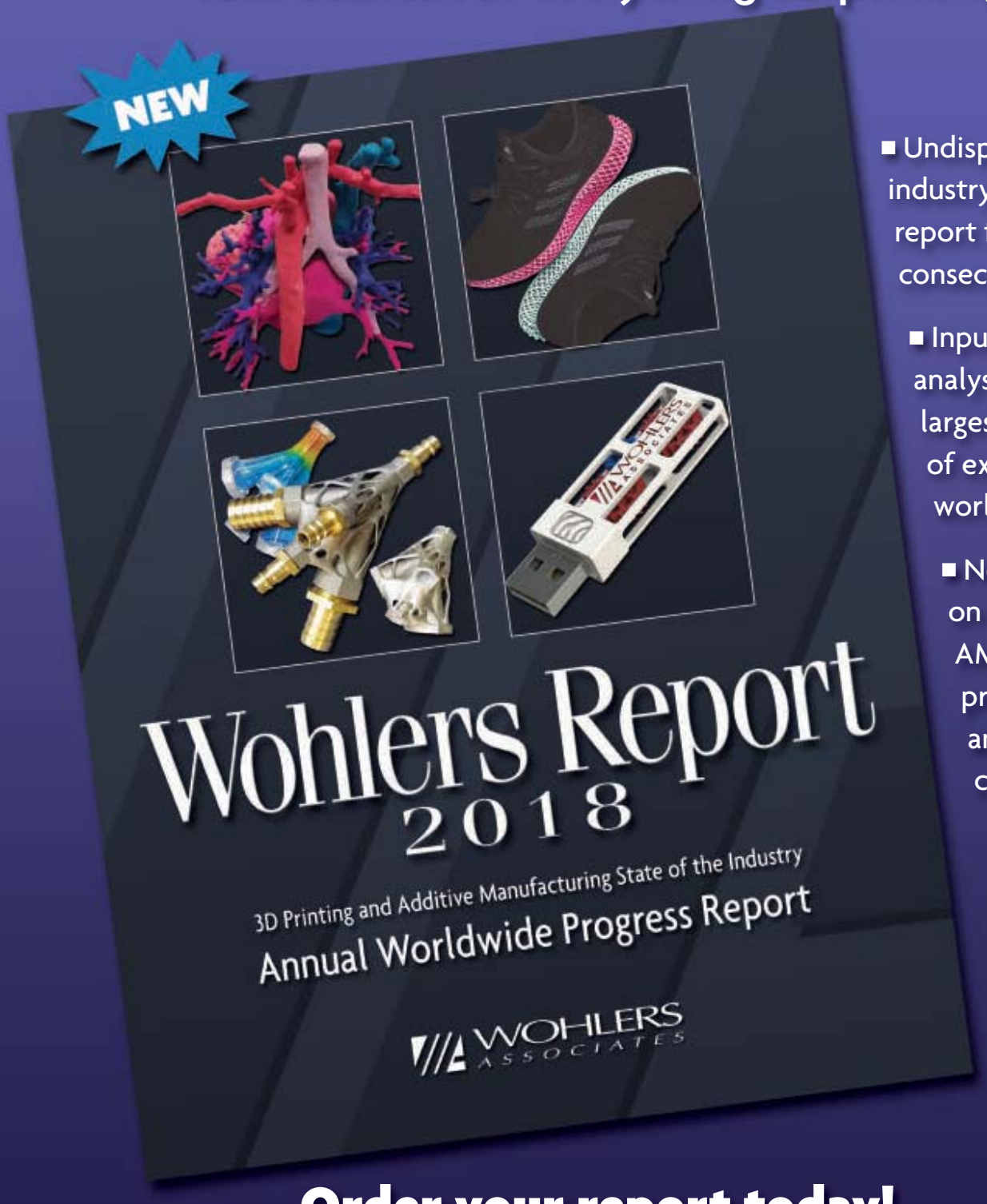

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MOTHER OF HARDWARE BUGS

Security isn't always a top priority when devices are deployed across industries or medical facilities, but it should be. That fact is reinforced by newly discovered hardware vulnerabilities that affect billions of devices.

The effect of the vulnerabilities, called Spectre and Meltdown, has been established for computers with Windows or Linux. But more details are still emerging, and it could hit robots, sensors, drones, control systems, autonomous cars, medical devices, machines, and other equipment.

The U.S. Department of Homeland Security's Industrial Control Systems Cyber Emergency Response Team has asked infrastructure and devices companies to check their hardware and software. Companies like ABB, Siemens, Rockwell Automation, GE, Medtronic, and Johnson and Johnson are still evaluating whether products have been affected.

Meltdown and Spectre were discovered in CPUs (central processing units), which are microprocessors or circuits that help computers run functions. Running arbitrary software code can expose sensitive user data like passwords to hackers, who can then extract the information for nefarious purposes.

The vulnerabilities are in a plethora of chips from Intel and AMD (which are in most computers and servers) and ARM (which dominate in IoT and mobile devices). Many affected Intel chips are used in autonomous cars, drones, and robots. It is possible that slower IoT devices could also be exposed, said hacker Andrew "bunnie" Huang.

The vulnerabilities are unique because they were found in hardware, unlike a software-based worm like Stuxnet, which broke into industrial system PLCs. Changes can't be made to the hardware to fix the problem, so software patches are being issued to cover the exploits. Windows and Linux have been updated to protect against the vulnerabilities.

"When hardware fails from a security perspective, it is devastating, it's hard to mitigate. You have to take draconian measures to fix it," said Bill Horne, an established security researcher who holds 33 patents in security and machine learning. He is also general manager and vice president of Intertrust's Secure Systems product group.

The hacks expose weaknesses in techniques used to speed up computers. In anticipation of specific tasks, computers pre-fetch data, some of it which may be passwords and may or may not be used. The technique reduces the number of computing cycles it takes to execute a program. The vulnerability patches clamp down on those techniques, thus slowing down computers.

In Meltdown, hackers broke into kernel memory that is typically not accessible to users. Spectre, which is considered tougher to exploit, fools applications into

accessing arbitrary memory locations, which could result in hackers gaining access to sensitive data.

Engineers running high-end CAD/CAM, design, imaging, or simulation software need to secure their systems. Philips issued an alert that its IntelliSpace Cardiovascular cardiac image and information management system software, which runs on Windows computers, was affected. Hackers could gain unauthorized access to user credentials, which can also be modified.

The hardware hacks are less likely to affect battery-powered devices like smart meters or health monitors, which are mostly used for data gathering and don't need advanced processing techniques to crank up horsepower. However, those devices could potentially be a target for Spectre-like exfiltration of secure data, Huang said.

Nonetheless, Meltdown and Spectre are grim reminders that more needs to be done to protect data on these endpoints, especially in hostile environments, Horne said.

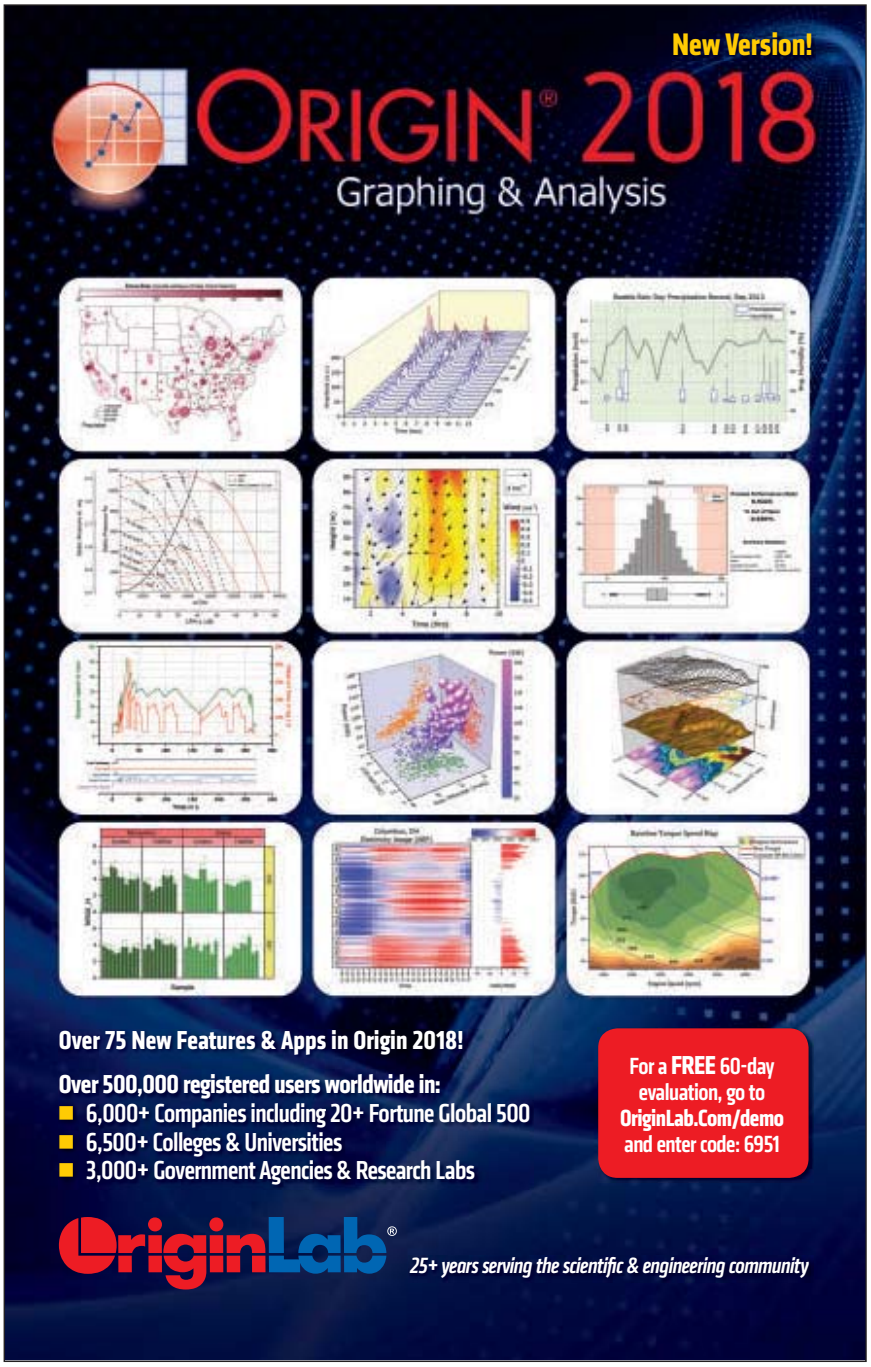
Many sensor devices remain defenseless, unprotected, and difficult to update, making them attractive targets for hack attacks. Devices in critical infrastructure are especially juicy targets, as Stuxnet has proven. There have also been documented hacks of people creating botnets out of IoT devices to carry out DDoS (distributed denial-of-service) attacks, a term used to describe an army of computing devices jointly launching an attack to bring systems down.

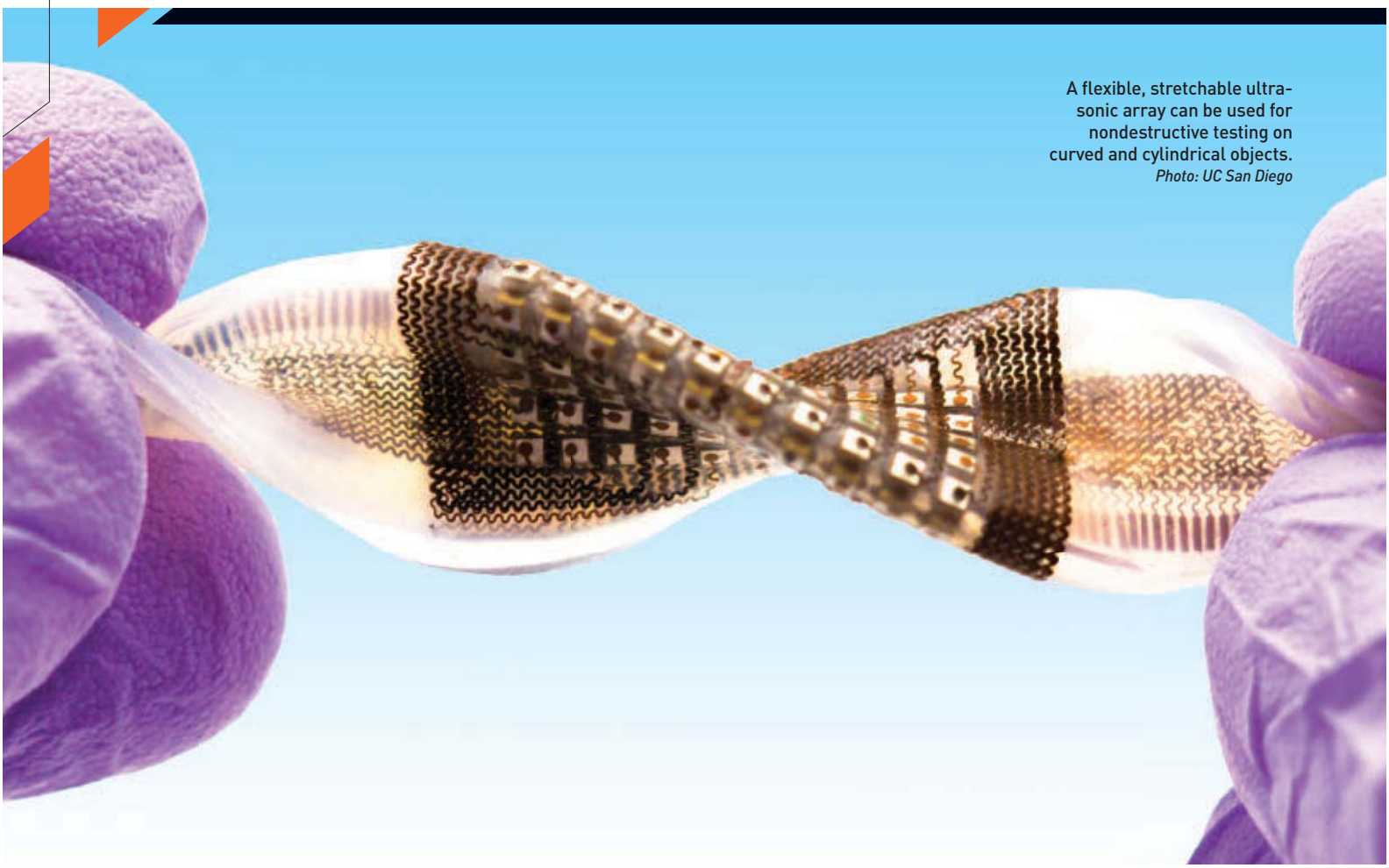
"There's a high chance the attacker's exploit will go undetected and unpatched for years. And persistent exploits are gifts that just keep on giving and giving," Huang said, adding that "if your infrastructure relies on that hardware, you're stuck between a rock and a hard place until you can afford or acquire the replacement."

It's never too late to assess aging hardware like PLCs or to implement new security measures when deploying new devices. Such a process would include reviewing security, threat assessment and monitoring tools, and establishing contingencies such as backup or failover systems. Detection is also important, and analytics could determine if systems were brought down by malicious attacks or anomalous activities, which helps differentiate between security and maintenance problems.

Another way to mitigate risk would be to store secrets on a separate chip or a secure enclave, and not putting it on the same chip—namely CPUs—that can run arbitrary user code. The feature is already available on chips, though one would need to look deep inside device specifications to scoop out the details. **ME**

AGAM SHAH





A flexible, stretchable ultrasonic array can be used for nondestructive testing on curved and cylindrical objects. *Photo: UC San Diego*

NEW TECH STRETCHES SENSING

UBIQUITOUS SENSORS WILL DRIVE THE Internet of Things. This month, we look at two innovative sensors. The first is a flexible system that lets technicians check curved parts as easily as flat surfaces. The second, a nanoscale transducer with applications ranging from 5G communications to biomedical and environmental sensing.

PIEZO ARRAY STRETCHES ULTRASOUND

THE LAB Xu Research Group, University of California, San Diego. Sheng Xu, director and assistant professor of nanoengineering.

OBJECTIVE Develop hard semiconductor-soft organic material combinations for wearable sensor arrays for healthcare monitoring.

DEVELOPMENT A flexible sensor array that can do in-situ nondestructive testing on curved and complex components.

A flexible, stretchable array of transducers developed at the University of California, San Diego can conduct ultrasound inspections on curved structures ranging from pressure pipe elbow joints and turbine parts to railroad tracks and bridges. The technology would let technicians find cracks, voids, and delaminations without disassembling the parts first.

"This device identifies flaws as well as a conventional transducer, plus we can detect those defects below the surface on nonplanar surfaces," said lead researcher Sheng Xu, an assistant professor of nanoengineering at UCSD.

Xu developed an interest in wearable piezoelectric sensors while working as a post-doc with John Rogers of University of Illinois, who pioneered the use of spring-like interconnects for flexible sensor arrays. At UCSD, Xu developed flexible arrays for medium-resolution medical imaging. He then teamed with Francesco Lanza di Scalea, a professor of structural engineering at UCSD, to find mechanical applications.

Xu uses piezoelectric transducers, which emit ultrasound

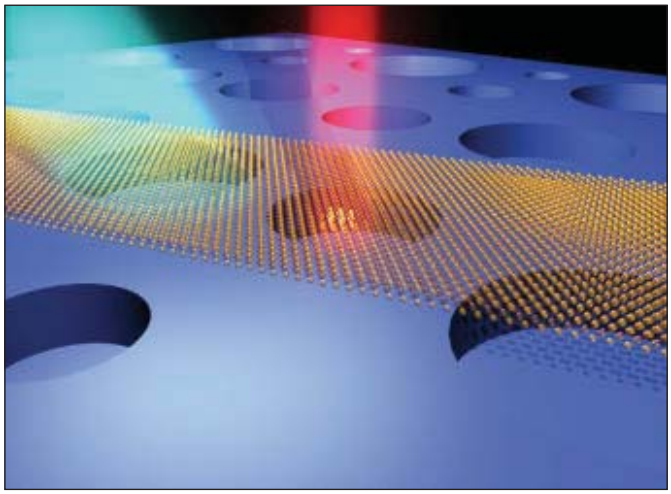
vibrations and measure the soundwaves reflected back when they hit boundaries between different types of tissues or cracks in metal to image the object's interior.

Ultrasound has been a mainstay of nondestructive evaluation for decades, but it cannot establish good contact with curved surfaces. This creates air gaps that reduce accuracy by reflecting or distorting ultrasound waves. Applying gel or immersing a part in water improves coupling, but it also attenuates signals and reduces resolution.

Xu's solution is a 10-by-10 array of small multilayer piezoelectric transducers linked by springy metal multilayer electrodes and encapsulated in compliant silicone elastomers. The resulting device shows excellent electromechanical coupling, minimal cross-talk—and it stretches more than 50 percent.

Integration proved a major challenge. The transducers are very small, only 1.2 mm square, and packed tightly together. To keep their emissions from interfering with one another, Xu and graduate student Hongjie Hu engineered a multilayer structure (including a vacuum layer) to reduce crosstalk. They also used a microbonding technique developed by Rogers to reduce the strains that build up at the interface of hard and soft materials.

Xu is starting a company to commercialize flexible arrays to image stationary and moving parts and for wearable medical sensors. ME



NANOSCALE RESONATORS CHANGE THE GAME

THE LAB Feng Research Group, Case Western Reserve University, Cleveland. Philip Feng, director and professor of computer science.

OBJECTIVE Understand the fundamental physics and engineering of nanoscale electromechanical devices and integrated systems.

DEVELOPMENT A tunable, low-noise nanoelectromechanical system based on atomically thin film that could be used for advanced communications and sensors.

It takes a laser to measure picometer changes in Philip Feng's atomically thin film.
Photo: Case Western Reserve University

Case Western Reserve University researchers led by Philip Feng have created nanoscale devices that "hear" about as well as a cat. Feng says he can tune the devices to change their resonance.

The devices are small enough to easily integrate into today's nanoscale electronics, and their tiny size reduces power consumption significantly. Potential applications range from tunable oscillators for 5G communications and signal processing to ultrasensitive resonant transducers for biomedical and environmental sensors.

The wide dynamic range came as a surprise for Feng, who first began investigating MEMS resonators as a graduate student at Caltech before moving onto carbon nanotubes and nanowires. These materials are often called one-dimensional because they are only a few atoms wide and deep.

While Feng and others made 1-D oscillators and resonators, they were so small that Brownian motion and tiny temperature variations caused fluctuations that masked signals and quickly led to nonlinear behavior. They were also noisy and had poor dynamic range.

Feng thought films of molybdenum sulfide one to three atoms thick (called 2-D materials) might prove equally noisy. After all, contact with even a few medium-sized molecules could be enough to corrupt the signal on a film only a few atoms thick.

Instead, he found 2-D films provided clear signals from 10 MHz to around 120 MHz. This is due to the material's mechanical properties—strength, elasticity, low areal mass density, and high-elastic modulus—and Feng's ability to suspend the film on a device like a drumhead.

Measuring changes in the film's vibration was challenging, Feng said. "We needed to figure out how to measure drumhead surface displacements from a picometer to a few nanometers at room temperature at frequencies between 10 to 150 MHz."

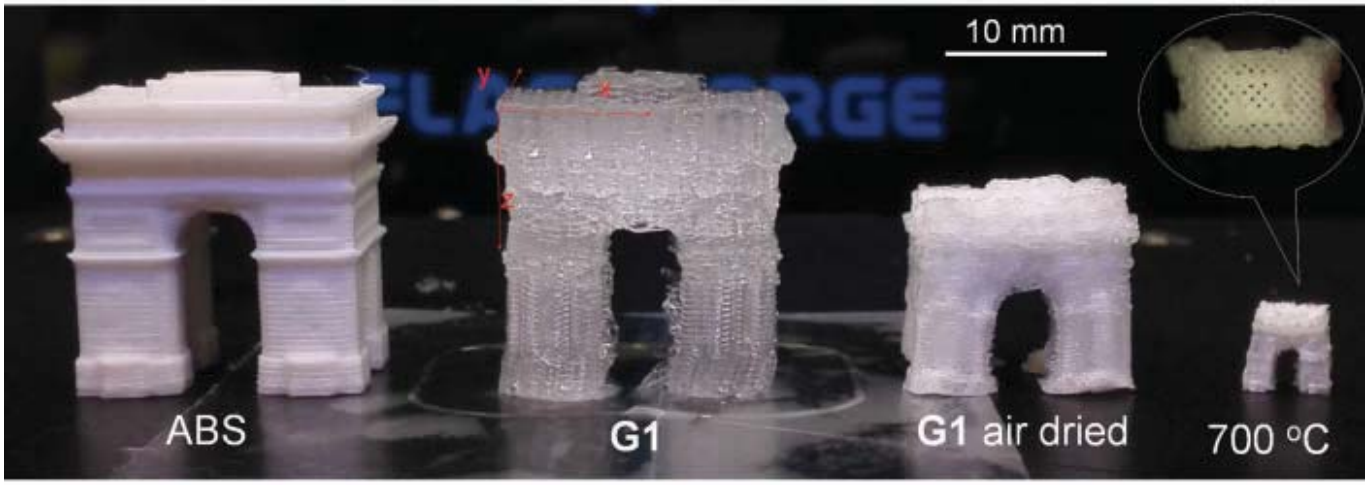
Feng did this primarily through optical detection.

He also found he could tune the response of the 2-D films by using electrostatic forces to change their stiffness. This gives Feng more control over their electrical, optical, and plasmonic properties.

His next step is to demonstrate these structures in devices that sense pressure and also small amounts of gamma rays. He is also looking for collaborators to grow wafers on which he can deposit the films. ME

ALAN S. BROWN

SMART INK CAN SHRINK PRINTED OBJECTS



Shrinky Dinks are a childhood toy that transforms from a large, floppy sheet to a small, hard object. Now a research lab at Dartmouth University in Hanover, N.H. has developed a material for 3-D printers that can change size or color based on surrounding stimuli.

The material, which the researchers call smart ink, may one day lead to the creation of shape-shifting 3-D printed devices, for instance, changing color if high blood sugar levels are detected and then releasing an insulin capsule. The ink could also be programmed to change the shape or size of soft robots that may be involved in rescue or medical operations.

"If we change the temperature, environment, moisture, or other stimuli, these molecules will respond or move around. The whole object moves," said Chenfeng Ke, assistant professor for chemistry at Dartmouth. "It depends on the molecule we put into the ink."

Filaments used in 3-D printing, such as ABS and FLA plastics, are rigid. To create 3-D printed objects that could change size radically, Ke needed a flexible, low-density material. Ke's team developed a material made with hydrogel, which is as frothy as sea foam. The hydrogel "smart ink" consists of pluronic polymer mixed with smart molecules including TEOS, organosilicate, and hydrogen-bending derivatives.

In experiments, Ke was able to shrink objects down to 1 percent of their original size. Conversely, he was able to increase the size of an object. Applying ultraviolet light changed the color of one 3-D printed object from sky blue to green.

Hydrogel-based smart ink downsizes a printed Arc de Triomphe.
Image: Chenfeng Ke, Dartmouth

"You need to tell the molecule to align and behave like other molecules. Then you have to work out self-assembled structures. Once you work out that structure, you can control all molecules simultaneously," Ke said.

It may take some time before 3-D printers start producing adaptable objects using smart ink, Ke said. "We are still trying to figure out how we can make the material." ME

AGAM SHAH

GREEN APPLE

Apple, the largest company in the world by market capitalization, recently staked a claim to be among the first large companies to rely completely on renewable energy for its offices, stores, and data centers. The company has 25 renewable energy projects worldwide, generating 626 MW, and plans to build 1.4 GW in capacity. Power is drawn from hydro, wind, biogas, and other resources, but solar power dominates, with 286 MW of generation coming online in 2017 alone. Apple even has a 17-MW rooftop solar installation at its new headquarters in Cupertino, Calif. The company also claims to have reduced its greenhouse gas emissions by 54 percent since 2011. ME

continued from p.12 »

A NEW BRICK COULD ELIMINATE INSULATION

moisture, making them ideal for use as a vapor barrier to prevent moisture from passing from the wall into the building's interior. Aerogel is also recyclable and nonflammable, Wernery says.

Because it can be difficult to find materials that fulfill structural and modern insulation requirements for the building envelope at the same time, Wernery's group began investigating aerogel's insulating properties when used within hollow bricks, he said.

Aerogel's use as an insulating material isn't new. NASA uses the material to insulate its spacesuits. Apparel-company Oros insulates its jackets and coats with a NASA-inspired aerogel because the material is thin and warmer than many then other options, says Michael Markesbery, Oros co-founder and chief executive officer.

But aerogel in the form NASA and Oros relies upon couldn't be used within

AEROGEL IS RECYCLABLE, NONTOXIC AND NONFLAMMABLE

the insulated bricks Wernery's group had in mind. The Swiss researchers sought a thick version of the material.

So the group developed a paste composed of aerogel particles that they stuffed into hollow bricks made of clay. While the base for the aerogel filling is mostly silicates, in volume it consists of more than 90 percent of air-filled pores with sizes in the nano range.

Aerogel is expensive, however, with only two companies making the material. Wernery calculates that using the bricks would add $550 for every three-square feet of wall.

But Koebel and Wernery expect aerogel costs to fall dramatically as they and others come up with lower-cost production methods. ME

JEAN THILMANY is a freelance writer who lives in St. Paul and writes about engineering technology.

"IT IS EXPECTED THAT OVER THE NEXT 3 YEARS at least 61,000 jobs—or 6 percent of government's targeted 1 million jobs—will be created in renewables as a result of moving this program forward."

Dominic Wills, chief executive of solar project developer SOLA Future Energy, quoted by The Johannesburg Citizen *on March 12, 2018, after the South African government signed deals with 27 independent renewable power producers.*

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STIRLING MACHINES: FROM POTENTIAL TO PRACTICALITY

BRAD ROSS
BATTELLE PACIFIC NORTHWEST LABORATORIES, RICHLAND, WASH.

The Stirling engine had long been seen as a potentially superior technology that just needed a little polish. In this article, an engineer surveyed how close and yet how far we were from seeing the engines reach the market.

N.V. Philips, of Eindhoven, the Netherlands, resurrected the idea of the Stirling engine in 1948, and used one as part of an engine-generator set without an ignition system to power portable radio. Since then, highly efficient, durable engines from a few watts to hundreds of kilowatts have been demonstrated. Still, improvements are needed in several areas.

The three major challenges facing Stirling machines are cost, cost, and cost. It is no coincidence that most programs devoted to developing Stirling machines are in areas like space power and military cryocoolers where cost is not a major consideration. Mass-produced Stirling engines are expensive because the heat exchangers (heater, cooler, and regenerator) must be made of strong, heat-resistant materials that are expensive and hard to machine, and they must be intricately constructed if they are to provide the required surface area. Ceramic heat-exchanger components may reduce these costs if the problems of brittleness, thermal fatigue, and the interface of metal and ceramic can be solved. Promising work is being done on iron-based alloys that use small amounts of strategic materials and have the properties required of hot Stirling components.

It is difficult to predict engine performance accurately during the design stage. Advanced engine designs are based on rigorous computer codes that attempt to model oscillating flows and non-steady heat transfer, which are not very well understood. The codes cannot be fundamentally verified, since it is not presently feasible to make the necessary high-speed measurements of oscillating, high-pressure gas flows. In some cases, current codes can predict power output within 10 percent and efficiency within 20 percent of test results. Analytical techniques are steadily improving and engine designs for specific duty cycles will improve as a result.

Stirling machines typically contain a pressurized working fluid, some at pressures over 150 atmospheres. The development of effective seals, with low leakage and low friction, presents a significant challenge, especially if helium or hydrogen is to be used as the working fluid. Mechanical seals have been used that last up to several thousand hours, and their reliability is improving. Hermetically sealed machines with internal close-fit clearance seals last even longer, but achieving the seals entails a small sacrifice in performance. Hermetic metal bellows are also long-lasting in some applications. ME

LOOKING BACK

Researchers were reexamining engine technology when this article first appeared in June 1988.

PERESTROIKA

While Ross was discussing the potential of Stirling engines, an enormous reform effort was underway in the Union of Soviet Socialist Republics. When Premier Mikhail Gorbachev assumed the leadership of the Soviet Union three years earlier, he and his advisers discovered that a decade of high oil prices had masked the decrepit state of the economy. Gorbachev initiated reform efforts. Glasnost, for instance, was intended to increase the degree of transparency in Soviet decision-making, and perestroika, which was launched in January 1988, was an attempt to introduce some market-economy flexibility to what had been a centralized Stalinist system. In the end, however, Gorbachev's reforms raised expectations without delivering improvement in living standards, and people in the republics started to revolt. By 1991 Gorbachev—and the Soviet Union—were on the way out.

Ronald Reagan (left) and Mikhail Gorbachev finalized an arms control treaty in Moscow in June 1988. *Image: U.S. Archives*

continued from p.14 »

CLEAN WATER TECH

Kingo was founded in 2013 by four entrepreneurs looking to improve human capacity by providing off-the-grid electricity at a low cost. Users can buy energy by the hour, day, week, or month the way they buy mobile phone minutes, making it more accessible. Users can buy credits from local salesmen directly or in designated stores. The energy they buy comes from solar generation systems (called Kingos) so it's clean energy, it is delivered to the end user using a cloud-based software platform. Kingo has made its mission to light up 1 million homes by 2021. ME

MAYARÍ PÉREZ is a former E4C Research Fellow pursuing a B.S. degree in mechanical and industrial engineering at Universidad del Valle in Guatemala. For more articles on global development visit www.engineeringforchange.org.

TALL TURBINE TO CAPTURE BIG WIND

Offshore wind power is more expensive to develop than land-based wind farms, but the potential is great. The wind out at sea is stronger and steadier, and because the facilities can be sited over the horizon from residents, the turbine blades can reach very high without incurring the wrath of neighbors.

Vattenfall, the Swedish renewable energy firm, took advantage of those factors in its design for the European Offshore Wind Development Center, a wind-power testing center in Aberdeen Bay in Scotland. The company deployed a Vestas V164 8.8 MW wind turbine at the facility in April, an installation the company calls the largest wind turbine ever installed. The turbine will be part of an 11-machine array that will generate as much as 93.2 MW of electricity—enough to power 79,209 homes, or about 70 percent of the demand in the city of Aberdeen.

One of the innovative technologies the wind farm will employ is suction bucket jacket foundations. Rather than anchoring the turbine towers to bedrock below the sea floor or mounting the towers on buoyant platforms, a vacuum was created between the base of the tower and the seabed. The pressure of the water column above the base then holds the tower in place.

The hope is that suction bucket jackets will make for faster and less expensive installation of wind turbines and lead to less costly remediation when the wind turbine is decommissioned.

The record won't last for long. Larger turbines from Vestas and GE are scheduled to be deployed in the next 12 months. ME

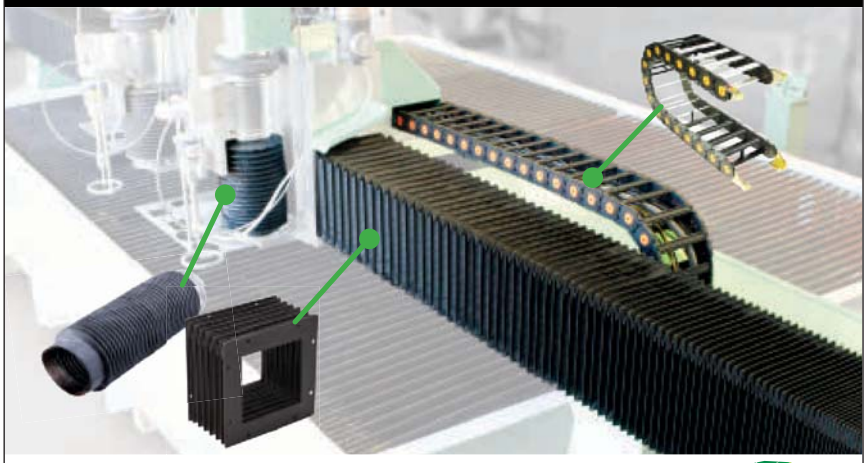
BIG NUMBER

49.996 Hz

AVERAGE FREQUENCY OF THE EUROPEAN ELECTRICAL GRID IN JANUARY AND FEBRUARY.

ELECTRICAL GRIDS DO MORE THAN supply power. The alternating current that flows along the wires is used by many electric clocks and motors to maintain their speed. In January, when an energy dispute between Kosovo and neighboring Serbia caused a slight draining of power from the European electric grid stretching from Portugal to Poland and Turkey, the result was a nearly imperceptible deviation from the average 50 Hz cycle that grid works to maintain. By the time managers at the European Network of Transmission System Operators for Electricity recognized the discrepancy, the 4 mHz difference had slowed electric clocks across Europe by more than 6 minutes.

PROTECT | MOTION DESIGNS CABLES AND HOSES



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BY THE NUMBERS: POWER POINTS

Americans feel better when they don't spend as much on energy.

Nostalgia for the 1980s is over-running the popular culture in the United States. Television shows like *The Americans* and *Stranger Things* and films such as *Ready Player One* play on the memories of grown-ups who remember the Reagan Era fondly.

One aspect of that decade might make people shudder: The cost of energy. The first half of the 1980s saw extraordinarily high energy costs compared to both the years before and the decades that followed. Today, in fact, we spend less than half what we did on energy in 1981.

Data on personal consumption from the U.S. Bureau of Economic Analysis tracks the expenditures on energy goods and services—a metric that includes not only electricity but also gasoline and fuels for home heating—from the 1950s to today. When charted as a percentage of total personal consumption, the energy data tells the story of some distinct economic periods over the past 60 years.

Up to 1972, there was a steady decline in the share of personal consumption devoted to energy. Then, through the rest of the 1970s, the share shot up, eventually reaching about 9.5 percent of all personal consumption, as an ongoing oil crisis jacked up gasoline prices. Over the next 20 years, energy expenditure fell, bottoming out at about 4 percent after the dot-com bubble burst. The share raced back up again until the global financial crisis and then fell back to record lows we now see.

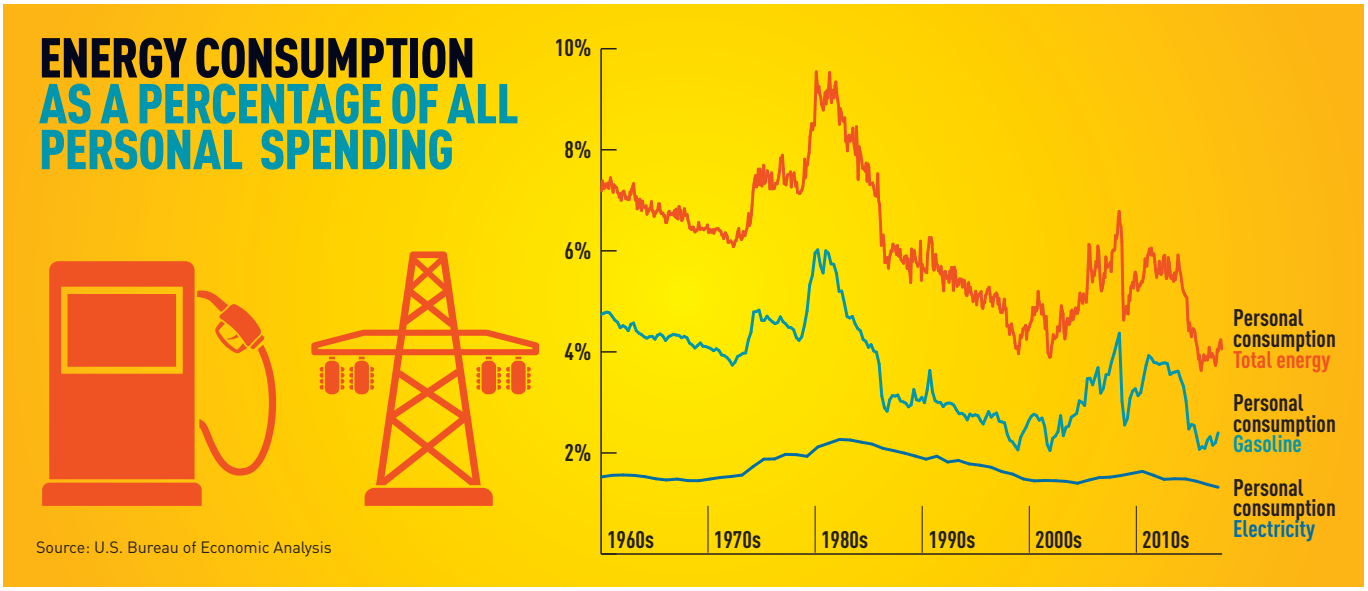
There are a lot of causes for these ups and downs, both technological—everything from the opening of the Alaska pipeline and the switch from oil to coal to fuel power plants to the widespread development of shale gas—and political. What's especially interesting, though, is the effect these swings seem to have.

Eras of reduction in the share of personal consumption going to energy generally have been marked by optimism, whether it was the early-to-mid-1960s or the dot-com boom following the so-called morning in America. The malaise of the late 70s, the post-millennial "prepping" fad of the mid-2000s, and the rise of the Tea Party all coincided with more money going to energy.

Since the start of 2016, energy has been at or near the smallest share of personal consumption recorded, and the February 2018 data shows it's now at 4.1 percent. Electricity makes up 1.3 percent of consumption, down from 2.3 percent in 1982, and gasoline is down to 2.3 percent from its Reagan-Era peak of 6.0 percent.

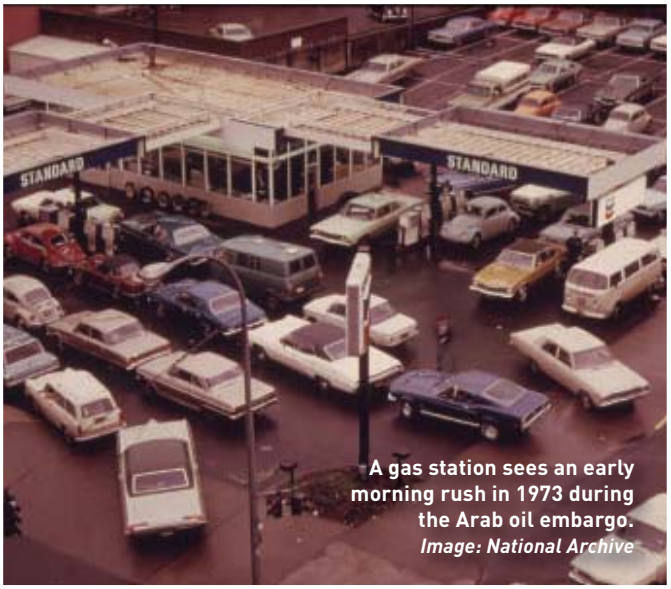
There's an upward tick at the end of the graph, however. Is it a blip, or the start of more unsettled times ahead? ME

JEFFREY WINTERS



A gas station line in 1979 during the second energy crisis within the decade.
Image: Library of Congress

A gas station owner spray-paints a sign to warn customers that he has run out of fuel.
Image: National Archive



A gas station sees an early morning rush in 1973 during the Arab oil embargo.
Image: National Archive

ENERGY STORAGE SMOOTHS THE DUCK CURVE

As solar energy becomes a bigger piece of the electric generation pie, utilities are grappling with the challenge of putting gigawatts of power online every afternoon.

By John Kosowatz

MECHANICAL ENGINEERING
THE MAGAZINE OF ASME
Special Report

THE STABILITY OF THE ELECTRIC GRID AFFECTS millions of residential and business customers. One blip—amounting to just seconds—can interrupt critical systems across a city or an entire region.

Maintaining grid stability is a challenge as utilities rush to add renewable power to their generating portfolio. The business case for renewables is undeniable: as prices for wind turbines and solar panels keep dropping and the costs of installation go down, renewable electricity becomes some of the cheapest power available. But the inherently inconsistent nature of solar and wind energy has grid operators looking for new ways to seamlessly integrate their output into the system.

This challenge is being faced around the world, and in the U.S. it is playing out initially in California.

A law passed by the California legislature in 2015 mandated utilities to reduce greenhouse gas emissions and increase the capacity of renewable projects. In response, the California Independent System Operator, CAISO, began seeing solar power provide an increasing share of electricity in the middle of sunny days. By 3:00 PM each day, however, the sun begins to sink toward the horizon and the power provided by the state's solar projects also starts to fall off—and this loss in power happens just as daily electricity demand starts to rise.

To meet that demand, California utilities figured they would turn to natural gas-fired peaking plants that could ramp up quickly. Southern California Edison, one of the state's three major electric utilities, owns five such peaking plants.

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In 2015, however, a massive leak of natural gas from underground storage wells at Aliso Canyon threw that strategy into question. The leak—the worst in U.S. history—threatened the reliability of fuel for those gas-fired peaking plants, and the California Public Utilities Commission ordered SCE to quickly build an energy storage project to mitigate the supply loss.

The utility turned to battery storage. In January 2017, utility officials opened two 10-MW battery systems supplied by Tesla at its Mira Loma substation that can store 80 MWh of renewable energy, one of the largest battery storage projects in the country. Today utilities and systems operators are recognizing battery storage as one of a number of effective tools for managing an increasingly interactive electric grid powered by more and more renewable energy projects. These tools will have to respond quickly to the sharply rising demand and must scale so as to add gigawatts of power in as little as an hour.

For an industry that had relied on large and lumbering baseload power plants, these sorts of fast and flexible systems may feel like a shaky foundation to support critical energy infrastructure. But the new energy paradigm promises to be cheaper and cleaner than anything that has come before.

THE DUCK CURVE

Over the course of a typical weekday, the electrical load follows a regular pattern. After a lull in the middle of the night, demand for electricity ramps up between 5:00 am and 9:00 am. From then, demand often stays fairly constant until the late afternoon or early evening, when residential lighting and air conditioning overlaps with the last few hours of the business day. The load only begins to decline around 9:00 PM as stores close and early risers head to bed. (The load curve changes on the weekend and over the course of the year, with August seeing the highest peak demand and April the lowest.)

Traditionally, the rise and fall of the load was met via a combination of baseload power generation from coal-fired or nuclear power plants and nimble peaking plants or dispatchable power from hydroelectric dams. But the addition of wind and solar power to the energy mix has altered the calculus. Wind, for instance, often blows most steadily in the middle of the night when demand is at its lowest. In regions where there are a large number of wind farms, deliverable wind power can at times be greater than the total demand.

Solar power can be more predictable than wind—on sunny days, the sun shines most strongly in the middle of the day—but it creates its own challenges to the load curve. Solar power generation ramps up in the morning and stays constant until mid-afternoon before fading for the last few hours before sunset. Unfortunately, that diminishing power supply corresponds with the rising load in the late afternoon, meaning the net load—the difference between electricity demand and the portion met by solar power—rises even faster than the actual load. That means peaking power has to be added, and fast.

Back in 2008, researchers at the National Renewable Energy Laboratory traced out the net load curve as it responded to more and more solar power being added to the grid. One wag noted that in time the curve looked like the back of a duck: high like the tail in the morning, sagging down in midday, then sharply up along the neck in the late afternoon and only rounding over the top of the head and bill in the evening. From that point on, that net load profile was referred to as the "duck curve."

In California, the middle is sagging ever deeper and the neck is growing even steeper as the state leads the way in mandating more renewables. By 2030 renewables must account for 50 percent of each of the state's large investor-owned utilities' generation portfolio.

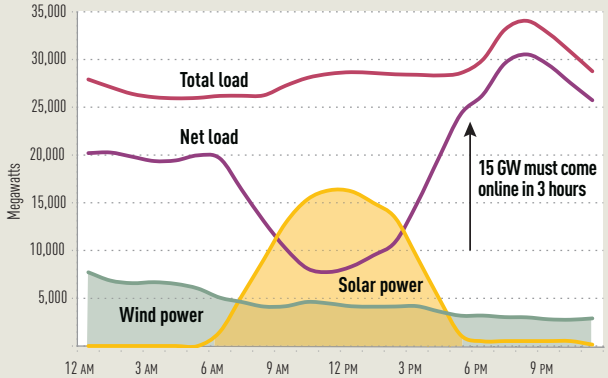
"Those are aggressive renewable goals," said Vibhu Kaushik, SCE director of grid technology and modernization. "Renewables have a lot of intermittency in them. Batteries can change momentarily to balance and maintain reliability. It is not the only thing, but storage for integration will be a big chunk of flattening the curve."

While the utilities are required to increase their mix of renewables, CAISO manages the grid and is responsible for integrating that power into the state's grid. At present, the system now comprises just under 30 percent of renewable sources. Of that, 48 percent is generated by solar power.

"Our job is to maintain reliability and renewables are just one part," said Peter Klauer, CAISO senior advisor for smart grid technology. "We don't favor one technology over another.

Shape of the Duck Curve

More renewables on the grid lead to stress on the system.



Load, solar, and wind profiles for California on a typical day in late March

In this scenario, wind and solar both make up 11 percent of annual generation.

Source: NREL

This 100 MW, 129 MWh battery array in South Australia was built by Tesla in just 63 days. The stored electricity helps Australia overcome inconsistency in power delivery that has led to blackouts.
Photo: Tesla

But there is a lot of solar generation hitting the grid and that presents an operating challenge to balance with other resources."

CAISO looks at many ways to find the highest value of its assets at the lowest cost. Klauer notes battery storage is just one way to do that. Shipping excess energy outside of the grid to neighboring states and connections is more effective.

Curtailing demand from renewables also is an option, and has been CAISO's most effective tool for managing oversupply. But that results in the state not using all of the renewable energy it could be generating.

According to CAISO data, in 2016 the system operator was forced to curtail more than 308,000 MWh of renewables, up from 187,000 MWh the year before. Most of that came in the form of economic curtailments: During times of oversupply, the bulk energy market competitively selects the lowest-cost power sources. Renewables can bid into the system in a way to reduce production when prices start to fall and CAISO's market optimization software automatically adjusts supply with demand.

Curtailing renewables runs counter to the state's economic and environmental goals, notes Klauer. As costs for lithium-ion batteries come down, battery storage "is helpful, and can alleviate the rush of solar during the day," he said.

"The whole energy world is shifting," noted Mark Frigo, vice president of energy storage North America at E.ON Climate and Renewables North America, part of global energy developer E.ON. The company has 2,700 MW of renewable projects in the U.S. "One factor is cost-effective renewables. But the increasing electrification requires a high quality of electricity and a decentralized demand-response system to deliver. Things are much more complex than ever before. That's where battery storage can come into play."

Battery storage can solve several simultaneous problems, from maintaining grid stability to deferred transmission and distribution. It provides both supply and load, although batteries are limited in how long they can produce power.

Operating batteries is not as simple as flipping the switch. It requires utilities to buy electricity in advance to charge the batteries, and at a low price so that the value of discharge is greater than the value of charging.

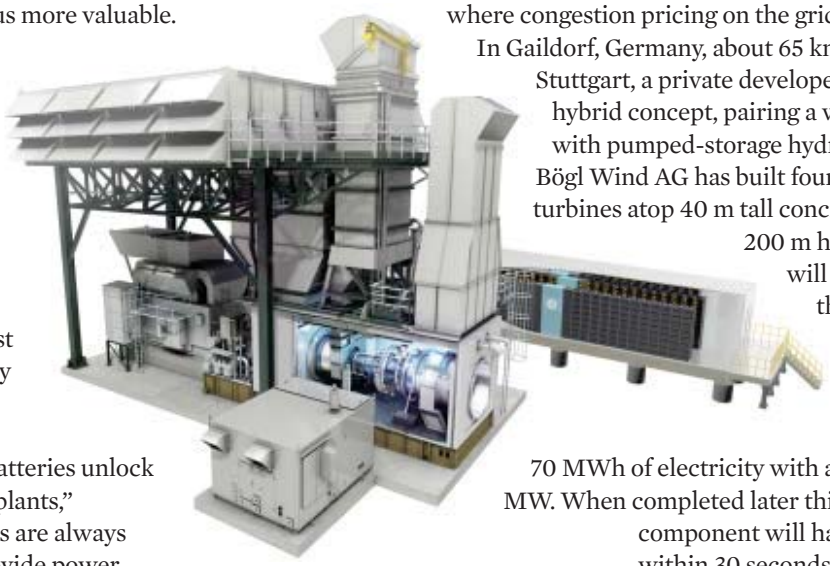
SCE's emergency 10-MW project has supplied power every day since being commissioned, the utility reports. It now has 400 MW of storage in its portfolio mix, including long-running pumped-storage hydroelectric plants. But in an innovative twist, it also is using batteries to supplement gas-fired peaking plants and respond to the state's frequency regulation market.

Peakers are linked to the frequency regulation market, but because they are nonspinning, they can take as long as 10 minutes to go online.

Adding batteries that can react immediately while the gas turbines are starting makes the entire unit eligible for spinning reserve status—that is, capacity immediately available to the grid and thus more valuable.

Last year, SCE partnered with GE and Wellhead Power Solutions to install an 11-MW, 4.3-MWh battery at two substations, pairing them with a 50-MW gas-fired peaking plant. The utility calls the Hybrid Enhanced Gas Turbine the world's first low-emission hybrid battery storage system to be fitted with a gas-fired peaker.

"These relatively small batteries unlock a lot of value with existing plants," Kaushik said. "The batteries are always synched to the grid and provide power at a moment's notice until the peaker comes on line."



Pairing batteries with a gas-fired peaker plant like this one creates a hybrid that is more efficient and less expensive.
Image: General Electric

Over the 40-year life of the plant the batteries are also projected to reduce operating costs for the turbines by 60 percent.

There is a lot to like about battery storage, Kaushik said. "For a small capital investment, you can add value to the grid and so much more," he said. "They are modular, easily stacked. It is a game-changing technology."

And batteries are getting cheaper. A recent analysis by Lazard pegs the cost of lithium ion batteries used for peaker replacement between $282 to $347 per MWh, with costs projected to drop by 36 percent over the next five years. Those declining costs will entice more utilities and systems operators to add installed battery capacity, though Kaushik sees more value in hybrid applications, except in locations where congestion pricing on the grid is high.

In Gaildorf, Germany, about 65 km northeast of Stuttgart, a private developer is using another hybrid concept, pairing a wind-power station with pumped-storage hydroelectricity. Max Bögl Wind AG has built four 12 MW wind turbines atop 40 m tall concrete tanks on top of 200 m high hills. The tanks will eventually serve as the upper reservoir for the pumped-hydro power plant, holding enough water to produce 70 MWh of electricity with a peak output of 16 MW. When completed later this year, the storage component will have a response time within 30 seconds.

"Pumped storage is a proven technology and this has a design life of about 50 years," said Susanne Kleineheismann of Max Bögl Wind. Batteries, she points out, must be replaced after about eight to 10 years.

The company will not release project costs, reportedly at $81 million, but Kleineheismann says capital costs for what the firm calls a "water battery" will be 300 to 400 Euros per kWh.

Even the Battery Hurdles Are Bigger in Texas

The electric grid in Texas is isolated from the rest of the country. Battery storage of electricity could find a great deal of use there, as the state is faced with integrating a slug of renewables into the system. Since 2000, 20 GW of wind power projects have come online, most on the sprawling plains of west Texas. Another 21 GW of solar power are expected to come online by 2021, according to the Electric Reliability Council of Texas, the state's grid management agency.

Unfortunately, the state's peculiar rules don't define how batteries can or should be used. State regulators differentiate between deregulated power generators and regulated power distribution companies. Most utilities cannot deliver and generate power, and private merchant generators worry that batteries, in smoothing price hikes when demand is high, will cut into profits.

The state's Public Utility Commission earlier this year announced it would begin to write rules for utilities that want to use batteries, but turned away a proposal from AEP Texas, a large utility, to use batteries to back up overloaded transmission systems in two remote and sparsely populated towns. The utility argued that batteries for backup power would be cheaper than doing expensive upgrades to an aging, hard-to-access transmission line.

E.ON has found some battery success in Texas. The company is building two 9.9-MW short-duration lithium-ion battery systems at wind farms in west Texas.

Compared to the market opportunity, though, it's a drop in the bucket.

Pumped hydro is not an option at sea level, so for offshore wind projects, electrochemical batteries still make sense. In March, Bay State Wind announced a partnership with NEC Energy Solutions to add 55 MW and 110 MWh of battery storage to a planned 800-MW offshore wind farm 15 miles off of Martha's Vineyard, Mass. Bay State claims the combination will help reduce Massachusetts winter electricity prices by some $158 million per year. In the U.K., Danish power company Ørsted said it will install a 2-MW battery to provide frequency regulation at its offshore 90-MW Burbo Bank wind farm. And the world's first floating wind farm, Norwegian energy giant Statoil's 30-MW Hywind complex, will be fitted with a 1.3 MWh battery system.

In a show of the flexibility and potential of battery storage, the electric car company Tesla installed a 100-MW station in South Australia last year in the wake of widespread outages, after a bet by Tesla's Elon Musk that the firm could have the station built and operational within 100 days. The station can respond to power outages within 140 ms and competes with natural-gas plants for peaking power and frequency regulation services. Grid operator Australian Energy Market Operator reports lower prices being bid into the system since the battery plant's startup.

By combining a wind turbine with pumped hydro, Max Bögl Wind AG created renewable energy storage that's more durable than batteries.
Image: Max Bögl Wind AG

RULES AND REGULATORS

Another way to smooth out the duck curve is to increase demand during the day, instead of tossing out the excess renewable energy. SCE, as part of its plan to meet California's energy and environmental mandates, thinks much of that wasted energy can be deflected to charging stations as electric vehicles gain market share.

In Columbia, Mo., Columbia Power & Light Co. last year started to pay higher rebates for solar arrays facing west rather than south. The move is an effort to bring solar production more in line with peak demand, as west-facing solar panels produce more power later in the day when demand picks up.

Batteries and storage now are getting a boost from the Federal Energy Regulatory Commission. In January it approved an order directing operators of wholesale markets to devise market rules for energy storage in wholesale, capacity and ancillary services. The rules, scheduled to be developed and implemented in two years, should codify how energy storage can be applied across the country, establishing market-driven parameters. That will change how the market has developed until now, driven by state regulatory demands. California, New York, and Massachusetts are already ahead of the ruling, and Texas is following suit.

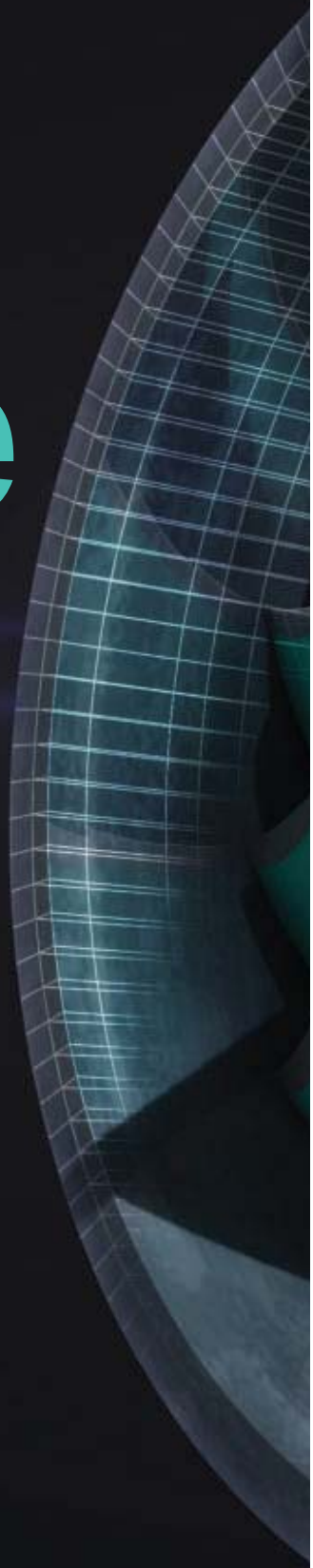
Texas does not yet have California's duck curve, but E.ON's Frigo says most parts of the country will soon face the challenge of integrating renewable power.

"The renewable train has left the station," Frigo said. "We'll see much greater numbers of renewables on the grid. Fossils will be retired. But that brings challenges of intemittency so you will see the duck curve elsewhere. Here's where energy storage plays as a good solution." **ME**

JOHN KOSOWATZ is senior editor at ASME.org.

Anticipated BUT Unwelcome

Even as gas turbines get bigger and better than ever, small problems beset new products—and the industry. BY LEE S. LANGSTON



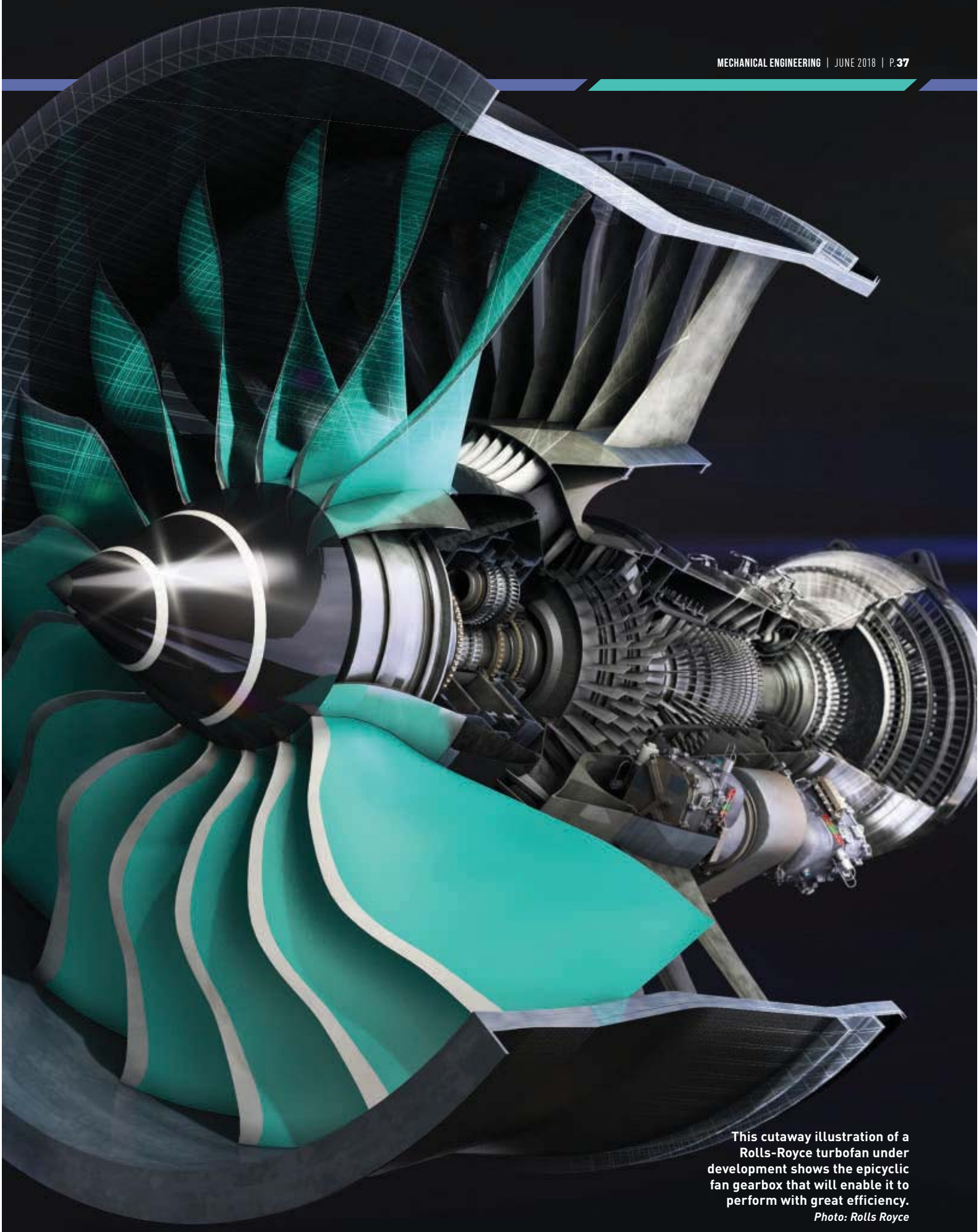
The launch of a new jet engine by a manufacturer can be a multi-billion dollar effort. Financial projections and executive careers hang on a smooth roll-out of the new technology.

Engineers know better. It is normal—even expected—that "new engine" problems should crop up when these machines first go into service. I remember that, as a young engineer at Pratt & Whitney in 1970, our team ran into problems with the introduction of the JT9D, the engine that powered the first Boeing 747s.

Today, two innovative jet engines are being launched to power new twin-engined single-aisle, narrow-body commercial aircraft. A lot is riding on these two new planes, the Airbus A320neo and the Boeing 737MAX. Yet, production of these aircraft is currently being delayed, in part, by the "new engine" problems being ironed out in their power plants, Pratt & Whitney's PW1100G geared turbofan engine and by CFM International's LEAP turbofan engine. Both of these new engines are in the 20,000-30,000 pounds thrust range and are demonstrating double-digit fuel savings, as high as 20 percent on longer flights.

To look only at the PW1000G, since that engine entered commercial service in January 2016 on a Lufthansa Airbus A320neo flight, Pratt has had problems that have included engine seals, combustion liners, and fan blade production issues. To be expected by engineers, perhaps, but frustrating to the rest of the company.

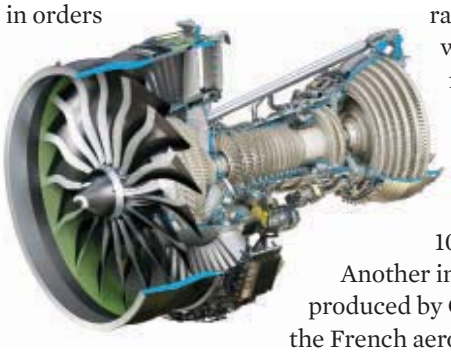
Such is the state of the gas turbine industry as a whole. The industry is beset by a myriad of problems that, while not exactly predicted, were at least predictable. The biggest parts of the industry are thriving, however, and even the areas where production is slipping, the problems seem temporary and easily surmountable.



This cutaway illustration of a Rolls-Royce turbofan under development shows the epicyclic fan gearbox that will enable it to perform with great efficiency.
Photo: Rolls Royce

According to *Aviation Week*, the last three years of operation have generated more profit for the commercial airline industry than the previous 30 years combined. That fire hose of money has led to new orders for commercial aircraft—combined, Boeing and Airbus have a 12,000-unit backlog of orders—and as a result, production of commercial aviation gas turbines is in full swing.

Engine manufacturers such as Pratt & Whitney, Rolls-Royce, General Electric, Safran, and others have taken this surge in orders as an incentive to develop new technology.



General Electric, for instance, is in the midst of developing the world's largest jet engine, the GE9X. Designed to produce just over 100,000 pounds thrust, the GE9X has an inlet fan diameter of 134 inches—a span of rotation equal to the 6 seat-across cabin width of a Boeing 737. The nacelle housing the GE9X exceeds a B737 fuselage width by more than two feet. This behemoth engine will be an attention getter at airport passenger terminals when it begins deployment on the new Boeing 777X 400-passenger jet beginning in 2020.

With a large frontal area, commercial aircraft turbofans are designed to produce peak thrust at takeoff, with most of the thrust produced by air drawn in by the fan and bypassing the jet engine core itself. Bypass ratios—the mass of fan air bypassed for every unit mass of air through the engine core—are currently as high as 9:1 on GE's GE90, used on Boeing's current 777s. As the bypass ratio is increased, engine fuel consumption goes down.

The new GE9X is designed to have a bypass ratio of 10:1. That ratio, together with a high aerodynamic loading fan design that features only 16 carbon-fiber fan blades instead of the customary 20 to 30, will enable the GE9X to improve its fuel efficiency over the GE90 by 10 percent.

Another innovative engine is the LEAP, produced by CFM, a joint venture of GE and the French aerospace company Safran. The CFM LEAP engine had its first commercial flights last year, in May on a Malindo Air Boeing 737MAX and in August on a Pegasus Airlines Airbus A3209neo. These high-efficiency engines are widely anticipated by airlines, and the high number of orders have led to production delays.

But as should be anticipated, the LEAP experienced some new engine problems of its own.

The GE9X (see cutaway illustration) will be the world's largest jet engine, with an inlet fan diameter of more than 11 ft. It will power the Boeing 777X.

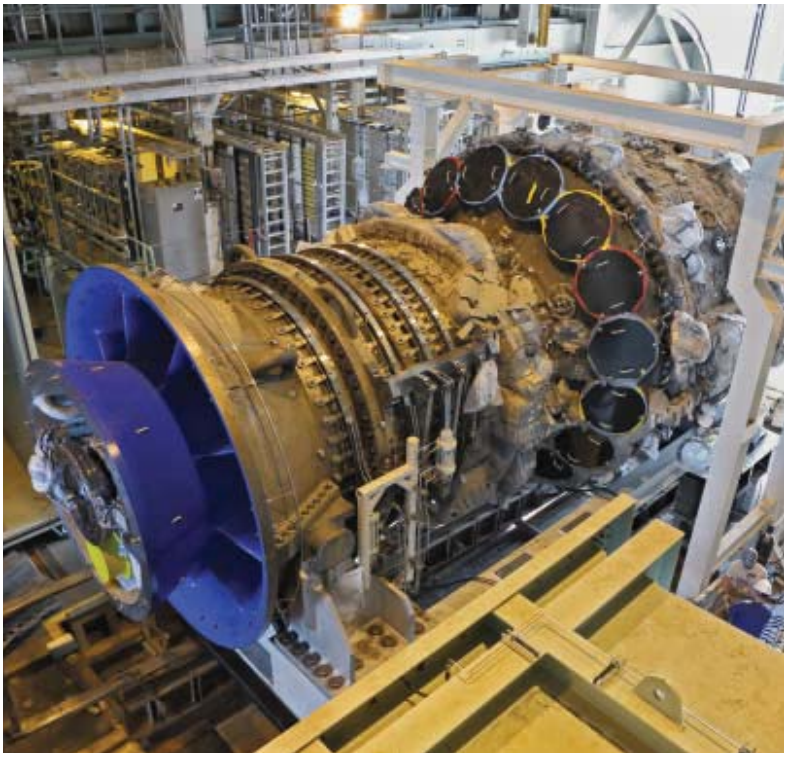
Photos: General Electric and Boeing

Cracks were discovered in a batch of low-pressure turbine discs, and recently a borescope inspection on one engine in service revealed the coating on GE's new innovative ceramic matrix composite high pressure turbine shroud had started flaking off. This is an important durability issue, since the coating protects the CMC from destructive chemical reactions with turbine gases.

The push into the technological frontier does bring rewards. For instance, the P&W epicyclic fan gearbox—the technology that sets the PW1000G apart and upon which the whole effort depends—has proved to be robust and trouble free. Its overall performance has met and exceeded targets for both fuel savings and engine noise reduction. In addition to powering the A320neo, Pratt's geared fan engines are also powering the Bombardier C Series, the Mitsubishi Regional Jet, and Embraer's new E-Jets, and the Irkut MC-21.

As an indication of gearbox success, Rolls-Royce is now developing a geared turbofan for its future engines in the 25,000-110,000 lbt range, slated for production in the next decade. This major OEM will then join Pratt & Whitney and Honeywell, who both have been designing, developing, and producing geared fan engines for decades—Honeywell since 1968.

The above gives some highlights of what is going on in the recent aviation gas turbine market, but a broader overview can be gotten by using data from Forecast International, or FI, a market research firm in Newtown, Conn. FI reports on the total gas turbine market, dealing with both aviation (commercial and military) and non-aviation (electrical power, mechanical and marine).



A GE 9HA turbine being readied for testing at a facility in Greenville, S.C. One such turbine makes up part of an 826-MW combined cycle plant that operates with better than 64 percent efficiency.
Photo: General Electric

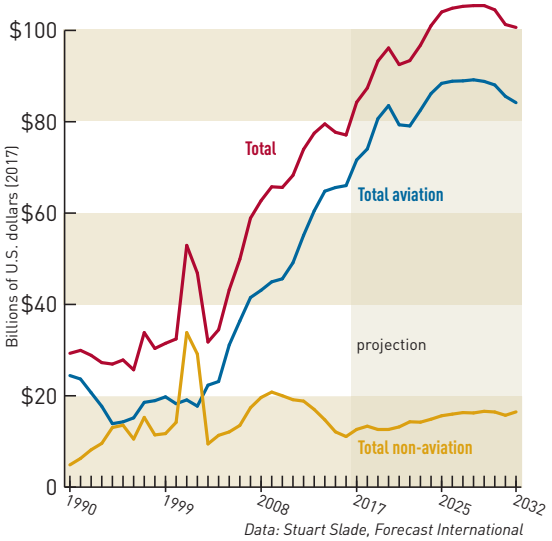
Using FI's computer models and extensive database, analyst Stuart Slade has provided the value of gas turbine manufacturing production from 1990 to 2017, and has projected values to 2032. FI considers value of production figures to be more accurate than reported sales figures.

Slade reports that the value of production for all gas turbines worldwide for 2017 was $84.3 billion, up from $77.1 billion in 2016. FI predicts that by 2032, production will reach $100.6 billion, representing a 19 percent growth in 15 years. Based on FI's value of production history and predictions, the worldwide gas turbine industry is and will be a global growth energy converter industry.

For 2017, FI data shows that the value of production of all aviation gas turbines was $71.6 billion or 85 percent of the total gas turbine market. Of this, $63.4 billion was for commercial aviation with the remaining $8.2 billion for military.

Although the military portion is only 11 percent of the total aviation market, it is very significant. Advanced technology developed for military jet engines, such as single crystal blades and film cooling, have historically provided for performance improvements in commercial and also non-aviation gas turbines.

GLOBAL VALUE OF PRODUCTION FOR GAS TURBINES, 1990 - 2016 AND PROJECTION TO 2032



Data: Stuart Slade, Forecast International

Pratt & Whitney's 40,000 lbt F135, the engine that powers the F-35 Joint Strike Fighter, is currently the largest military jet engine program. The fighter is currently being deployed in large numbers and now is being purchased by U.S. allies. The U.S. Air Force Adaptive Engine Transition Program is underway to use mature adaptive technology to eventually provide a future replacement for the F135 engine in the mid-2020s.

Another program may torch off the development of new gas turbine technologies. As I and many others have pointed out, the most advanced, most extreme, most superlative-laden military engine ever built was Pratt & Whitney's J58, which powered the SR-71 Blackbird. This supersonic reconnaissance aircraft, which flew at Mach 3.2 at 100,000 feet, was in service from 1963 to 2001. Recent news reports suggest that a Mach 6 "SR-72" is being developed. Who knows what will be needed to power that hypersonic aircraft?

For 2017, the analysis of FI's Stuart Slade shows that the non-aviation gas turbine market amounted to $12.64 billion, a 16 percent increase from 2016. Over the next 15 years, FI predicts the value of production for that market will grow by 30 percent, to $16.5 billion.

The 2017 non-aviation portion is subdivided as follows: Electrical power gas turbines amounted to $10.16 billion; mechanical drive gas turbines, used mostly to drive compressors to boost pressure along natural gas lines and for liquefaction natural gas plants, amounted to $1.85 billion; marine gas turbines used to drive generators for propulsion and shipboard electricity, amounted to $0.63 billion.

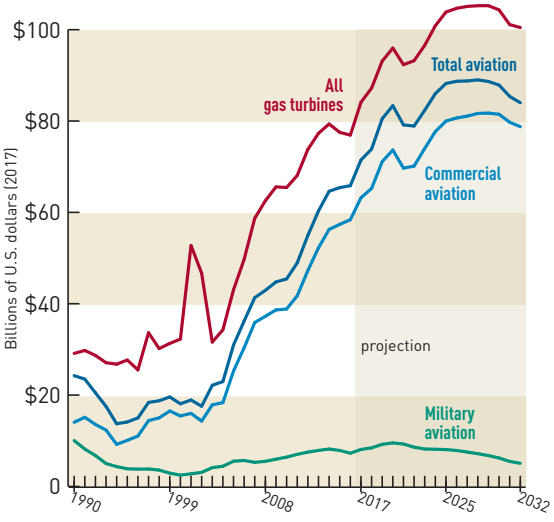
The most fuel-efficient systems for electric generation are gas turbines in combined-cycle plants, where gas turbine exhausts are used to produce steam to drive a steam turbine. Such systems are becoming increasingly popular among electric generating utilities and operate under base load conditions in many regions of the country. According to the U.S. Energy Information Administration, natural gas fired combined-cycle units accounted for 53 percent of the 449 GW of total U.S. natural gas-powered-generator capacity in 2016.

To get a sense of how efficient these plants can be, Mitsubishi Hitachi Power Systems recently reported that their M501JAC gas turbine powered combined-cycle 575 MW unit had achieved 64 percent thermal efficiency. GE has also announced that their 9HA.02 gas turbine powered 826 MW combined-cycle unit had exceeded 64 percent thermal efficiency. Siemens has introduced a new H L-class gas turbine, forecasting combined-cycle efficiencies approaching 65 percent. As an academic, I await thermodynamic text book authors to formally document these gas turbine powered combined-cycle plants as the most efficient heat engines yet produced by mankind.

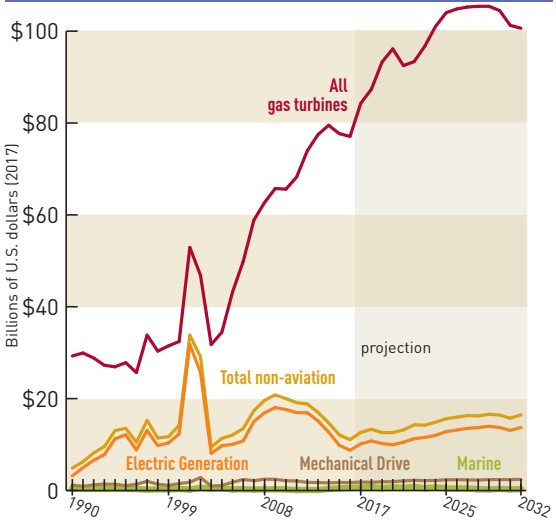
So, given past market trends, favorable predictions, and proven technical performance, one would expect electric power gas turbine OEMs to be gearing up to reap future market rewards.

Instead, 2017 saw continuous reports of gas turbine manufacturers being forced to restructure

GLOBAL VALUE OF PRODUCTION FOR AVIATION GAS TURBINES



GLOBAL VALUE OF PRODUCTION FOR NON-AVIATION GAS TURBINES



Data: Stuart Slade, Forecast International

The SR-72, shown in an artist's rendering, is being developed as a reconnaissance plane capable of flying at Mach 6. It would replace the storied SR-71 Blackbird.

Image: Lockheed Martin

their power businesses. GE, which two years ago acquired Alstom's power business (proclaimed by one pundit as the "best deal in a century"), in December announced it would reduce its global power workforce by about 12,000. In November, Siemens reported it would cut 6,900 jobs, given that the power generation industry is experiencing disruption of an unprecedented scope and speed. Mitsubishi Hitachi is also looking at ways to reduce its cost structure to match cuts its competitors are making.

Some of these trends were foreseeable, and last year in my annual industry recap I listed some trends that were adversely affecting this segment of the gas turbine market. Those factors—such as the great efficiency of combined-cycle plants reducing the need for more gas turbines, the uncertainty of the future of coal power prompting owners of those assets to run them into the ground to produce income while they still can, and the surge of wind and solar power facilities warping the electricity markets such that some gas turbine power plants often operate at a loss—still seem to be in force this year.

The result is that the rosy forecasts for electricity-generating gas turbines, which were underlying the industry only a few years ago, seem to be on hold indefinitely. Within the 15 year forecast window, FI does not foresee the value of production for these gas turbines reaching the level of ten years ago, let alone that of the spike of the early 2000s.

This is the sort of difficulty that could have been anticipated, but wasn't. Much like the new engine problems that vex jet manufacturers, however, they should be worked out in time. The technology is too good, and the need is too great. ME

LEE S. LANGSTON is professor emeritus of mechanical engineering at the University of Connecticut in Storrs and a frequent contributor to *Mechanical Engineering*.

TO LEARN MORE

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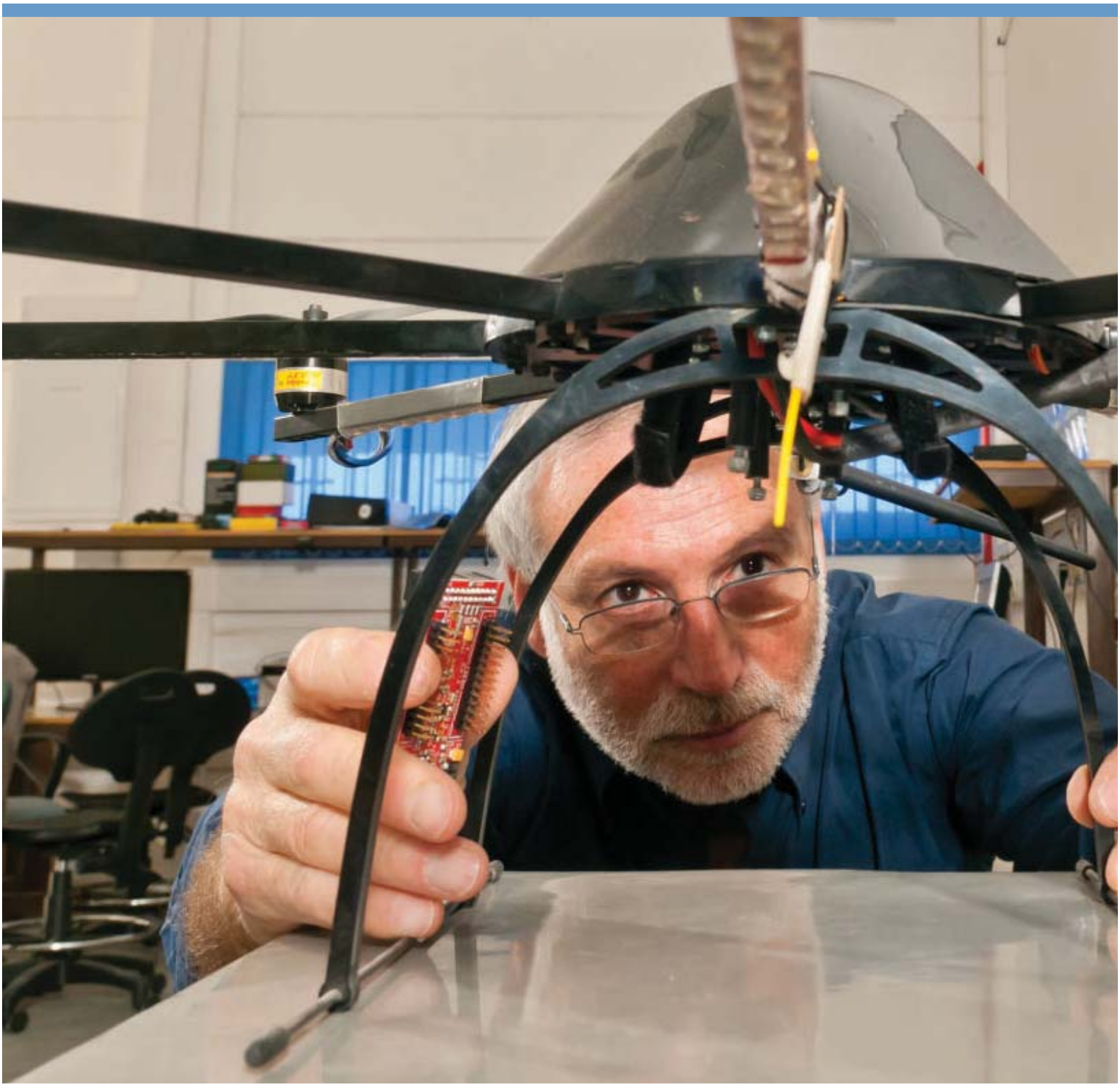

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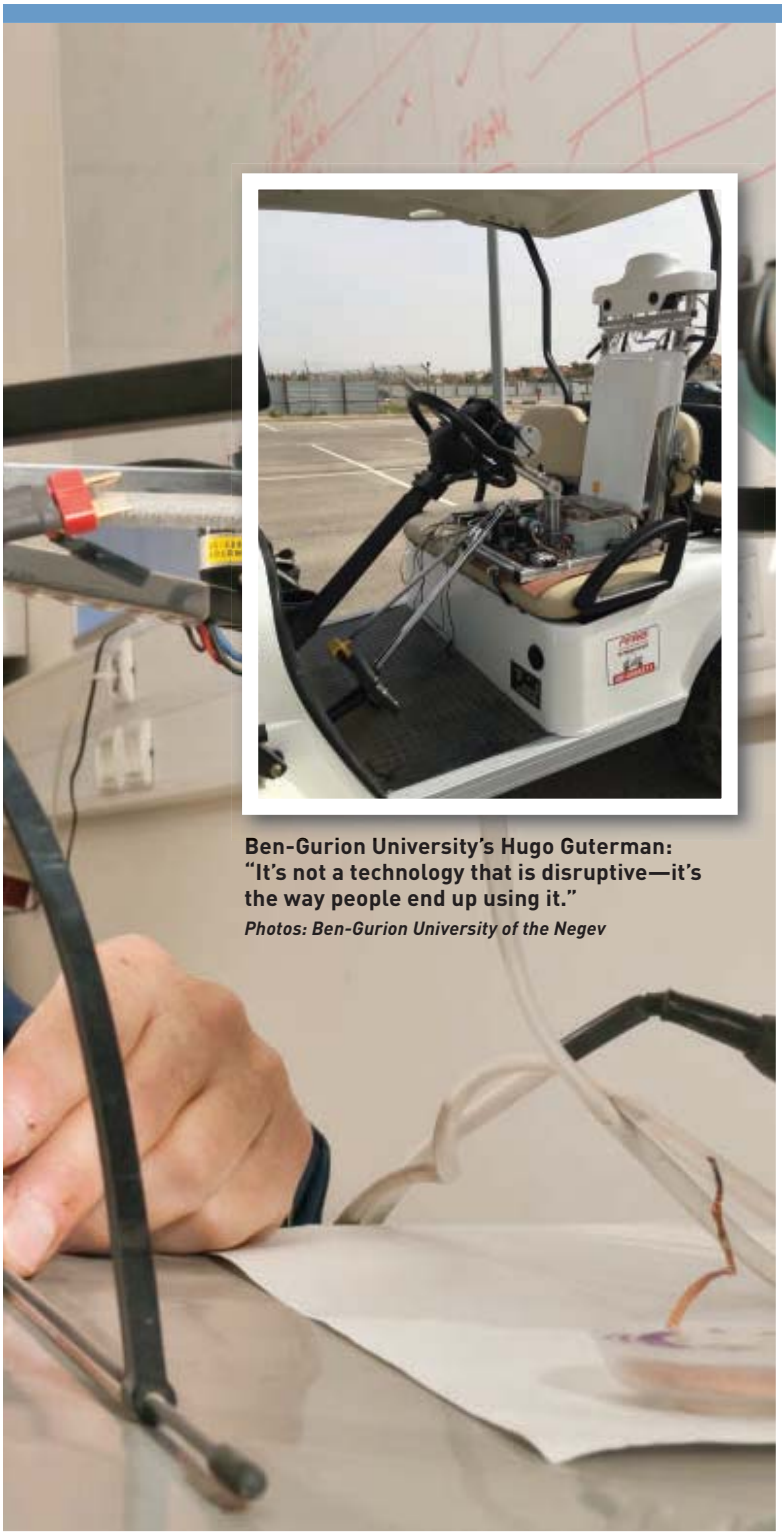


Ben-Gurion University's Hugo Guterman: "It's not a technology that is disruptive—it's the way people end up using it."

Photos: Ben-Gurion University of the Negev

Viable

IN TODAY'S DIGITAL AGE, CAN TRADITIONAL MANUFACTURING COMPANIES HARNESS DISRUPTION BEFORE IT ENGULFS THEM?

BY KAYT SUKEL

Automakers and other traditional original equipment manufacturers are well aware that their companies are ripe for disruption, Simon Euringer, head of the Silicon Valley-based BMW Group Technology Office USA, said.

"There is a certain sense of urgency—because we have seen so many strong players who have been made redundant in so many industries," he explained. "We are paying attention. Because we understand that so many technologies that have turned out to be disruptive to a legacy player were started by someone who wasn't even in the realm of the business they were about to disrupt."

That's a critical point. Google did not need a press to upend the newspaper and magazine publishing industry. Netflix didn't change one physical aspect of the DVD. And many still argue that a basic Nokia phone, knocked out of the mobile phone market by Apple's iPhone, was a better example of physical engineering than the smartphones that replaced it. But data—in wily and unanticipated ways—found ways to determine who would reign supreme even among the most sophisticated physical objects.

Everyone seems to have a favorite disruption story. Inside business school classrooms, outside C-suite conference rooms, or on the stages of the latest viral TED talks, you'll hear riffs on David and Goliath. These tales inevitably highlight how strong, successful manufacturing giants were taken down by young disrupters like Uber, Google, SpaceX, and Netflix. These companies, and others like them, changed the direction of entire industries. The stories serve as an inspiration for budding entrepreneurs—and, increasingly, a warning for even the most competitive manufacturers.

"Simply stated, disruption is the convergence of technology and business model innovation that makes it possible for entrepreneurs and companies to create new products and services," said Tony Seba, an entrepreneur and author of *Clean Disruption of Energy and Transportation*. "Disruption can help transform or even create entirely new markets—and, in doing so, have the power to destroy the investing industry that's been transformed."

Often, that transformation is digital in nature. Take Kodak, a company that was long considered the very model of American innovation. Fun fact—Kodak created the very technology that changed the way the world takes and shares photographs and that ultimately brought about its ruin: the digital camera. Where mechanics and physical assets once ruled the day, bits, bytes, and pixels became the new foundation upon which the image market was built.

"'Kodak moments' was a marketing phrase that everyone used to know and use," said Tom Mayor, an industrial manufacturing strategy practice leader with KPMG. Kodak's photographic film was the medium on which families captured their vacations and memories, he explained. Kodak dominated the film market, which it primed by churning out easy-to-use cameras. Today, a much diminished Kodak makes business printers.

"This was a fantastic manufacturing company," Mayor continued. "But digital capabilities are offering new ways to improve all manner of productivity and inefficiency improvements across manufacturing in quite extreme ways, offering new capabilities with the power to transform the market. You have to find a way to keep up, or risk getting left behind."

Keep up or risk getting left behind. That mandate raises a critical question for today's manufacturers: how can large corporations, especially those that specialize in mechanical products like aircraft, rockets, cars, and other machinery, stay viable in the digital age? Can they harness disruption before it engulfs them?

Disruption in the Data

Today, Seba said, manufacturing companies need to understand that they need core competencies in both the physical and digital realms to endure. This is true even in industries that traditionally see themselves solely as creators of physical assets.

"Everything is digitized nowadays," he said. "And that data can give you critical information to make your physical assets even better. So you can't think of the physical and digital separately anymore. You just can't."

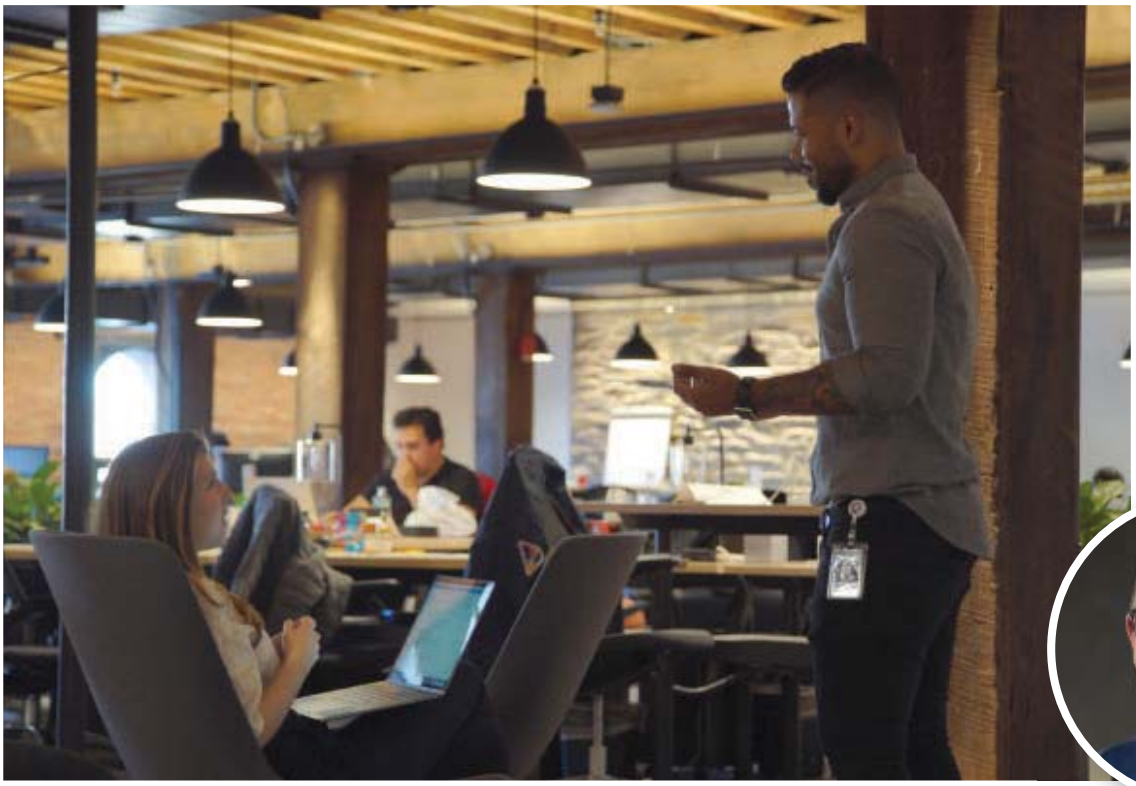
It is the data, even more than the digital connectivity, which makes marketplace disruption possible. For many startups, the only way to challenge established companies is to use data the way David used his sling, to even the odds.

Many of these startups are tiny. To succeed, they must become experts in sensing the right information, knowing what to retain and what they can safely throw away, and mining the amassed data to boil it down into actionable intelligence to drive software and engineering initiatives.

A company that offers plug-and-play manufacturing analytics to small factories or harnesses additive manufacturing to print a

Kodak's Steven Sasson invented digital cameras in the 1970s, but the company never profited from the technology. Today, SpaceX's reusable rockets are disrupting the space launch industry.

Photos: Kodak and SpaceX



United Technologies' Vince Campisi: UTC understands electronics, but it built a small research center in Brooklyn to tap the current of the latest digital technologies.

Image: United Technologies

car or turbine engine is not going to threaten industry leaders today. Yet software and data scale quickly.

Spotify took just 12 years to reach 2017 revenues of $5.5 billion while replacing CDs with streamed music. In less than 10 years, Airbnb grew to $2.6 billion while unsettling the hospitality industry. Uber, also less than 10 years old, brought in $7.4 billion as it replaced taxis.

Digital technology has enabled small startups to upend industry after industry. These David and Goliath stories are nothing less than startling. They also encourage small startups to set their sights on industries whose barriers to entry once ran into billions of dollars.

To keep up, legacy OEMs need people on board who can keep up with these startups. And, given the speed of digital change, they need to get up to speed quickly. This is the reason why BMW's Euringer stresses urgency.

Vince Campisi, chief information officer of United Technologies Corp., agrees.

"Our industries will be written in code, going forward," he said. "The next chapters will be written in data. And that's what we really need to harness when we think about disruption and using it as a vehicle to grow our business results."

Lightning in a Bottle

As manufacturing giants across the globe seek to improve their fusion of digital and physical engineering, they are seeking investments—in technologies and digital startups—to guarantee smooth sailing in disruptive markets, KPMG's Mayor said.

Essentially, they are trying to capture "lightning in a bottle." If this sounds easy, it is because we can look back and see which technology or business model gained prominence. History teaches us that no one can say, definitively, which technologies—and the ways we apply them—will be game changers and which ones will be only flashes in the proverbial pan.

"Many players in both automotive and aerospace are making active efforts to get out in front of this," Mayor said. "They know it's not something that can be ignored. But the way these new technologies change markets are often unexpected. How can you know which way to go?"

Trying to innovate from within is a tough proposition. Most large-scale manufacturing companies are simply too large and structured to foster true innovation, Seba argued. The very bureaucracies and procedures that help them do what they do best—make products—often get in the way of creative adaptation.

BMW's Simon Euringer: BMW may have opened an autonomous driving campus near Munich, but it also operates a Silicon Valley research center.

Photos: BMW

"Disruptions usually come from the outside," he explained. "It doesn't mean that it can't be done from the inside, but it's hard. You need a very agile organization that can not only anticipate the disruption but also identify the right way to act on it. That's why we see many companies looking at Silicon Valley, and the companies there, to help them figure out a way forward."

That often involves acquisitions. According to Accenture, nearly one-third of companies who acquired or merged with another company over the past two years describe themselves as traditional companies acquiring digital companies. Of those who completed five or more deals, half were done to gain digital capabilities.

Companies are also forging unique partnerships with academic laboratories and small companies in hot tech communities. OEMs look to Pittsburgh for robotics, to Israel for machine learning and to New York for intelligent building technology. Companies are going to where the technologies are being nurtured and developed.

Despite Seba's warning, others hope to innovate from within. United Technologies Corp. just opened its own digital accelerator in Brooklyn, N.Y. Its mission is to translate new technologies into ways to serve UTC's aerospace and smart building businesses. Campisi said this approach allows them to cultivate technologies that can integrate "within the fabric of the company."

"We are trying to balance our approach with a 70-20-10 model," he said. "We spend 70 percent optimizing the core of our business, the things we've historically done really well. Then we have 20 percent allocated to the new things where software and analytics can improve what we're doing today or potentially broaden a particular customer segment. That last 10 percent? That's

AIRBUS DIALS INTO SILICON VALLEY

When Elon Musk first shared his idea for a low-cost, reusable booster rocket with commercial satellite launch companies, they essentially blew him off. Now, his SpaceX Falcon 9 dominates the orbital launch business.

Airbus did not want to be caught unawares again, so it launched an outpost in Silicon Valley to explore unusual concepts. These include (from left to right) Vahana, an autonomous electric vertical take-off and landing passenger craft for cities; Transpose, a modular aircraft interior system; and Voom, an affordable helicopter service.

VAHANA

about the moon shots, the things that could be disruptive in the future."

Such moon shots, however, Euringer said, can't be mandated by the traditional business hierarchy. He says the BMW Group Technology Office's mission is to simply "surprise" the folks back in Bavaria.

"This doesn't work if headquarters is giving us requirements," he explained. "Surprising them means doing the work to offer something they wouldn't have done if the Technology Office did not exist. We are here to remind them that just because something has always been done a certain way, that doesn't mean it necessarily has to stay that way because times, technologies, and behaviors change."

While there is no blueprint for successfully harnessing disruption, Mayor said, large companies looking for ways to embrace the digital world do have an advantage over small start-ups.

"The cool thing is when a Fortune 500 does manage to capture something, they know how to scale things," he said. "They have presence in markets around the world, they have armies of manufacturing engineers that can actually take a product and figure out how to deliver it in a warrantable form. There's a huge amount of power in OEMs when they do catch these new technologies, because they can make them real and scalable in a hurry."

Revolution or Evolution?

Of course, it does not always work out that way. Too often, said John Dolan, a professor at Carnegie Mellon University's Robotics Institute who is working on autonomous automobiles—which many believe will be the next great industrial disruption—when companies try to "catch" disruption, they fail. This is because they cannot see the forest for the trees as they race to be first in a particular market.

"Right now, at least in autonomous automobiles, what I see is that many of the large automobile companies are developing a lot of the same things," he said. "Maybe their way has a little special twist, but we seem to be trying to solve the same problem over and over again. That makes it hard to be truly disruptive."

But Hugo Guterman, head of the Laboratory for Autonomous Robotics at Israel's Ben-Gurion University of the Negev, who is currently working on an autonomous robotic chauffeur instead of an autonomous vehicle, says, ultimately, it's not a technology that is disruptive—it's the way that people end up using it. And that's important to remember.

"With all this data, we are entering the second industrial revolution," he said. "There are already so many technologies being developed in universities and industry that have the power to disrupt companies, markets, and even society. But I don't know if we understand how they will do that yet."

His graduate student, Oded Yechiel, agrees. And he suggests that digital disruption is more of an evolution than a revolution when it comes to changing physical industry.

"These markets are evolving as these new technologies become available," he explained. "But, to a certain extent, disruption is part of that evolution. There have always been companies that have been strong and then fell when a new technology came about. It's the nature of things.

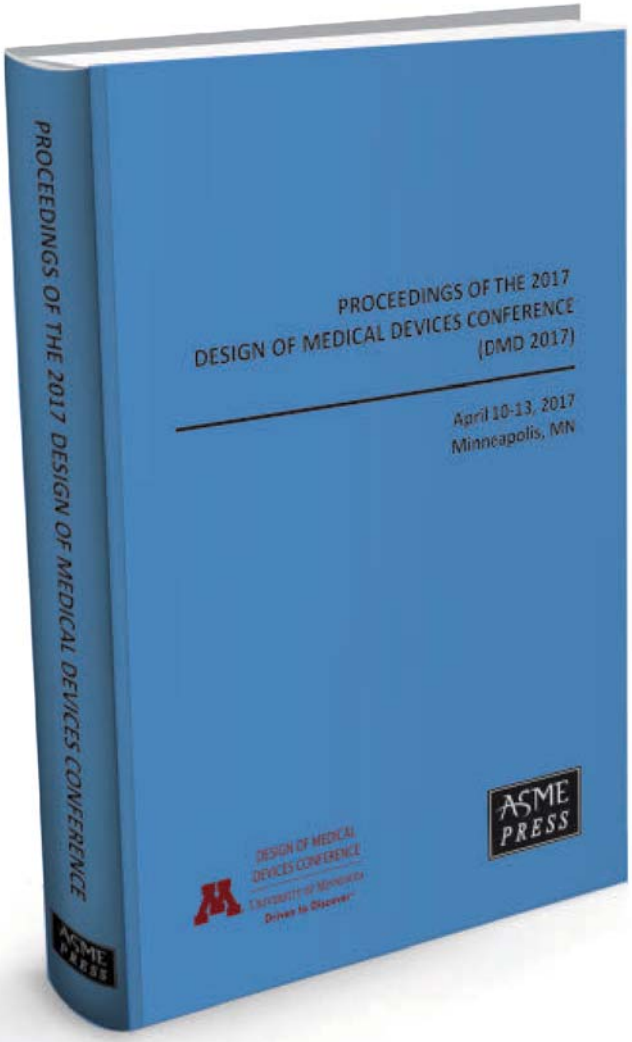
"But if bigger companies can get past their bureaucracies and regulations, to work with small companies and also laboratories that can really think outside the box, there is always the possibility to move forward."

And in doing so, perhaps, those companies can become the next big disruption story. ME

KAYT SUKEL is the author of *The Art of Risk*. She covers science and technology from outside Houston.

TRANSPOSE

VOOM



FEATURED

PROCEEDINGS OF THE 2017 DESIGN OF MEDICAL DEVICES CONFERENCE

ASME Press Books, 2 Park Avenue, New York, NY 10016. 2017.

Biomedical design is a field rich in possibility. The annual *Design of Medical Devices* conference brings together medical device designers, manufacturers, academic researchers, and representatives from public sector stakeholders—all of whom attend to find out where the cutting edge of biomedical design is and where the fast-moving field is going. This volume brings together papers given at last year's event, which was held in Minneapolis. The topics are far-ranging, including the use of smartphone-based virtual reality imaging, 3-D printing of models and implants, and haptic feedback systems in prosthetic limbs.

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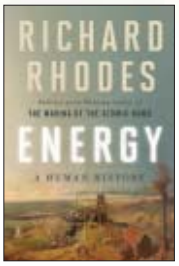
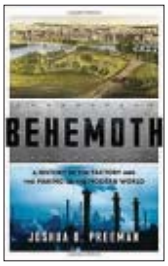


ENERGY: A HUMAN HISTORY

Richard Rhodes
Simon & Schuster, 1230 6th Ave, New York, NY 10020. 2018.

The term energy transition can seem abstract, but Pulitzer Prize-winning author Richard Rhodes makes the topic come alive by telling the story through characters as varied as Queen Elizabeth I, Benjamin Franklin, and Henry Ford. In the process we can trace the energy transitions from animal traction and wood to coal, then how coal made room for oil, and now the move to natural gas, nuclear power, and renewable energy. Each new discovery opened a world of opportunity but then presented challenges no one could have anticipated. The new energy paradigm of zero- and low-carbon sources promises clean and bountiful power, but Rhodes contends we should be wary of unforeseen pitfalls ahead.

512 PAGES. $30. ISBN: 978-1-5011-0535-7.



BEHEMOTH: A HISTORY OF THE FACTORY AND THE MAKING OF THE MODERN WORLD

Joshua B. Freeman
W. W. Norton & Company, 500 5th Ave # 6, New York, NY 10110, 2018.

Freeman, a historian at Queens College in New York City, examines the development of extraordinarily large factories that arose at the turn of the 20th century, churning out steel and vehicles on scales unfathomable just decades earlier. Those plants could trace their roots to the beginning of the Industrial Revolution, but the new industrial facilities that arose in the 1920s and going forward started to shape not just the economy, but art and culture. "Understanding the history of giant factories can help us think about what kind of future we want," Freeman writes, and while we tend to think about factory work with sepia-hued nostalgia, Freeman would contend we are living in a factory-dominated world even today.

448 PAGES. $27.95. ISBN: 978-0-3932-4631-5.

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DYNAMIC SYSTEMS & CONTROL

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PRECISION AGRICULTURE:

ROBOTS HELP FEED THE WORLD

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Agricultural Robotics: Technology to Feed the World

Technology will be an important driver in future agriculture, and robotics will play an important role in order to obtain more efficient, environmentally friendly, and sustainable food production for an increasing population. New technological innovations ranging from assistive technology, precision agriculture, agricultural robots and sensor development for land and resource monitoring are expected to significantly impact the day-to-day operational ease and costs of farming. However, to achieve revolutionary advances in the future, technological innovation research needs to converge with various other engineering, socio-behavioral, and humanistic disciplines such as human factors, health and safety, systems engineering and an integrated approach to sustainability in food and farming systems. Such research needs to go hand-in-hand with extension, outreach, education, and farmer capacity-building efforts best achieved through a community participatory framework, to maximize the impact and acceptance of technology in farming.

The average age of farmers has been steadily increasing. As they get older, farmers will deal with impaired vision and hearing, slow reaction times, and many other age-related disabilities such as arthritis. All of these factors may adversely affect their ability to operate equipment safely, resulting in primary or secondary injuries. Additionally, some states are seeing an increase of new and beginning farmers who do not come from, or have less experience in agriculture, including young, women, socially disadvantaged, and military veteran farmers. With a lack of alternative solutions available, robotics is a welcomed approach for assisting a wide variety of farmers with mobility limitations or inexperience that are impeding their ability to work safely, effectively, and productively.

This issue of the *Dynamic Systems and Control Magazine* provides a sample of the challenges that researchers in this area are facing, including a few examples of how they are addressing them. In the first article, Mohammadreza Davoodi, Javad Mohammadpour Velni, and Changying Li, present a system composed of a team of unmanned ground vehicles that cooperate in order to address optimal data collection, which is a key component of precision agriculture.

In the second article, Lars Grimstad and Pål Johan From, present a modular robot that can operate on farms with a wide variety of different growing and production methods which can be found in greenhouses, polytunnels, orchards, and open fields. This is important because farms are typically diverse in the way they grow the crops. It is simply not a viable approach to develop one specific robot for each and every environment found in agriculture.

In the third article, Pål Johan From et al, combine the results presented in the first two articles by introducing the RASberry project, which bridges several current technological gaps through a collaboration between academia, the robotics industry and strawberry growers. This project aims to develop autonomous fleets of robots for the horticultural industry, hence demonstrating the potential for automation in agriculture and addressing the issues faced by the soft fruit industry.

Finally, in the fourth article, Mythra VSM Balakuntala et al, address the need for data-centric approaches for automating and optimizing the growth of animals. The opportunity to increase productivity of the farm by improving safety, resource management and sustainability has been demonstrated but not in a way that is scalable across the entire farm. Accordingly, they develop a system that includes monitoring of the overall herd behavior and productivity, affected by the complex social and physical dynamics of the herds within the farm.

If you have any ideas for future issues of this magazine, please contact the Editor, Peter Meckl **(meckl@purdue.edu)**.

Alexander Leonessa, PhD
Guest Editor, *DSC Magazine*

COVER IMAGE: RÉMY ZAKARIA

AWARDS AND ANNOUNCEMENTS

We would like to take this opportunity to celebrate the achievements of our ASME DSCD members!

Jin-Oh Hahn receives NSF CAREER Award for feedback control in healthcare automation.

Jin-Oh Hahn, Assistant Professor of Mechanical Engineering at The University of Maryland, was awarded a National Science Foundation CAREER Award for his proposal on "Enabling 'White-Box' Autonomy in Medical Cyber-Physical Systems". At his Laboratory for Control and Information Systems, Professor Hahn has focused his efforts on physiological closed-loop control for the medical application of cyber-physical systems. This award will enable him to develop control-oriented models of the patient's physiological and pharmacological response to medication and develop resilient multi-variable controllers. With advances in the detection and feedback of patient state of heath, as well as automation event timing and sequencing, he is poised to advance healthcare automation.

Anna Stefanopoulou, Professor of Mechanical Engineering and William Clay Ford Professor of Manufacturing at The University of Michigan delivered a plenary talk at the 56th annual Conference on Decision and Control. Her talk, titled "Control Engineers: the Unsung Heroes of Battery Technology", focused on battery management strategies that have been developed to regulate battery state of charge, state of health, and state of power in order to meet performance demands while minimizing long-term cell damage. She further explored sensor placement and advanced sensing strategies developed to reduce localized hot spots, internal shorts and thermal runaway. Stefanopoulou was recently selected to receive the University of Michigan Rackham Distinguished Graduate Mentor Award and elected to be a Society of Automotive Engineers Fellow.

Anna Stefanopoulou delivered a plenary talk on the complexities of battery performance regulation at the 2017 Conference on Decision and Control in Melbourne Australia.

Xu Chen receives NSF CAREER Award for high accuracy, reproducible, additive manufacturing processes.

Xu Chen, Assistant Professor of Mechanical Engineering at The University of Connecticut, was awarded a National Science Foundation CAREER Award for his proposal "Adding to the Future: Thermal Modeling, Sparse Sensing, and Integrating Controls for Precise and Reliable Powder Bed Fusion". His work aims to develop physics-based, control-oriented thermal models of layered materials for closed-loop control of thermal fields in periodic and near-periodic deposition of thermal energy. His modeling and control strategies will enable technological developments in a wide range of applications, from turbine components to personalized prosthetics.

Lauren Linderman receives NSF CAREER Award for networked sensing and control of cyber-physical components in civil structures.

Lauren Linderman, Assistant Professor of Civil Engineering at The University of Illinois at Urbana-Champaign, was awarded a National Science Foundation CAREER Award for her proposal "Multi-Objective Optimization of Sensor Placement for Reliable Monitoring and Control of Structures". Focusing on civil infrastructure, her work examines sensors and sensor placement to identify and isolate structural response. Her work investigates optimal networked systems through the deployment of cyber-physical sensors and actuators to identify the computational bounds for structural monitoring and control.

UPCOMING CONFERENCES

THE 2018 AMERICAN CONTROL CONFERENCE (ACC)
Milwaukee, WI. Wisconsin Center
June 27-29, 2018

THE ASME CONFERENCE ON SMART MATERIALS, ADAPTIVE STRUCTURES AND INTELLIGENT SYSTEMS (SMASIS)
San Antonio, Texas Grand Hyatt San Antonio
September 10-12, 2018

THE 2018 DYNAMIC SYSTEMS AND CONTROL (DSC) CONFERENCE
Atlanta, Georgia Hyatt Regency
September 30-October 3, 2018

THE 2018 ASME INTERNATIONAL MECHANICAL ENGINEERING CONGRESS AND EXPOSITION (IMECE)
Pittsburgh, Pennsylvania David L. Lawrence Convention Center
November 9-15, 2018

THE 57TH IEEE CONFERENCE ON DECISION AND CONTROL (CDC)
Miami Beach, Florida
December 17-19, 2018

COVERAGE CONTROL WITH MULTIPLE GROUND ROBOTS FOR PRECISION AGRICULTURE

BY MOHAMMADREZA DAVOODI
JAVAD MOHAMMADPOUR VELNI
CHANGYING LI

SCHOOL OF ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY OF GEORGIA

The concept of precision agriculture (PA), as a farming management strategy, has received considerable attention in the last few years [1]. PA is a data-driven strategy for collecting, processing and better management of farm data with the aim of improving the understanding and management of soil and landscape resources in order to estimate and manage the health of crops in a farm. Consequently, it can improve crop productivity (yield) and farm profit that lead to higher environmental quality. Moreover, it assists farmers to make appropriate decisions, as well as automating some basic farming tasks [1], [2].

A key component of precision agriculture is data collection. This article presents a system composed of a team of unmanned ground vehicles (UGVs) that cooperate in order to address this requirement. Ground robots are capable of traveling long distances, carrying large loads, and measuring soil data. On the other hand, the use of multi-robot systems has several advantages in comparison with a single robot system, e.g., in reducing mission time, limiting human exposure to agriculture chemicals, and introducing fault tolerance by assigning another robot to cover the region initially assigned to a faulty robot. Although such a collaboration can be used for site-specific management of crops and developing treatment plans [3], very limited work exists on the collaboration between robots for agricultural use. In [4], the main goal is to design, develop and test a fleet of heterogeneous ground and aerial vehicles to cover various agricultural situations including effective weed and pest control, increasing crop quality and improving the health and safety of production operators. The authors in [5] examine the use of autonomous robotic platforms for experimental testing in agricultural fields. The authors in [6] present an augmented Voronoi partitioning and path planning approach for non-uniform sensor data collection in precision agriculture using unmanned aerial systems (UASs) and then generate focused trajectories about areas of interest, namely stressed areas. In [2], a system consisting of small, low cost UASs and UGVs working together is built for data collection and precision agriculture. The work in [7] has proposed the use of a team of UASs and UGVs for environmental monitoring in greenhouses especially in the presence of obstacles in the greenhouse.

In this article, a new scenario for the collaboration between a team of UGVs, equipped with multi-spectral and hyper-spectral cameras, for precision agriculture with no human intervention is considered to ensure that important areas in the field can be precisely inspected and monitored. This problem can be generally considered as a sensor coverage problem and is formulated as a locational optimization problem. The mobile sensor coverage problem was first formulated as a locational optimization problem in [8] and a distributed control and coordination framework for optimal coverage of mobile sensors was developed. It is worth mentioning that most of the existing literature on multi-robot deployment and coverage control are formulated for (spatially) continuous, convex environments. However, there exist many practical applications that have a discrete nature, such as in assembly, construction, transportation and resource allocation, among many others. Hence, it is necessary to develop a discrete

formulation of coverage algorithms for these applications. Very recently, in [9], [10], distributed algorithms for coverage control of an environment represented as a graph with teams of robots were developed.

On the other hand, in many practical applications, the duration of the coverage task exceeds an agent's maximum energy level. Consequently, to ensure a safe and long-term operation, it is required to propose control schemes that can account for each agent's energy level. However, there exists only a very limited work that explicitly addresses energy-aware control. For example, in [11], an energy-aware coverage control with docking for robotic teams is proposed. In [12], a multi-robot path planning and optimal deployment strategy for a team of micro air vehicles with limited energy reserves and finite recharge times is proposed.

Based on the related literature review, we present an energy-aware coverage control strategy that integrates the two goals of coverage task and using a docking station to recharge. A specific scenario is examined to convert the field into a weighted directed graph. Then, by solving a locational optimization problem, motivated by the recent work of [9] and [10], the UGVs are deployed in the field in such a way as to maximize monitoring and coverage of the areas of interest. In the proposed approach, if an agent reaches a low energy reserve, it leaves the team's coverage formation and will be driven to the closest available base station for recharging. In this case, its teammates appropriately adjust their coverage to support its responsibilities.

The remainder of this paper is organized as follows. Our problem is defined and explained in Section II. In Section III, the process of modeling the field as a graph and also the energy-aware coverage control strategy for deployment of robots are presented. The simulation results are presented in Section IV followed by the conclusion and future work in Section V.

Notation: We use $G(V, E, C)$ to denote a weighted directed graph, consisting of the node set $V=\{1, 2,...,m\}$, the directed edge set $E\subseteq V\times V$, and the specific costs (weights) C. By considering a group of n robots r_i, $i\in\{1, ..., n\}$, $p_i\in V$ is assumed to be the vertex location of the ith robot. Moreover, $N_G(x)$ represents the set of robots (y) that robot x can sense and is designated as the nearest neighboring set of the robot x, i.e., $N_G(x)=\{y\in V|\vec{xy}\in E\}$. Let also $\varphi:V\rightarrow\mathbb{R}^+$ be a distribution density function that represents a measure of information or probability that some event takes place over a field Q. The distance $d(x,y)$ is a function that denotes the cost of the shortest path between nodes x and y. The distance $d(x,y)=\infty$ when there is no path from x to y in the graph.

PROBLEM STATEMENT

Our main objective in this work is to propose a framework for monitoring and inspecting important areas in an agricultural field Q using autonomous vehicles. These regions of interest can be considered, e.g., as plants with biotic or abiotic stresses or with particular interesting phenotypic traits such as flowering in the crop field. Hence, we consider a team of UGVs with limited onboard power, equipped with multi-spectral and hyper-spectral cameras, and propose an appropriate methodology to achieve the above objective.

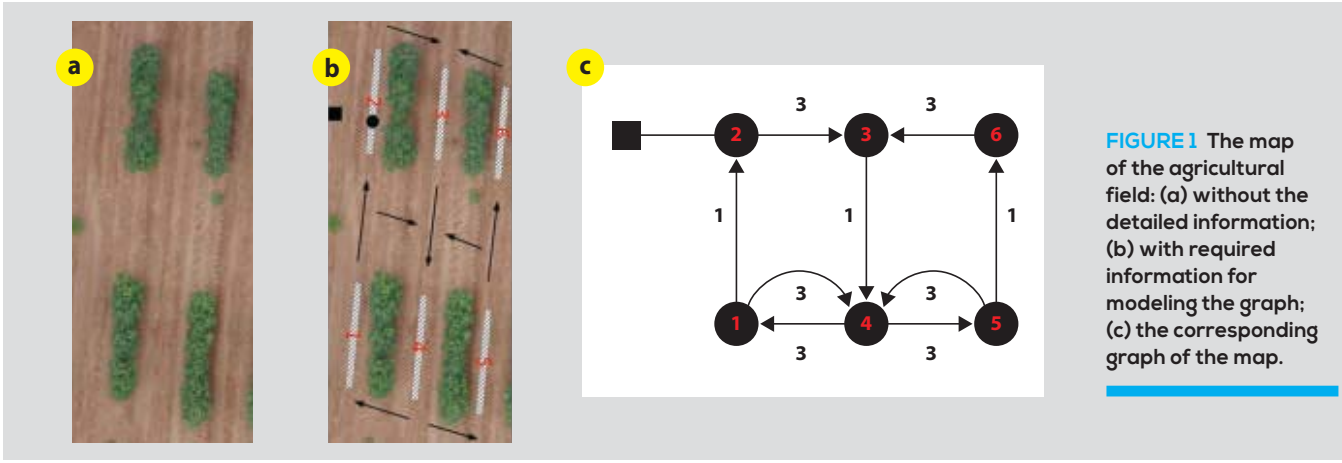

FIGURE 1 The map of the agricultural field: (a) without the detailed information; (b) with required information for modeling the graph; (c) the corresponding graph of the map.

Problem Definition: Distribute the team of n UGVs with limited onboard power and without the use of any type of metric information in a partially known field in such a way that events of interest over the field can be precisely monitored.

Since it is assumed that the robots have limited onboard power, while each robot's energy approaches a minimum level during a coverage mission, we would like it to exit the field Q and return to one of the existing base (charging) stations. At the base station, its batteries can autonomously dock to a charger [11]. To achieve this goal, q base stations with positions $x_{B_i}\in\mathbb{R}^2$, $i\in\{1,...,q\}$ for recharging the robots are considered. It is assumed that r_i is capable of measuring its time-dependent voltage reserve, denoted as $\gamma_i(t)$. Furthermore, Γ_i is defined as the desired voltage level that each robot should maintain before transitioning to one of the base stations. Additionally, with

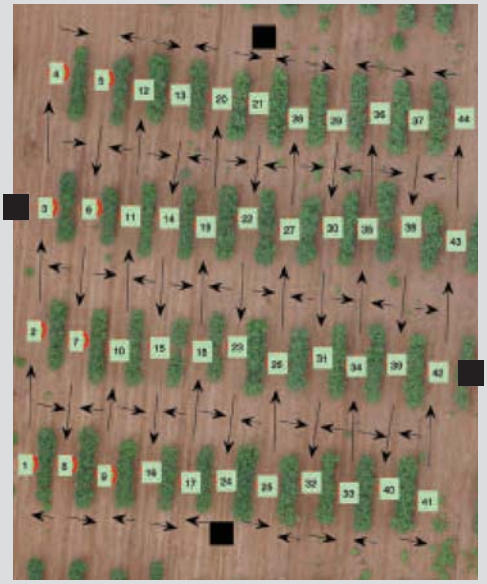

FIGURE 2 The map of agricultural field: Image is captured by a UAS and the map is constructed using MATLAB. The black arrows indicate the allowed motion in each region and constrain the direction of movements of the robots. Numbers indicate the nodes of the corresponding graph.

each base station, a unique access point $x_{E_i} \in V$ is considered. As agents are leaving charging stations, they travel from x_{B_i} to x_{E_i} and enter Q from this position, at which point their coverage control takes over.

METHODOLOGY

In this section, the field is first represented as a topological map so that the group of robots can use it to navigate. Then, by solving a locational optimization problem, the UGVs are deployed in the field in such a way as to maximize monitoring and coverage of the areas of interest.

A. Modeling Field as a Graph

The field is converted into a weighted directed graph $G(V,E,C)$. To obtain the graph, we define nodes as parts of the environment. The considered scenario is based on the methodology first proposed in [10]. To obtain an insight into the underlying process, let us consider a map of agricultural field, as shown in **Figure 1a**. The required information to model the presented field in **Figure 1a** as a graph is shown in **Figure 1b**. Each of the regions next to the plant rows, represented as a hachured rectangular, is considered to be a cell and is associated with a node in V. The black arrows indicate the allowed motion in each region and constrain the direction of movement of the robots. If a robot can move from one node to another, we assume that these nodes are neighbors and add a corresponding edge to E. Given the graph G, a cost (weight) between two neighbor nodes $c(x, y) \in C$, $x, y \in V$ means that, to go from node x to y, a robot must execute a command $l(x,y)$ (such as Go-Straight, Turn-Right or Turn-Left) that will result in a cost $c(x,y)$. In this particular example, for going from one node to another node, one of the following two commands should be executed by the robots, namely: **Command 1**: Go-Straight, and **Command 2**: Turn-Right (-Left), Go-Straight, Turn-Right (- Left). It is assumed that the cost values (weights) *one* and *three* result from Commands 1 and 2, respectively. Moreover, the black square and circle denote, respectively, the docking station and access point for recharging the robots. Based on the above description, the weighted directed graph corresponding to **Figure 1b** is shown in **Figure 1c**.

B. Deployment Strategy

In this section, a distributed strategy is proposed for deploying the robots in the agricultural field modeled with a graph G and with a density function defined over it. To achieve this goal, motivated by [9], [10], the problem of optimally deploying the team of robots on a graph is treated as a locational optimization problem. In this methodology, the graph is first partitioned into n Voronoi regions g_i

$$g_i = \{x \in V \mid d(p_i,x) \le d(p_j,x), \forall i \ne j\}. \quad (1)$$

If $d(p_i,x) = d(p_j,x)$, then the node x is assigned to the robot with smaller index number. Note that the ith robot is in charge of monitoring all the events that occur at the graph nodes in region g_i. Then, the general deployment problem is reformulated as the one of minimizing the following cost function:

$$H(p,G) = \sum_{i=1}^{n} \sum_{q \in g_i} d(p_i,q)\varphi(q) \quad (2)$$

The density function $\varphi(q)$ in (2) is defined over the graph G to indicate the nodes that have higher priority to be serviced. In order to define $\varphi(q)$, by considering a continuous density function over the original field, a large number is assigned to the node corresponding to the center of the

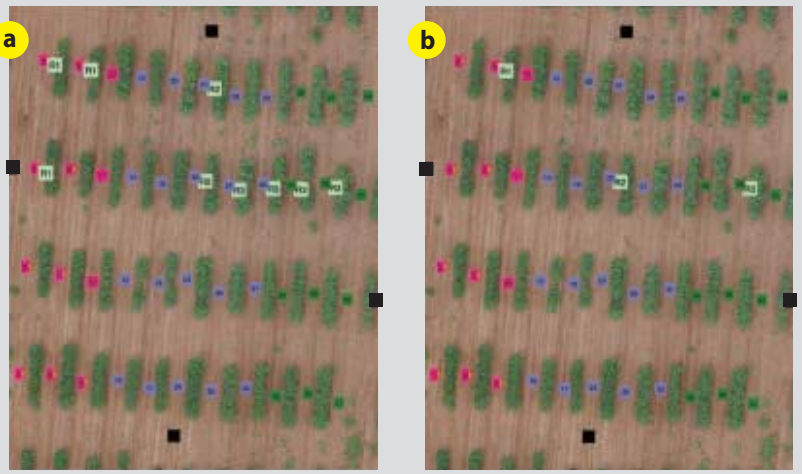

FIGURE 3 The results corresponding to the first region of interest, (a) Voronoi regions and the traversed trajectory by robots, (b) the final deployment of robots.

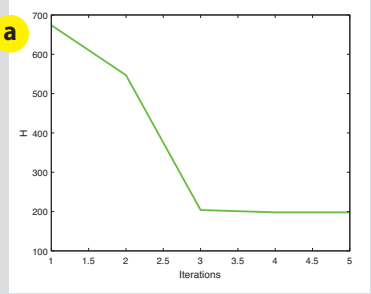

FIGURE 4 *(Above)* Coverage cost for the first region of interest.

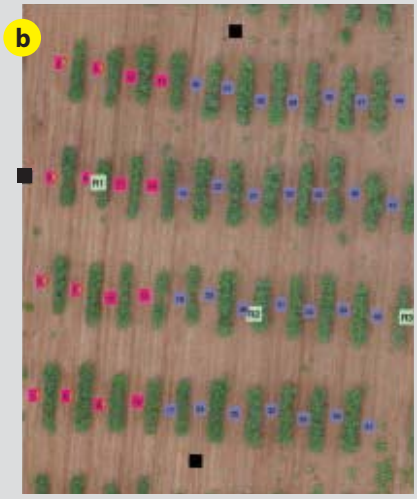

FIGURE 5 *(Right)* The results corresponding to the second region of interest.

density function, and then lower numbers are assigned to the nodes that are far from this node.

Assumption: All the robots have access to the graph G and full knowledge of the density function $\varphi: V \to \mathbb{R}^+$.

The main idea behind our solution method is to generate successive iterations in which the robots are relocated to different nodes in such a way that H decreases until reaching convergence. In fact, these iterations consist of choosing a special node inside the robot subgraph and then moving the robot to this node. Our solution is presented in the form of a distributed control given in Algorithm 1. In this algorithm, we have extended the deployment strategy proposed in [9] to an energy-aware control policy with a fail-safe switching mechanism that permits an agent to drop out of the formation when it determines it can no longer support the coverage task without jeopardizing itself. In addition, Algorithm 2, motivated by [10], is proposed for finding the special nodes inside each robot subgraph.

To summarize, our proposed methodology is applied by implementing the following three steps.

1) After receiving the important regions, they are listed from smaller to larger index number.
2) For each region of interest, a density function is defined over G that indicates the node that has priority to be serviced.
3) Algorithm 1 is implemented for each of the important regions and the process is continued until all regions are effectively covered.

SIMULATION RESULTS

In this section, different aspects and capabilities of our methodology are demonstrated using a case study for the agricultural field shown in **Figure 2**. As shown in **Figure 2**, in our case study, the field is modeled as a directed graph G with 44 nodes. The four black squares in **Figure 2** are the docking stations for recharging the UGVs. Three robots with the initial positions 3, 21 and 27 are considered. Moreover, three nodes 5, 26, 37 are selected as the regions of interest that need more investigation. Based on our approach proposed in Section III, node 5 is first defined as the center of the density function, and so the robots are expected to autonomously relocate such that the whole field is optimally covered, while simultaneously this node is precisely monitored. After some iterations and the change in size of various Voronoi regions contributing to minimize the cost function, the robots converge to their final positions. The results are shown in **Figure 3**. It is worth mentioning that different Voronoi regions are indicated by different colors in this figure. As observed from **Figure 3**, robot 1 moves toward node 5 to monitor it more precisely. The positions of other robots are also changed so that they can effectively cover the whole field. Furthermore, the cost H decreases over time as shown in **Figure 4**.

Next, node 26 is considered as the (second) region of interest. It is also assumed that robot 3 is reaching to its predefined voltage reserve. The final deployment of the robots is demonstrated in **Figure 5**. As observed from **Figure 5**, robot 3 moves to its access point while other robots appropriately adjust their positions for field coverage. Moreover, node 26 is precisely monitored by robot 2.

Finally, node 37 is considered as the (third) region of interest. It is also assumed that robot 3 is now fully charged and returns to the mission from its access point. The final deployment of the robots is demonstrated in **Figure 6**. As observed

TABLE I: ALGORITHM 1: IMPLEMENTATION OF THE DISTRIBUTED CONTROLLER.

Require: Check
1. Check the voltage reserve, γ_i, of each robot.
2. **if** $\gamma_i < \Gamma_i$ **then**
3. $\quad x^*_{Ei} \leftarrow$ Find the closest docking station for recharging.
4. $\quad$ State $\leftarrow$ Recharging
5. **else**
6. $\quad$ State $\leftarrow$ Compute
7. **end if**

Require: Compute
8. Recieve locational information of neighbor robots.
9. Compute the Voronoi subgraph of each robot.
10. $p_i^* \leftarrow$ Find next best point using Algorithm 2.
11. **if** $p_i^* \neq p_i$ **then**
12. $\quad$ State $\leftarrow$ Moving
13. **end if**

Require: Moving
14. Move to p_i^*.
15. **if** $p_i^* = p_i$ **then**
16. $\quad$ State $\leftarrow$ Check
17. **end if**

Require: Recharging
18. Move to x^*_{Ei}
19. **if** $p_i = x^*_{Ei}$ **then**
20. $\quad$ State $\leftarrow$ Compute
21. **end if**

TABLE II: ALGORITHM 2: FINDING THE NEXT BEST POINT.

1. $\mathcal{H}_i \leftarrow$ Compute the cost function of the current position of robot r_i, namely, $\sum_{q \in g_i} d(p_i, q)\phi(q)$.
2. **for** $a \in \mathcal{N}_g(p_i)$ **do**
3. $\mathcal{H}_a \leftarrow$ Compute the cost value for all the neighbor nodes of p_i, namely, $\sum_{q \in g_i} d(a, q)\phi(q)$.
4. $p_i^{\min} \leftarrow$ Find the minimum cost $\mathcal{H}_k$ among the neighbor graph nodes, namely, $\text{argmin}_{k \in \{\mathcal{N}_g(p_i)\}} \mathcal{H}_k$.
5. **if** $\mathcal{H}_k < \mathcal{H}_i$ **Then**
6. $\quad p_i^* \leftarrow p_i^{\min}$
7. **else**
8. $\quad p_i^* \leftarrow p_i$

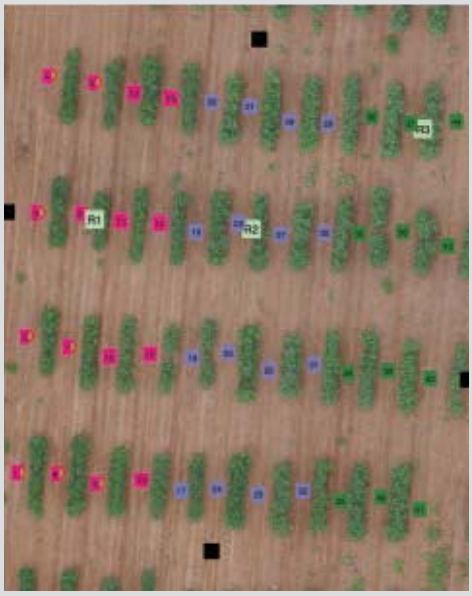

FIGURE 6 The results corresponding to the third region of interest.

from **Figure 6**, the robots converge to their final positions such that node 37 is precisely monitored by robot 3.

CONCLUSION

In this work, collaborative coverage and monitoring of an agricultural field using a group of UGVs was studied. To this end, the field was first represented by a weighted directed graph. The important areas on the field were detected and identified on the graph using a distributed density function. Next, this information was sent as input to a distributed energy-aware deployment strategy. Based on the proposed strategy, the robots were optimally deployed in such a way that coverage of the whole field and monitoring of the areas of interest were maximized so that UGVs could acquire more measurements of those areas. Furthermore, the robots continuously checked their level of energy; when a robot approached its threshold value, the team would cooperatively adjust the coverage formation to allow the robot to visit the closest base station to recharge before rejoining the coverage mission. The experimental validation of the proposed methodology is ongoing research. ■

ABOUT THE AUTHORS

Mohammadreza Davoodi received the M.Sc. and Ph.D. degrees in Electrical Engineering from Tarbiat Modares University, Tehran, Iran, in 2008 and 2012, respectively. Currently, he is a Post-Doctoral Fellow at University of Georgia (UGA), Athens, USA. Before joining UGA, he was a Post-Doctoral Fellow at Qatar University, Doha, Qatar and a Visiting Researcher at Concordia University, Montreal, QC, Canada. His research interests include fault diagnosis, robust control, multi-agent systems, networked unmanned systems, hybrid systems and agriculture robotics.

Javad Mohammadpour Velni joined the University of Georgia as an assistant professor of electrical engineering in Aug. 2012. Prior to that, he was a Research Investigator at the University of Michigan. He has published over 120 articles in international journals and peer-reviewed conference proceedings, served in the editorial boards of ASME and IEEE conferences on control systems and edited two books on control of large-scale systems (2010) and LPV systems modeling, control and applications (2012). His current research interests are in secure control of cyber physical systems and coverage control of heterogeneous multi-agent systems.

Dr. Changying Li is a Professor in the College of Engineering and the Founding Director of the Phenomics and Plant Robotics Center at the University of Georgia. The long-term goal of Dr. Li's research program is to develop sensing and robotics technologies for high-throughput plant phenotyping, precision agriculture, and postharvest biology. Dr. Li's research efforts have resulted in more than 100 peer-reviewed journal articles and conference proceedings. His work has been recognized by several major awards in his professional societies.

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A HARDWARE AND SOFTWARE MODULAR ROBOT FOR THE AGRICULTURAL DOMAIN

FIGURE 1 A handful of Thorvald robots.

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Technology will be an important driver in future agriculture, and robotics will play an important role in order to obtain more efficient, environmentally friendly, and sustainable food production for an increasing population. These robots have to operate on farms with a wide variety of different growing and production methods. Modern food production is extremely diverse with crops grown in environments as different as greenhouses, polytunnels, orchards, and open fields. In this paper we present a modular robot that can operate in all these domains.

Developing robotic systems that can operate across all these domains is important for several reasons. Firstly, farms are typically diverse in the way they grow the crops; even within a single farm, the farmers often produce several different products. Between farms and different regions of the world, the differences are even bigger. There is thus a need for robots that can operate in different domains. It is simply not a viable approach to develop one specific robot for each

BENJAMIN WARD

FIGURE 2 Thorvald modules. A) Battery enclosure module, B) drive module, C) steering module, D) suspension module.

and every environment found in agriculture, as it is too diverse. Some form of modularity is thus required. Secondly, there is a huge opportunity to learn across domains, both when it comes to navigation and the operation of the robot on the one hand, and on the biology and agronomy on the other hand. Finally, using the same robots in different domains will increase the number of robots and will also reduce cost of the robots and make them more accessible to farmers. For all these reasons, we believe there to be several reasons for developing modular robots that can be modified to operate in all these domains.

In this article, we present a robot specifically developed for the agricultural domain which is completely modular both in the hardware and the software. This means that the robot, called Thorvald, can be modified using only standard tools to take different forms and sizes. The robot consists of different modules that can be assembled so that the robot takes different shapes depending on the operating domain such as greenhouses, polytunnels, orchards, or open fields. In addition, each type of robot can take different sizes so that it can adjust to local variations in, for example, track width, terrain, and so on. The robots also come with a software that adjusts to the type and size of the robot so that the same overall control, trajectory planning and intelligence can be developed and used independently of what robot is used. The Thorvald robot is the first completely modular robot that has been developed for the agricultural domain.

SYSTEM OVERVIEW

In this section, we present the modular agricultural robots that have been developed by the authors [1]. In the next section, we look at the various application domains where these robots are currently being used.

Robotic Platform

Thorvald robots are based on a handful of modules that can be combined to create a wide range of robots with different properties. One robot may have all-wheel drive, all-wheel steering, while another may be of a differential drive type, yet another may employ Ackermann steering. They are all supported in both hardware and software. Some of the different types of robots are depicted in **Figure 1**.

Each type of module serves a specific purpose like propulsion or battery storage and the complexity is contained within these modules. Combining modules into a robot can therefore be done by means of simple mechanical and electrical connections. This means that the robot's frame, the structure on which modules are mounted, may be made very simple. The most common way to create a Thorvald frame is by using aluminum pipes and clamps, but it is also very easy to create custom frames.

The modular system also allows robots to be modified or completely rebuilt as needed. A robot configured for one type of environment can easily be reconfigured to fit another. For example, changing the width of the average Thorvald robot is in most cases achieved in a few minutes using only basic hand tools.

Robot Operating System (ROS) is used, and all Thorvald robots run the same software for driving the base. The only aspect separating one robot configuration from another is one configuration file listing the various modules of the robot with key properties like module position in the robot's coordinate frame, communication ID and so on.

The most important modules are depicted in **Figure 2** and described in brief below.

Battery Enclosure

The battery enclosure holds a battery and electronics for connecting to other modules. Battery enclosures may be connected

in parallel to increase the robot's range. The module acts as a connection point for communication and power to other modules. On each robot, one battery enclosure module holds the robot's main computer and low-level logic for managing the robots power system. This module can also be fitted with a weatherproof touchscreen.

Drive Module

The drive module is the drive unit of the robot. It contains a 500 W brushless DC motor connected to a wheel through a transmission assembly. More powerful motors can be used if more power is needed. The reduction from the motor to the wheel is done through two stages, one through a belt and one through a gear in the hub. The gear also substantially lowers the center of gravity for the robot.

Steering Module

The steering module holds a brushless DC motor connected to a transmission assembly with a flange on the output. A drive module connects to this flange. The steering module can rotate the drive module ±180° about a vertical axis so that the wheel of the drive module may be pointed in any direction. The steering module is optional and can be left out if, for example, skid steering is used to reduce the price of the robot.

Suspension Module

The robot may encounter difficult terrain in the farm field. To maintain good traction it is important that the robot maintains all drive wheels in connection with the ground. To achieve this, suspension modules may be fitted between the drive units and the robot's frame. These modules allow vertical travel and thus help the robot keep its wheels in contact with the ground.

Frame

The frame can also be considered a part of the modular design. Normally a very simple standard frame consisting of simple aluminum tubes is used, but there is also an option to design frames that are specifically suited for the application at hand. For phenotyping, for example, a tall frame that gives a higher ground clearance of up to 180cm has been designed. The frame is also well suited to carry sensor systems for navigation and soil and plant measurements.

APPLICATION DOMAINS

The robotic system described above is designed so that it can be transformed into robots that can operate in basically all domains that we find in modern food production. In this section, we will go more into details on what these robots look like and how they operate and navigate in the different domains, such as greenhouses, polytunnels, orchards, and open fields.

Open Fields

A robot for the open field must be capable of traversing rough terrain, including steep slopes and muddy surfaces. It should also be capable of operating in harsh weather conditions. The Thorvald modules were designed with this in mind, and are made to handle rough conditions. Several Thorvald robots have been assembled for open fields. Examples of applications are soil sampling, wheat phenotyping and tillage.

FIGURE 3 A robot for operating in polytunnels.

In the open field there are not many restrictions on the size of the robot, the only parameter that we need to take into account is the track width. This can easily be adjusted with the design of the Thorvald platform by changing the aluminum bars into the appropriate length. The current version of the robot has a payload of 200 – 300 kg. With a total weight of 180kg, this means that it has a payload that is substantially higher than the robot's weight.

The robot can be fitted with two battery packs. Each battery gives the robot about 10 hours of autonomy, so during normal operation the robot will have up to 20 hours of operation without the need to charge.

FIGURE 4 A robot for use in greenhouses.

Navigation in open fields heavily relies on GPS. The standard field version of Thorvald is equipped with GPS, inertial measurement unit (IMU) and odometry. These sensors are used for standard navigation in open fields. In addition, the robot has laser scanners and cameras for obstacle avoidance.

Polytunnels

Polytunnels are used by farmers to obtain a more controlled growing environment and a longer growing season. Inside the polytunnels, plants may grow in beds in the ground, on tables mounted on poles in the ground or on tables suspended from the tunnel itself. In other words, there may be a great deal of variation in infrastructure from one farm to the next, even if they grow the same crop. As this is the case, it is difficult to design a single robot to fit all environments. By using Thorvald modules, it is easy to create custom robots for each farm. If unforeseen requirements to the design should be uncovered after a robot has been assembled, the robots can easily be adjusted or rebuilt on location.

The Thorvald robot is currently used in various research projects in polytunnels. Here the robot is used in plant treatment, logistics tasks and berry picking [2]. **Figure 3** shows a robot configured for operating in polytunnels.

The plastic and steel bars commonly used to construct polytunnels interfere with the GPS signal. The indoor navigation is thus performed using different sensors. For the localization and navigation in polytunnels we use a SLAM-based approach where the robot builds a map and then finds its position in the map using a 2D laser scanner in combination with odometry. Obstacle avoidance is done using the same scanner or a safety laser.

Greenhouses

Robots created from Thorvald modules have been used in greenhouses growing cucumber. Here, plants grow in long rows, stretching from a concrete floor at one side of the greenhouse to a wall at the other side. A set of two long pipes separate consecutive rows of plants. These pipes are primarily used for heating, but double as rails for hand-pushed and semi-automatic trolleys used by workers, either as a platform to get access to the taller plants or for transportation. The concrete floor ends a few centimeters after the pipes start. At this point there is a difference in level of the concrete floor, which makes it extremely critical to hit the rails to prevent the robot from tipping over.

Some greenhouses employ semi-automatic trolleys. These are capable of driving automatically along the plant rows, using the heating pipes as rails. When a trolley comes back after finishing a row, the trolley has to be moved manually by workers to the next set of rails. Other systems use a second robot to move the first robot between the rows.

If a robot is to be in fully autonomous operation in this environment, it must be able to locomote on rails along the rows, and it must also be able to navigate from one set of rails to the next on a flat floor. To achieve this, we created a differential drive robot from Thorvald modules, and fitted it with custom-made double-drive wheels. Each wheel consists of a rail wheel and a rubber wheel of slightly larger diameter. When driving on a flat surface, only the rubber wheels are in contact with the ground. When the floor drops under the rails, the robot is supported by the rail wheels. Caster wheels and passive rail wheels help support the robot when it is driving on flat surfaces and on rails. The track-width has also been made adjustable to accommodate various rail-spacing. The robot is depicted in **Figure 4**.

When the robot is navigating between rows, it uses a laser scanner and a 2D map to localize. The first operation when taking the robot to a new greenhouse is thus to make a map of the area with the concrete floor. Then the rows with the rails are automatically identified in this map and labelled as starting points for each row. During operation, when the robot gets to a set of rails, a 3D camera is used to determine the robot's position relative to the rails. The robot uses this information to align itself to, and center itself in front of, the rails. As the robot enters the rails, it uses an array of downward-facing supersonic range finders to verify that the transition goes according to plan, i.e., that the wheels will in fact drive on to the rails.

There are also greenhouses that do not have rails. In these greenhouses, the plants normally hang from the ceiling over a flat floor. In this case, the robots will look more like the ones that operate in tunnels or open fields. The robots that operate in this environment do not require the same maneuverability as the ones that are being used in open fields or tunnels, so these robots are typically without suspension and in many cases without the steering module.

Orchards

Orchards can be as different as all the other domains mentioned above. Some orchards, for example for apple production in Norway, are found in mountainous areas that require extreme maneuverability, traction, and a low center of mass. Other orchards are far more accessible, especially in large-scale professional fruit production.

The type of produce and infrastructure on the farm determines what robot is more suitable to be used in an orchard, but in general we can use the same robots as for greenhouses and open fields. The navigation, on the other hand, is very different from these, as we typically cannot rely completely on GPS signals, especially if the plants or trees are very high, and there are also less-structured or fixed installations to be used in a LIDAR-based navigation approach as the ones used in greenhouses and polytunnels. In general, this will require fusing different sensors to obtain efficient and robust localization and navigation.

DISCUSSIONS

Modularity has shown to be an extremely important property when developing robots for agriculture. The first robot that was developed was the Thorvald platform for open fields. When we decided to build a robot for greenhouses, we designed and implemented a completely new robot based on the existing Thorvald modules into a completely new robot in a matter of weeks. This shows that there are huge benefits with this modularity when it comes to designing new robots for new domains. Now we have designed 5-6 completely different robots based on these modules.

This allows us to work in several different domains and, more importantly, learn across these domains. We see that even though a solution from one domain is not necessarily directly transferable to a different domain, there is a lot to learn across domains. Robust navigation uses many of the same components in the different environments, which helps to speed up the development when moving from one domain to another. This learning across the domains is not only related to navigation, but also in the operation, setup and user interface of the robot, there is plenty to learn.

We also see that experience in using sensors is extremely valuable. Especially for the phenotyping robots we have done a lot of work on sensors, data collection and data analysis. This experience is easily transferred to other crops and environments, and we see that the experience from these tests can be applied in greenhouses, polytunnels and open fields. This increases the value of the technology, since it is not only applied to the domain for which it has been developed, but also to other completely different domains.

CONCLUSIONS

In this article, we have shown the advantage of the modularity found in both the hardware and the software of the Thorvald agricultural robotics system. We show that it is extremely fast to develop new robots for new domains based on the existing modules. It is also very easy to re-build a robot to fit a new domain so that robots can transition between open fields, polytunnels and greenhouses with very little work. The fact that this is supported in the software adds to the flexibility of the robotic system. This modularity makes the development of new robots and transitions into new domains extremely efficient. This drives the technology and development faster than if a new robot were to be developed for each domain.

Furthermore, this kind of modular robot will be important to make robots a widespread technology to be used on farms across the world. The modularity can reduce the production cost of the robots and make them more accessible to farmers. We also foresee that the value of the robots is higher due to the modularity as we can learn across domains. This will further increase farmers' motivation for taking these system into use at a larger scale. ■

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RASberry –

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The soft fruit industry is very important globally: soft fruit is an important part of a healthy diet and the sector contributes significantly to economies of many individual countries. For example, the UK soft fruit production sector is worth £244 m to primary producers and employs 35,000 people to pick fruit each day. The fruit production is labor intensive and therefore facing many socio-economical challenges. In many developed countries such as the UK, the industry relies mainly on migrant labor which is unsustainable in the long term due to socio-political pressures (e.g. Brexit), labor inflation (higher minimum wages) or changing aspirations of migrant workers. Countries that traditionally do not rely on a migrant workforce face labor shortages due to other problems such as aging population in Japan or after-effects of one-child policy in China.

Soft fruit production involves many operations such as planting, plant care, fruit picking and transportation of the crop to storage facilities. So far, these processes have been very difficult to automate using the current technology due to their complex character. For example, picking strawberries requires advanced cognitive abilities to locate and assess the fruit ripeness and fine manipulation skills allowing to reach and carefully pick a specific fruit. And yet, there are many opportunities for optimization of the entire soft fruit production that could improve productivity, cut cost and address labor shortages. For example, an automated solution for in-field transportation on its own could save around 20% labor cost and 10% land usage.

To unleash the potential for automation in agriculture and to address the issues faced by the soft fruit industry, a new robotics initiative was recently launched. The RASberry project (Robotics and Autonomous Systems for Berry Production) aims to develop autonomous fleets of robots for the horticultural industry. In particular, the project considers strawberry production both in a traditional open ground fashion and in polytunnels. The first major objective is to support in-field transportation operations to aid and complement human fruit pickers, followed by other objectives on applications such as plant treatment, yield forecasting and fruit picking. To achieve this goal, the project will bridge several current technological gaps including the development of a mobile platform suitable for strawberry fields, software components for fleet management, in-field navigation and mapping, long-term operation, and safe human-robot collaboration. RASberry is a collaboration between academia, the robotics industry, and strawberry growers to cover multidisciplinary competencies required for successful delivery of the project.

In this article, we provide a general overview of the project, describe the main system components, highlight interesting challenges from a control point of view and then present three specific applications of the

ROBOTIC AND AUTONOMOUS SYSTEMS FOR BERRY PRODUCTION

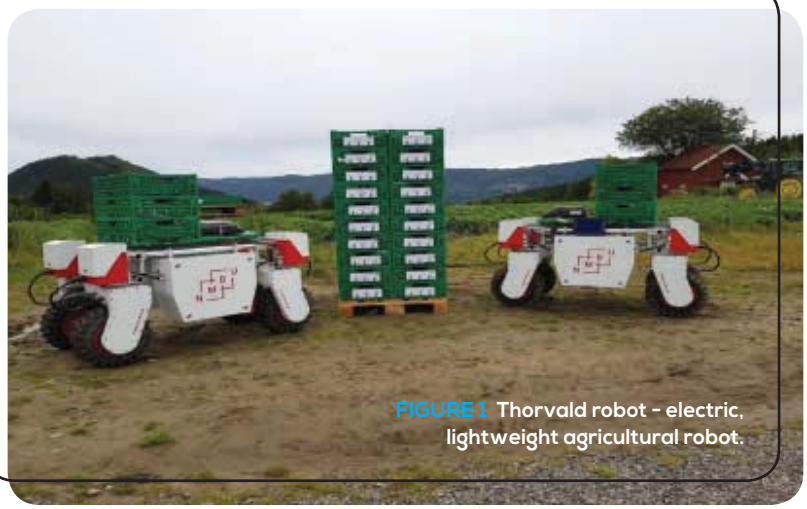

FIGURE 1 Thorvald robot – electric, lightweight agricultural robot.

robotic fleets in soft fruit production. The proposed system involves low-level motor control for robot actuators, but also intelligent control for safe navigation of individual robots and finally the coordination of the entire fleet. Many of the control aspects involve not only direct information provided by sensors, but also the learned representations of the environment and intelligent interpretation of its state illustrating the complex requirements faced by control systems deployed in the agricultural domain.

SYSTEM OVERVIEW

The RASberry system consists of a coordinated fleet of dedicated mobile platforms, which navigate safely around the strawberry environment and interact intelligently with human workers to achieve a given task (e.g., transporting a tray of picked fruit). The mobile platform and its control software are customized for the tasks such that no changes to the environment are necessary. The individual robots are able to interact and support human workers in an intuitive way. All available tasks are shared between multiple robots, which are orchestrated by a central coordination system to assure the best utilization of the entire fleet. The key innovation here is the development of autonomous systems that can work safely and over long periods of time in a complex farm environment.

Robotic Platform

The robotic platform employed in this project is Thorvald, a modular, general purpose, lightweight outdoor mobile platform designed for autonomous operation in the agricultural domain. The robot design is based on a selection of modules, with modules serving various purposes, like propulsion, battery storage, suspension, etc. Modules can be combined to create a wide array of robots with various properties. The robot's software is designed to support the modularity found in hardware, and can control robots with any number of arbitrarily-placed modules. This means that differential-drive robots, Ackermann steering robots and all-wheel drive, all-wheel steering robots all run the same software. Configuration-specific parameters are read from one single configuration file at startup.

The modular design allows for easy re-configuration for a specific application and environ-

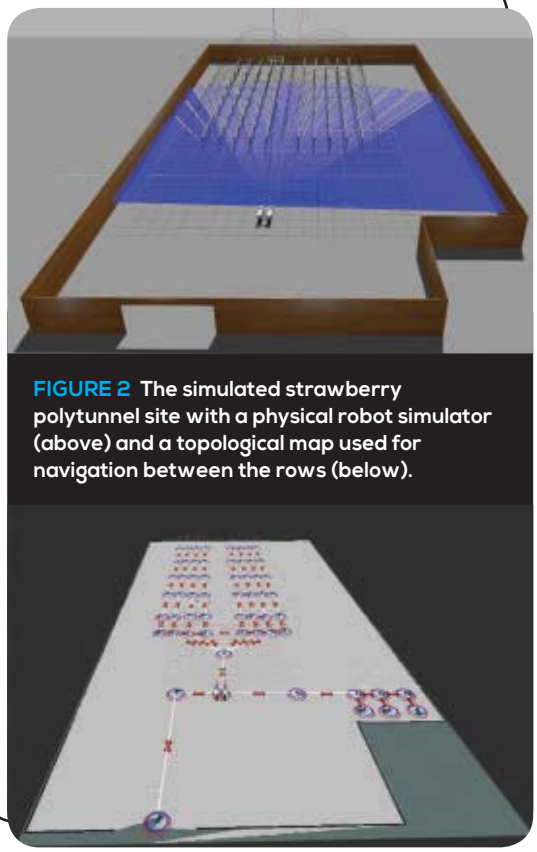

FIGURE 2 The simulated strawberry polytunnel site with a physical robot simulator (above) and a topological map used for navigation between the rows (below).

ment. To support strawberry production, we use a 1.0 m wide robot fitted with four-wheel drive and four-wheel steering. This particular robot configuration can carry up to two batteries. However, to limit the unit cost of the robot, only one battery is installed. This single battery pack provides roughly 10 hours of autonomy without payload. The robot is controlled through a built-in computer running Linux OS and Robot Operating System (ROS). The final configuration of the robot will also include on-board multi-modal sensing to support safe and autonomous navigation of the robots and their collaboration with humans.

The presented platform is generic but each specific application will involve additional customizations: for example, a dedicated apparatus for UV-light treatment or a picking tray storage for in-field transportation.

Autonomous Operation

The core ability of each robot in the fleet is its autonomous operation including safe navigation, automated charging and fault detection. For precise positioning, typical GPS-based systems used in modern agricultural machinery are not suitable in the polytunnels where severe signal losses and reliability problems are quite common. Therefore, we will use a combination of GPS, inertial, and LIDAR (Light Detection and Ranging Device) sensors to achieve centimeter precision and robustness. LIDAR and time-of-flight 3D cameras will be used to build geometric maps of the environment and sense the presence of obstacles and humans so that the path of the robot can be adjusted accordingly. The system will use the topological representation of the field with all its important features utilizing the existing navigation and simulation solutions developed by the RASberry team (see **Figure 2**). To ensure continuous operation of the robot, an automated fault detection system and remote reporting will need to be devised and the infrastructure will also need to provide auto-charging functionality.

Safe Human-Robot Interaction

Safe and effective interaction of the robotic platform with human workers is of paramount importance in the agricultural domain. Therefore, the project will develop appropriate techniques for the detection of humans and the characterisation of their behavior such that the use of appropriate interactive strategies can be employed. Human-aware navigation will ensure that the humans are treated not just as obstacles, but as interactive agents with intentionality. This will improve the general safety of operation. Human-appropriate means of coordination and communication with the robot will ensure that the intentions of the robot are

FIGURE 3 The initial trial of a robotic strawberry transportation system in polytunnels (left) and a dedicated design for an on-board picking tray storage (right).

clear to the human (such as intent to pick up crates or just passing by), and that the human can communicate their requirements to the robot. The information about humans will be provided by a dedicated, multi-modal people detection and tracking system utilizing sensors such as 3D LIDAR, RGB-D, thermal cameras but also RFID antennas.

Fleet Coordination

In this project, a fleet of robots is to be coordinated and its utility to be maximized. Hence, individual robots need to be scheduled to arrive where and when they are needed. A central coordination unit will allocate tasks to robots and coordinate their behavior, by activating and monitoring operational modes (e.g., a robot is ready to receive picked trays). In order to optimize the robotic fleet, the fleet coordination component will learn to anticipate human worker needs and optimize the spatial distribution of robots, i.e., making robots available for a picker, anticipating their needs, to further optimize workflows. One aspect considered here is that, while the fleet is scheduling itself autonomously, anticipating tasks, it will still have to be responsive to on-demand tasks, requested by workers in the environment. Furthermore, resource constraints, such as battery charge, will have to be factored in as anticipated tasks.

APPLICATIONS

In-field Transportation

About 20-30% of the labor cost is spent walking trays of picked fruit and empties back and forth from the crop to the ends of field/greenhouse and on farm logistics hubs. In addition, around 10% of the field area is designated for transportation needs (access for tractors, trucks, etc.). Our fleet for in-field transportation will eliminate the need for workers to carry picked crop and replenish them with empty trays. In addition, the transportation infrastructure can be significantly reduced since the robots do not require special arrangements. The robot will be equipped with a dedicated picking tray storage and weight sensors for basic quality assurance. This functionality will enable more precise traceability of the produce and more precise yield estimation. The in-field transportation is an universal problem for production of various crops and hence the results of the project will be directly transferable to other domains.

We have conducted an initial study, in which tele-operated robots were working with the expert human pickers, to evaluate how an autonomous robot-based in-field transportation system would work for them, what constraints are imposed by such a solution, and also what benefits this may confer [2]. The results indicate that after the experience with the robots, they were

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Simon Pearson is Professor of Agri-Food Technology and Founding Director of the Lincoln Institute of Agri Food Technology (LIAT) at the University of Lincoln. His research interests focus on the application of technology, in particular robotics and digital systems, within the agri-food supply chain from farm through to consumer. All LIAT's on-going research is cross disciplinary with both national and international partners. Prior to joining Lincoln, Simon spent 15 years in industry running significant farming estates and with a large international retailer.

Dr. Grzegorz Cielniak is a Senior Lecturer at the School of Computer Science, University of Lincoln. His research interests include mobile robotics, artificial intelligence, real-time computer vision systems and multi-sensor fusion. In particular, he is interested in robotic applications in agriculture. Grzegorz holds a number of funded grants for collaborative projects with the agri-food industry and others totalling more than £1.5M. He has published widely in the international scientific community, has served as a program committee member for international conferences and as a reviewer for several international journals, conferences and European funding proposals.

FIGURE 4 The two-arm strawberry picker mounted on the Thorvald platform.

generally viewed positively, with the behavior viewed as appropriate and safe. This was despite the participants having mixed views on robots in general, although they seemed less worried about the prospect of their work being directly replaced by robots, which is in contrast to an overall relatively negative view of robots in terms of job replacement reported in other areas of industry.

UV-light Treatment

It is well-known that UV light has a positive effect on plants. Our experiments show that if UV light is applied to plants during the night-time, even with a very small dose, this will practically eliminate outbreaks of fungus. Tests have shown that this works extremely well on mildew, and we are now testing for greymold. There are also other likely positive effects such as on bacteria, and even on the plant and the fruit itself. Even though the effects of UV on plants have been known for a long time, there has not been an efficient way to apply this treatment to the plants without exposing humans to UV's harmful effects. We have therefore mounted UV lamps on the Thorvald platform. The robot has been working autonomously several times every week throughout the season on a strawberry farm in Norway with very good results. We have also designed a UV rig for use in greenhouses with cucumber and tomato, where we are currently doing similar experiments.

Fruit Picking

A robotic fruit picker has also been developed for the Thorvald system [3]. The system consists of a specially-designed gripper for strawberry harvesting, which contains a container that encapsulates the strawberry, and then once the strawberry is identified to be inside the container, the gripper cuts the stem and stores the berry in the container. We are currently able to pick strawberries at a speed of 7.5 s per berry. The system is relatively fast because we can store the strawberries locally in the gripper and pick up to 500 grams of berries before we return them to the base. This reduces the time needed to pick each strawberry. Furthermore, the system is gentle on the berries as we do not touch the fruit, but only cut the stem. Currently the system struggles with berries that are localized in clusters, but a new gripper design is currently being tested to deal with these problems.

CONCLUSIONS

In this article, we have presented an overview of the RASberry project aiming to develop fully autonomous fleets of agricultural robots to support the soft fruit industry. We have presented the individual system components and their main characteristics, demonstrated some initial design efforts and presented three application examples of the robotic fleet for in-field transportation, plant treatment and fruit picking. We have discussed how such solutions can revolutionize the soft fruit industry but also lead to widespread adoption of robotic systems in agriculture in general.

The project is still in its early stages and over the next two years we will be developing our fleet's autonomy, efficiency and long-term robustness so that it is ready for adoption by the industry. A solution for autonomous fleets of agricultural robots will significantly decrease soft fruit production costs, address labor shortages and be the first step towards fully autonomous robotic systems for berry production. ■

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GLOBAL SUSTAINABILITY THROUGH CLOSED-LOOP PRECISION ANIMAL AGRICULTURE

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The Earth is at a sociotechnical crossroads with humanity hanging in the balance – and high-tech agriculture can help bail us out. Human population growth, increasing urbanization and rising incomes are likely to drastically increase demand for animal agriculture in the coming decades. The US Department of Agriculture (USDA) predicts the need to double global food production by 2050 as the global population increases from 7.3 billion in 2015 to 9.7 billion in 2050 as shown in **Figure 1**. Much of this growth will be concentrated in the world's poorest countries where standards of living are set to rise rapidly, increasing the demand for resource-intensive

meat and dairy products, which has been the historical trend. At the same time, agriculture in the 21st century faces multiple challenges: it must produce more food and fiber to feed a growing population with a smaller rural labor force, produce additional feedstocks for a potentially huge bioenergy market, contribute to overall development in the many agriculture-dependent developing countries, adopt more efficient and sustainable production methods, and adapt to climate change. Additionally, the world's arable land is already fully employed and shrinking -- the world has lost a third of its arable land due to erosion or pollution in the past 40 years. All these factors put enormous pressure on improving the production efficiency of the world's supply of food to meet the demand.

Since 1940, the number of people fed annually by a single farmer in the US has increased eight-fold. Automation and use of hybridized and genetically modified crops are widely adopted methods credited for these significant increases in agricultural production efficiency over the past seven decades. Yet, despite the rapid adoption of genetically modified (GM) crops by farmers in many countries, controversies about this technology continue, creating uncertainty and public suspicion in certain markets. In addition, introducing a new GM crop is highly expensive and time consuming, incurring a mean total cost of US $136 million per new introduction (for the period 2008–2012). The mean approval time for a GM crop in the US was 2,467 days and 1,763 days for the EU (Smart *et al.*, 2017). These regulatory issues and bias against GM crops in certain markets, coupled with increasing demand for organic foods, increase the need for automation to make up the bulk of the food production efficiency shortfall that is looming.

HUGE IMPACTS AND OPPORTUNITIES IN ANIMAL AGRICULTURE

With animal agriculture consumption poised for worldwide growth well beyond the rate of population growth, coupled with increasing concerns of environmental sustainability, food security, and the welfare of the animals we depend on, there are tremendous opportunities for

technology-enabled advances in agricultural productivity for the common good. We have already seen the explosive growth of precision crop agriculture, but precision animal agriculture is fundamentally different; in animal agriculture, we care about individual animals and their psycho-physiological state changes hourly. Taken together, this necessitates the ethical development of animal agricultural productivity-enhancing practices that efficiently manage water consumption, reduce greenhouse gas (GHG) emissions, and ensure food safety while simultaneously enhancing the well-being of animals we use for food.

Environmental Footprint of Farms and Methods for Sustainability

In the US, animal agriculture accounts for 56% of the fresh water consumption with two-thirds to three-fourths of that water being used for feed stocks. Other uses for water in animal agriculture include sanitation, cooling facilities for the animals and animal products such as milk, animal waste-disposal systems, and incidental water uses.

Today's state-of-the-art animal agriculture management carefully monitors growth, consumption and production across the entire farm to drive statistical models of animal growth, nutrition and wellness. In turn, diets are actively formulated for the average member within the herds, meaning that half are overfed and the other half are underfed, so individualized feeding can have significant impact. Finally, one of the greatest concerns in animal agriculture is the relatively high levels of GHG emissions. Global estimates suggest livestock account for 11 to 18% of global GHG emissions. In the U.S. alone, GHG emissions from the entire agriculture sector are roughly evenly split between crops and animals, with each accounting for 4 to 5% of total US GHG emissions, equivalent to 344 million metric tons of carbon dioxide equivalent. Since methane is 30 times more potent as a GHG than carbon dioxide by some estimates, we project a 10% increase in metabolic methane efficiency by the year 2030 could reduce global carbon dioxide emissions by an amount equal to eliminating 12 million cars.

Opportunities to Improve Animal Health and Food Safety

Automated animal disease monitoring has potential to increase animal health and improve food safety. Most livestock animals are stoic and do not show outward signs of subclinical or clinical disease. This makes disease detection by humans difficult. Given that metabolic diseases like ketosis and acidosis are prevalent on U.S. dairies (>30% of cows) in early lactation when cows transition from low-energy diets to highly fermentable diets, many sick cows likely go undetected. Another example of a costly animal health problem that currently relies on human detection prior to treatment is mastitis. Mastitis, mammary inflammation, is most often due to bacterial infections. Mastitis lowers milk quality, can be contagious, and often results in animal culling due to chronic infections. Precision animal technologies that result in automated early mastitis detection could undoubtedly improve animal health and food safety. These examples are some of the most prevalent, but additional opportunities exist for rapid and precise intervention, such as conception, and even bullying and social behaviors. Rapid, automated detection of ailments can facilitate targeted treatment for affected animals and have positive implications for animal health and food safety.

CPS REFERENCE ARCHITECTURE FOR PRECISION ANIMAL AGRICULTURE

Our multi-university team, with support from industry, has proposed a cyber-physical system (CPS) inspired closed-loop precision animal agriculture architecture for a dairy farm exemplar based on the three components of feedback control – sensing, analysis and actuation. The sensing is done through a hierarchy of monitoring systems that include output sensors for milk yield and quality as well as animal growth, input sensors for feed and water, and process sensors including novel active in-rumen (stomach) sensors for measuring pH, temperature, and volatile fatty acid content as well as cow physical activity level. The amount of data generated on the farm is large and we are mating the sensors to a hierarchical wireless networking system that transmits this data to a cloud-based platform with big-data analytics from edge to cloud using models for health and nutrient management plus productivity. The actuation system, which implements the actions provided by the analytics, includes feed dispenser robots to manage the individual nutrient and food supplies and interfaces for human prompts for health/wellness care for the cows.

Model-Based Analytics for Health and Nutrient Management Interventions

The analysis of the data is performed on a cloud-based platform using predictive models to provide the necessary interventions. To estimate the nutrient supply and medication for each animal, closed-loop control with discrete-time Kalman filters is employed with separate models for controlling metabolic health and nutrition. Data regarding the pH and volatile fatty acids are sensed by the in-dwelling "RUMENS" robot *(Rumen Understanding through Millipede-Engineered Navigation and Sensing)* and fed back for the health management control loop. In a simplified example, low pH of a particular cow for a short duration suggests a metabolic imbalance that impacts production and quality, so the cow is earmarked for buffer feeding to ease the indigestion. Yet, if pH is low for a prolonged period, other medical interventions are necessary and are suggested to health and wellness practitioners. In fact, feeding is determined in two stages. The first stage formulates the basal ration and feeding level and the second stage suggests additives for any individualized feed supplement needs.

Network Layers Composing the Generic Precision Animal Agriculture CPS

The proposed reference architecture consists of three networking layers with appropriate analytics protocols at each layer. The variety of data mentioned above is transmitted through a network of wired and wireless nodes that implement both a "normal" path and an "urgent" path for transmission. The goal seems simple: to move data from various layers in the network from the edge to the core of a cloud-based data storage platform to enable real-time decisions regarding the productivity, quality, safety, and efficiency of the farm and its products. Yet, because of the complexity of living entities, it is not so simple and involves a novel collection of hardware layers, routing and analytics protocols, and distributed decision support across the system to support both top-down and bottom-up decisions and control.

The intelligent animal health monitoring and control system is built on a configurable three-level architecture, illustrated in **Figure 2** for the dairy farm exemplar, that is intended for farms of any size and animal type. In level 1 – the edge – each node represents a sensor, actuator, or computer with sufficient intelligence to perform the analytics necessary to carry out its dedicated functions. These nodes include the developed rumen-dwelling RUMENS robot, yield and feed sensors, and actuators. The sensor and actuator nodes are highly specialized and purpose-built, such as the dairy farm millibot "gut crawler" sensor node. These sensors and active devices intimately interact with *individual members* of the herd, so analytics at this level are not re-programmable.

By contrast, the "collar nodes" at level 2 act as consolidators of data and as mini-gateways to the higher-level analytics. The collars periodically receive measurements from in-body robotic sensors using a low-power body area network and local sensors on activity. The collar supports the protocols for basic computational and communication capabilities, which will be leveraged to perform user-defined analytics, such as simple filtering on the measurements received from the in-body sensors or activity estimation from on-collar sensors. The level 2 analytics will also be used to locally determine if information is urgent or time-critical, hence, these filtering algorithms must be downloadable by the higher control levels.

Level 3 is the network backbone for the architecture. The data gathered at multiple level 2 nodes are transmitted to level 3, which is further transmitted to the cloud through a series of repeaters and a base station. This three-level configuration integrates wireless body sensor networks (WBSNs) and mobile ad hoc networks (MANETs) to minimize power consumption without impacting opportunities for distributed analytics in a uniform architecture. The three-level network provides a high degree of configurability, rendering the proposed real-time health and behavior-monitoring architecture suitable for farms of any size, delivering true precision animal agriculture.

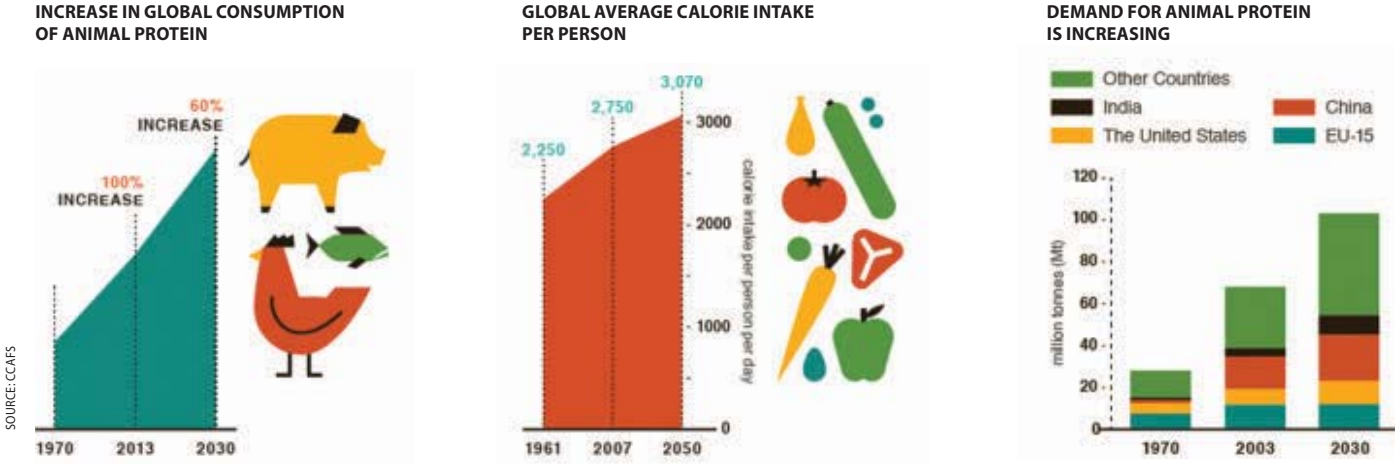

FIGURE 1 Global animal protein and food consumption estimates.

The Physical Layer of the Generic Precision Animal Agriculture CPS

The physical layer of the developed architecture includes all the systems for generic animal and herd networking as well as the purpose-built sensors and actuators for a particular animal type. The sensor suite along with the actuated milking, feeding stations and the feed dispenser robot comprise the physical layer of the architecture. Generic elements include an enhanced animal collar/mobility sensor and field-ready wireless access points. The purpose-built elements include an in-dwelling active rumen sensor platform, automated feed delivery device, cow weight sensor, and in-line milk analysis equipment.

RUMENS Robot for Active Sensing Inside the Animal

One of the core components of the sensing suite is the novel RUMENS robot, which is an active sensing platform hosting an array of sensors such as the purpose-built

polymer thin-film volatile fatty acid (VFA) sensors, pH and temperature monitors. Three primary VFAs (acetic, propionic and butyric acid) perform the bulk of the fermentation process, yet all are formed in the rumen and are absorbed across the ruminal epithelium, from which they are carried by ruminal veins to the portal vein and hence through the liver. The proposed polymer-based VFA sensors are a high-risk/high-reward aspect of our work that we expect will enable a new type of "digestive observatory" that will produce high-density data on a greater variety of VFAs and fermentation parameters than is currently possible. Many VFAs exist in the rumen and influence fermentation, which provides greater than 70% of the ruminant's energy supply.

We are developing a pair of sensor packages for the RUMENS robot for either remote sensing or collection of physical samples, such as biopsies. The novel RUMENS robot is an in-rumen remotely operated vehicle (ROV), inspired by millipede locomotion, that is capable of navigating, sampling, and characterizing the rumen and its contents, without the complexities of legs or other appendages that could potentially harm the animal. This development will transform understanding of rumen biology and feed

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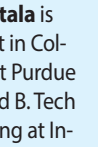

Mustafa Ayad joined Purdue University as a Post-Doc researcher in Nov., 2013 and his current research interests include RF Mapping and robotic networks connectivity maintenance. He received the Ph.D. degree in Department of Electric and Computer Engineering from the University of Denver in 2013.

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Byung-Cheol Min is an Assistant Professor in the Department of Computer and Information Technology at Purdue University and directs the SMART Lab, which performs research in multi-robot systems, robotic sensor networks, and human-robot interaction, with emphasis in field and service robotics and assistive technology and robotics. He holds a Ph.D. in Technology from Purdue University, an M.S. degree in Electronics and Radio engineering, and B.S. degree in Electronics Engineering from Kyung Hee University, Republic of Korea.

Kristy Daniels joined the department of Dairy Science at Virginia Tech in 2014 as an assistant professor. An animal systems biologist, her current research interests include elucidating mechanisms that govern rumen and mammary growth; she is especially interested in studying how nutrition affects these.

efficiency, fermentation science, and microbiology by providing a comprehensive map of the cow rumen environment in the highest resolution known to-date. This understanding of ruminant animal digestive efficiency can be scaled up to many animals and many herds.

Collar-Based Monitoring and Communication

Getting data from inside the animal to the base station is not trivial due to the fact that the rumen ROV will be submerged in a caustic, electrolytic fluid. To achieve this, we utilize wireless body sensor networks (WBSNs) to hop from ROV to a collar around the neck of the bovine. The collar uses conventional Wi-Fi to link to a base station, which is assumed to be within range. Using RF communication from the rumen will be too power-intensive so the WBSN is used because Intra Body Communication (IBC) offers low-loss coupling directly to biological tissue, which provides a low-loss, low-power path to the collar. We use capacitive coupling to the body and on to the collar as it is difficult to get sufficient electrode separation for galvanic coupling.

Feed Dispenser Robot

The new feed dispenser machine is an integral part of our sustainable dairy CPS. Upon entry into the station, a gate will close behind the cow preventing her egress for a minimum of 1 min. The cow's RFID ear tag and RFID leg tag will be read by an RFID reader. This will initiate autonomous action by the feed dispenser system. Depending on individual animal needs, as determined by the data-driven individualized models, the cow is delivered a specified quantity of feed supplements to support lactation needs or to remedy acidosis, or other conditions. The feed dispenser pan will contain load cells for automatic weighing of any feed refusals; weighbacks of uneaten feed will be weighed and discarded as the animal leaves the station. The machine is modeled after construction of automatic dairy cow feed stations (e.g., Lely Cosmix; Lely, The Netherlands). Further, to entice cows to enter the station, a grooming roller will be installed over the cow chute (e.g., Lely Luna; Lely, The Netherlands). These rollers are popular and objectively enjoyed by cows.

SUMMARY

A variety of economic, social and technological factors are converging to increase the demand for animal agriculture well above the rate of growth of human population. This presents a number of opportunities to improve the safety of the food supply and sustainability of production methods driven by the economic enabler of increased efficiency and productivity in precision animal agriculture. We believe this unique combination of social demand, economic viability and technical feasibility will allow these benefits to evolve simultaneously with the same explosive growth of the precision crop agriculture revolution.

Although we expect the growth curves to be similar, precision animal agriculture has two key differentiators from precision crop agriculture: data dependence down to the individual animal and real-time control loop closures. Consumers just don't care about an individual ear of corn or soybean plant the way they care about a cow or lamb. In addition, animal feedings may occur many times per day for thousands or tens of thousands of cycles while some plants may experience fewer than ten water and food cycles in their entire lives.

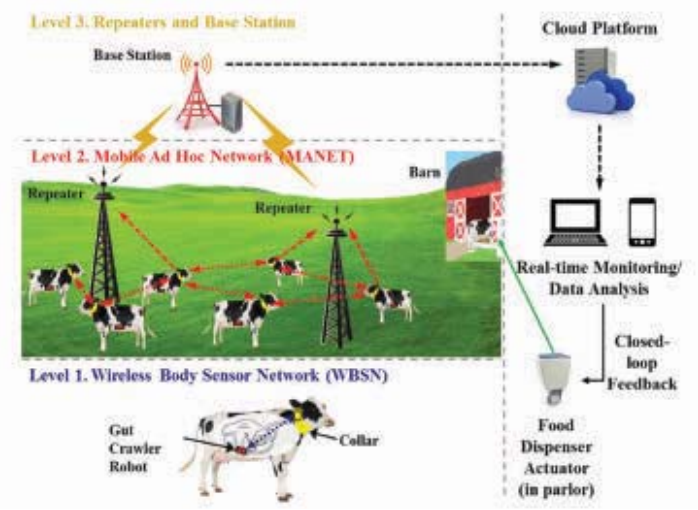


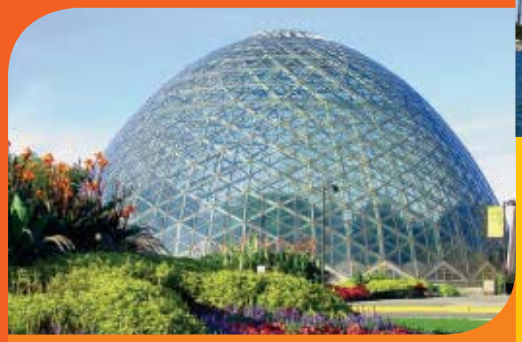
FIGURE 2 Three layer wireless sensor network architecture for precision animal agriculture.

The data-centric CPS reference architecture for precision animal agriculture that we are evolving based on the prior work of a generation of scientists and engineers holds the solution to sustainable and safe increases in productivity in a way that is scalable throughout the developed and developing world. The presented approach involves real-time monitoring and real-time analytics at three levels of granularity: the entire farm, the herd, and the individual animal. Sensing of individual characteristics is done through the developing "RUMENS" ROV, which actively and intelligently gathers animal-specific real-time data to map the animal microbiome at a level of precision never imagined before. This information is relayed through a body-sensor network to the collars around the animals' necks, where local analytics protocols add information about the aggregate local herd. A wireless sensor network of these collars and repeaters is used to transmit the data to the cloud where global analytics is performed. The processing at individual nodes (collars) is limited, but assigned a communication priority based on context (normal or urgent). The developed models for analyzing the feeding behavior, growth, sickness and metabolic activity predict the necessary feed and supplements to be provided in reaction to the sensed data and to signal quarantine. The actuation is done through a feed dispenser robot that controls the feed and supplements to support the lactation needs or to remedy illness based on the analysis. ■

2018 AMERICAN CONTROL CONFERENCE

MILWAUKEE, WI
JUNE 27-29, 2018

DETAILS CAN BE FOUND ON THE CONFERENCE WEB SITE AT HTTP://ACC2018.A2C2.ORG



The 2018 AMERICAN CONTROL CONFERENCE will be held Wednesday through Friday, June 27-29, at the Hilton Milwaukee City Center Hotel in the heart of Milwaukee, Wisconsin – mere steps from the Lake Michigan shoreline. The conference venue is near nightlife, restaurants, shopping, and entertainment, including the Henry Meir Festival Grounds - host to the world's largest music festival, SummerFest, which will celebrate its opening day alongside the ACC.

The ACC is the annual conference of the American Automatic Control Council (AACC), the U.S. national member organization of the International Federation for Automatic Control (IFAC). National and international society co-sponsors of ACC include American Institute of Aeronautics and Astronautics (AIAA), American Institute of Chemical Engineers (AIChE), Applied Probability Society (APS), American Society of Civil Engineering (ASCE), American Society of Mechanical Engineers (ASME), IEEE Control Systems Society (IEEE-CSS), International Society of Automation (ISA), Society for Modeling & Simulation International (SCS), and Society for Industrial & Applied Mathematics (SIAM).

The 2018 ACC technical program will comprise several types of presentations in regular and invited sessions, tutorial sessions, and special sessions along with workshops and exhibits. Submissions are encouraged in all areas of the theory and practice of automatic control.

Photographs courtesy of VISIT Milwaukee

DSCC 2018

ATLANTA

THE ASME 2018 DYNAMIC SYSTEMS AND CONTROL CONFERENCE
SEPTEMBER 30 – OCTOBER 3, 2018
HYATT REGENCY ATLANTA
ATLANTA, GEORGIA

The DSC conference is the showcase technical forum of the ASME Dynamic Systems and Control Division. It provides a focused and intimate setting for dissemination and discussion of the state of the art in dynamic systems and control research, with a mechanical engineering focus. The 2018 DSC Conference Technical Program will consist of sessions in all of the usual areas of interest to the Division that include, but are not limited to, automotive and transportation systems, bio-systems and health care, energy systems, mechatronics, modeling, identification, intelligent systems, robotics, vibrations, and smart structures.

https://www.asme.org/events/dscc

COREL'S CAD SOFTWARE

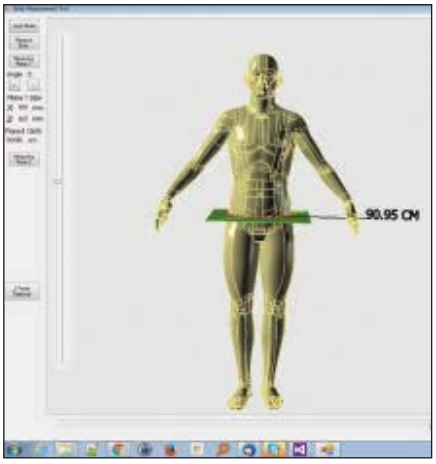
COREL, OTTAWA, CANADA

Corel, known more for its graphics software, has released CorelCAD for Windows PCs and Macs. The software is intended for 2-D and 3-D drawing and modeling, and is also tuned for 3-D printing with support for DWG files. CorelCAD is compatible with all major CAD programs, so any designs in the software can be easily exported to popular programs like AutoCAD. The software has enhanced 3-D editing and workflow tools, advanced table tools for design measurements, and small tweaks so it is easier to cut, copy, and paste objects. A new "Helix" tool to create 2-D spirals and 3-D helixes will be appreciated by architects. The software is also faster and has an improved user interface. It uses a CAD engine powered by ARES, which also drives other software like DraftSight.

BODY PARAMETERS FROM 3-D SCAN

PROTOTECH SOLUTIONS, PUNE, INDIA

3D Measure Up is a tool that can measure body parameters from a 3-D scan. That helps in the fields of tailoring and healthcare, which rely heavily on accuracy of measurements, including height and waist size. The software can measure length and girth of head, neck, bust, waist and other body parts. It also allows users to visualize, zoom and rotate body images. To get measurements, users are first asked to wear tight-fitting clothes, and then their body is 3-D scanned, with the file saved in OBJ/STL format. Then the model can be loaded up in 3D Measure Up, and the software can do the measurements. The software relies on algorithms for precise measurements. It can be used in VR and mobile formats, or as a plugin for the Autodesk, SOLIDWORKS, and Cero software.



3-D PRINTING SOFTWARE

DESKARTES, HELSINKI, FINLAND

The latest 3DEdit Pro 3.0 is a 3-D model repair, painting and tool for printing on 3D Systems ProJet x60 printers. The software is faster and has a range of tools to manipulate 3-D printing files. Those include commands to facilitate stereolithography (STL) file, a common file format for 3-D printers, verification and repair, offsetting, splitting, connecting, decimation, smoothing, solidify (aka "shrink wrap") as well as faceted model coloring, texturing, and texture painting. A new Solidify command can fix architectural problems with a single click. and other models often with a single click. It supports import translators such as STEP, CATIA 4/5/6, CATIA CGR, NX Unigraphics, SOLIDWORKS, Solid Edge, Inventor, Parasolid, JT and Creo/ProE formats. With just a single click, files can be transferred to 3D Systems' 3DPrint software.

ANALYZE PLASTIC COMPONENTS

E-XSTREAM ENGINEERING, NEWPORT BEACH, CALIF.

e-Xstream engineering's Digimat software is used for the structural analysis of reinforced plastic components. The latest version, v2018.0, of the software has a new user interface, and incorporates more manufacturing data related to weld lines, fiber volume fraction, fiber length, and residual stresses. The additive manufacturing capabilities have been enhanced, and it's also easier to analyze metal-to-plastic replacements. The software is designed to reduce failure rates and it is possible to reduce damage by modeling more precise structures. The software has enhanced physics to predict build failure and ensure tight control of tolerances. e-Xstream is owned by MSC Software.

SUBMISSIONS

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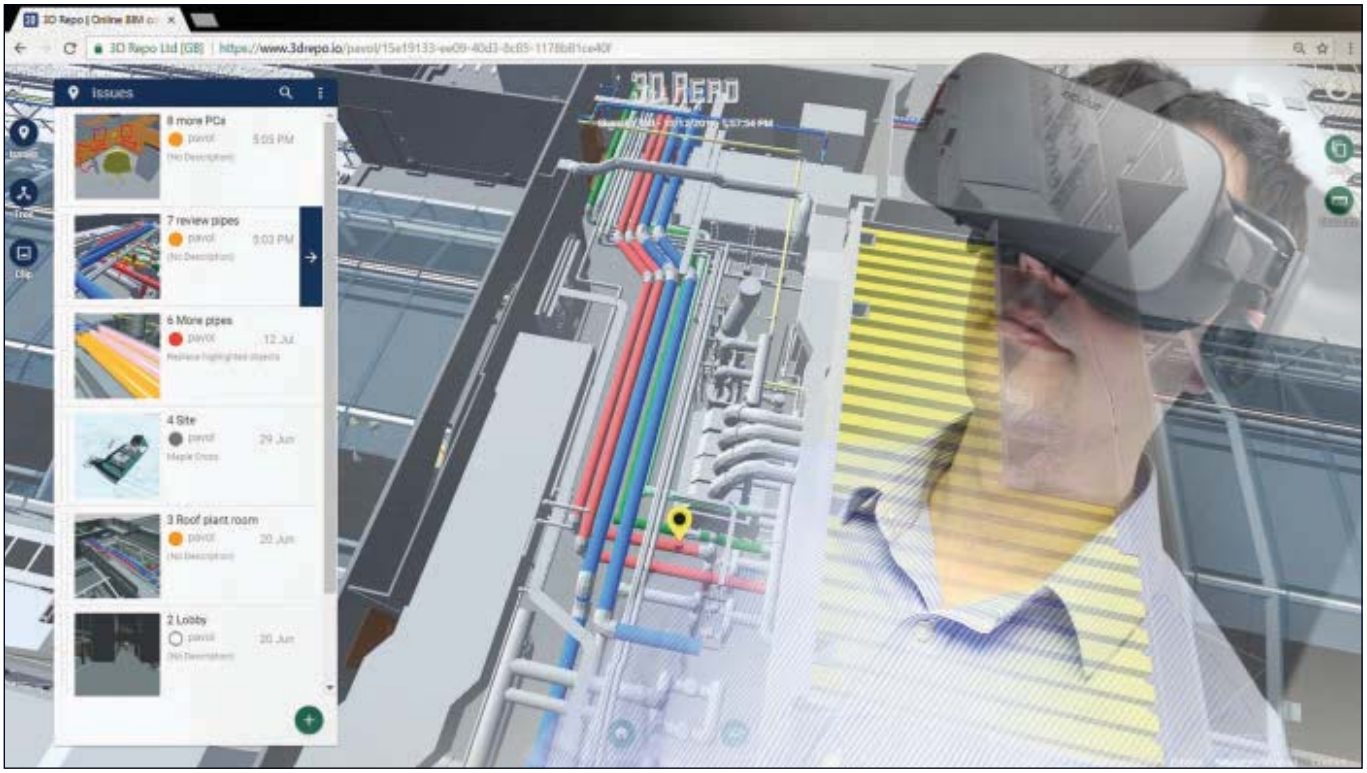
SOFTWARE



MANAGEMENT TOOLS FOR DRONES

3DR, BERKELEY, CALIF.

3DR's Site Scan drone software, which collects and processes drone data, has been integrated into Autodesk BIM 360 project management software. Site Scan users will be able to import CAD and PDF design files from BIM 360 into Site Scan, and any changes in BIM 360 will be automatically received in Site Scan. The collaboration improvement tools include the ability to share the latest drone data with teams, including orthomosaics, point clouds, digital elevation models, and more. The integration also makes it easier to address issues with drones on the field much quicker. There are also the latest design files, and more efficient collection and processing of aerial data.

CONVERGENT MODELING

SIEMENS, MUNICH, GERMANY

Siemens's NX software is used to engineer or reverse-engineer products. For example, users can 3-D scan a model of a medical device into a computer, and start engineering a product based on that data. The latest NX 12 does that, and also does a better job at meshing electrical and mechanical engineering disciplines in complex product design. NX 12 has better design tools, shaping capabilities for large assembly performance, and model-based engineering. The software has technology from Mentor Graphics, which is owned by Siemens, to provide links for the electrical and mechanical systems in a 3-D model. Such features reduce cost and the time it takes develop products, and also make prototyping easier. For example, the modeling software allows designers of wiring diagrams and harnesses to work much more closely together to reduce any electromechanical issues. NX 12 isn't just about shaping a product better, Siemens says.

3-D PRINTER SOFTWARE

ULTIMAKER, CAMBRIDGE, MASS.

Ultimaker makes 3-D printers, but released the new Cura 3.0 slicing software to support its hardware. The software has CAD integration to easily support applications such as SOLIDWORKS and Siemens NX. Cura 3.0 has an updated user interface that makes it easier to use and 3-D print designs. It has a new color scheme and intuitive sliders to control print settings. It also starts up two times faster, and as a result, is also faster at 3-D printing. New skin settings result in less strings, better top details, and faster prints. The software represents a big effort by Ultimaker to tie its hardware and software offerings closer together as it looks into the future.

SURVEY SOFTWARE

MICROSURVEY SOFTWARE, WEST KELOWNA, B.C.

MicroSurvey CAD is used by the surveyors for design, drafting and plotting in infrastructure projects. The new MicroSurvey CAD 2018 adds more surveying tools for land surveyors and civil engineers, and is based on a faster engine. The software adds support for file formats such as DWG, which is commonly used to store three-dimensional data. The IntelliCAD 8.4 engine improves editing and drawing. The sotware also better handles formats, patterns, and shapes. It can also import data from Esri's GIS mapping software, and also Trimble and Spectra precision data files. The software also has a cloud engine for online processing, but it is available only in the Ultimate and Studio editions. The software is also available in the less expensive Basic, Standard, and Premium editions. The software works on PCs with Windows 7 or 10.

PROTECT CAD MODELS

CT CORETECHNOLOGIE, FRANKFURT, GERMANY

The new version of 3D Evolution, a computer-assisted planning and design software, has a unique security feature with hooks to protect intellectual property of CAD models so they don't fall into wrong hands. That ensures designs are safe and not shared by mistake, especially when collaborating. Beyond better security features, the new software significantly reduces file size by as much as 80% for packaging, market-ready geometry and in plant layout applications. The new software also allows removal of specific details in a CAD model, depending on where it is shared. The software also includes CAD data conversion for 24 major formats; advanced data analysis tools; quality checker; and data management tools.

MATERIAL TRACKING SOFTWARE

GRANTA DESIGN, CAMBRIDGE, U.K.

GRANTA MI Version 11 has new components that unite the materials information management system with its CAD and CAE product lifecycle management system. The software allows engineering organizations to digitize materials information, and links it to PLM systems to ensure correct, consistent definitions of materials throughout the product lifecycle. The materials are better defined with GRANTA MI, and the PLM provides better workflow tools for design and simulation, substance compliance analytics, and re-applying materials. The software is especially handy in engineering a product, simulation and additive manufacturing, and it can point out restricted substances in the manufacturing processing and point out alternative materials that could be used.

IMAGE RECOGNITION FOR PLCS

BECKHOFF AUTOMATION, VERL, GERMANY

Beckhoff Automation's TwinCAT Vision software is a PLC-based control system that now has image processing capabilities. The software calls up an engine in the software for image recognition, which can be useful in identifying products. The software can implement machine learning techniques for image recognition, and over time, the software will get better at identifying products on the production line. This helps in the automation of tasks in industries, tracking and tracing products on a line, and real-time synchronization of workflow systems. The TwinCAT PLCs have the processing power to meet the computing demands of image recognition tasks. Cameras can be calibrated to work with TwinCAT Vision, and there is no need to learn any specialized programming language.

3-D PLUGIN FOR TRANSPARENCY

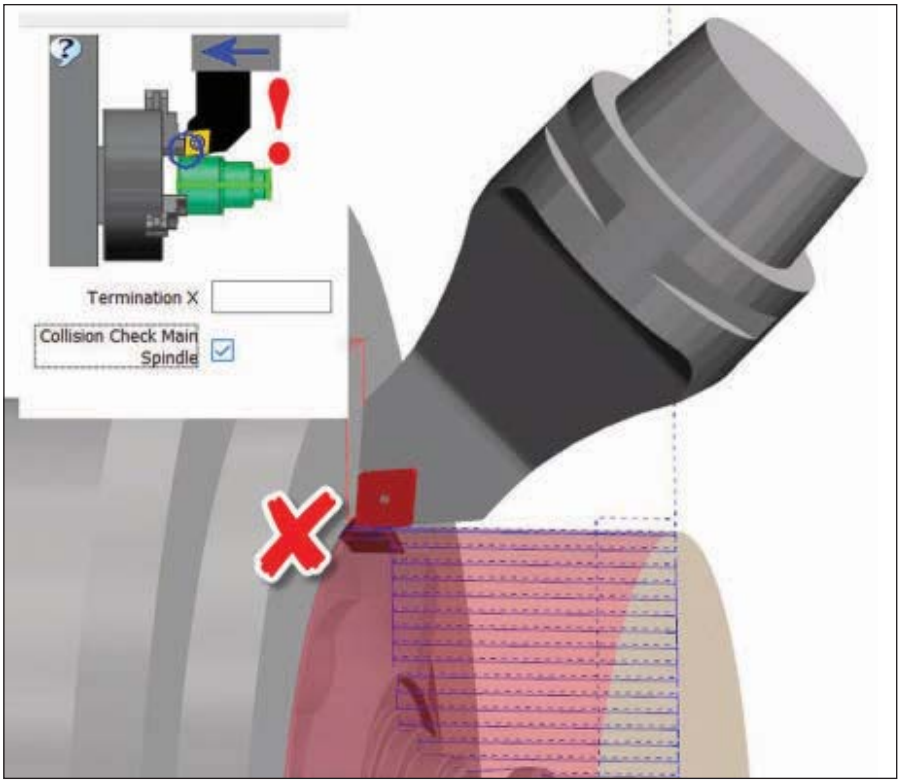
ARTVPS, CAMBRIDGE, U.K.

Shaderlight 2018 is a rendering plugin for SketchUp 3-D modeling software that allows for image and animation creation. The new features include cloud capabilities, and it also has a simpler user interface. It works with the latest SketchUp Free or Pro. A new feature is the ability to add realism to images via the new transparent material feature, which helps when rendering bodies or water or glass objects. The feature also gives a better sense of the thickness of the object. Shaderlight fits in cleanly into the free and professional versions of SketchUp.

MACHINING SOFTWARE

VERO, GLOUCESTERSHIRE, U.K.

Edgecam 2018 provides time-saving updates and improvements to roughing cycles for milling, turning and multi-task machining. The software also adds new tools like automatic collision detection, which results in better accuracy and surface finishes. The software also improves the cycle time calculation, and offers better control over the drilling process. Additional features have been added, but the overall goal of the software is to reduce machining time. There is no regeneration if the alteration does not affect the corresponding cycles with aspects such as coolant or high-speed. There is also support for deep-hole drilling for the first time. The software supports the JT file format, an increasingly popular 3-D model file format developed by Siemens. There is also support for AutoCAD 2018.



PACKING AND LABELING SYSTEM

KHS GROUP, MÜNSTER, GERMANY

KHS Group's compact packaging and labeling systems are targeted at the food and dairy sector. The KHS chunk dosing unit permits gentle filling of chunks measuring up to 10 x 10 x 10 millimeters for different milk packaging. The filling and packaging systems are compact, safer and cut down on space. The company also has flexible systems for filling and packaging in growing areas like yogurt and breakfast-on-the-go. A new KHS compact Innoket Roland 40 labeler can roll out labels for 2,500 to 25,000 containers per hour, from food cans and jars to glass bottles. The labeler can be put in labeling stations. All the new products are designed for power efficiency.

LASER MARKING WORKSTATION

SIC MARKING, POMMIERS, FRANCE

The XL-Box works in metal additive manufacturing to facilitate the 3-D laser production of very small and technically intricate components or parts with complex geometric shapes for mass production or prototyping using mainly chromium cobalt (medical or dental prostheses), ceramics (defense), and aluminum or titanium (aerospace). Factories ensure traceability by marking Data Matrix codes on these components using a 20W or 50W fiber laser incorporated into an XL-Box marking station, which is easy to use, with a 570-x-564-mm working area; ergonomic, with an automatic and wide opening on three sides; and economical, thanks to its robust design and reduced maintenance.

LINEAR POSITION SENSOR

ALLIANCE SENSORS GROUP, MOORESTOWN, N.J.

The LA-25-R series LVDT linear position sensors operate in the industrial settings of steam and hydro power plants; paper, steel, and aluminum mills; die and stamping presses; building and bridge monitoring; and industrial automation and fluid power systems. Available in ranges from 3 in. (75 mm) to 15 in. (375 mm) full scale, the LA-25-R is designed for roller gap positioning, process valve displacement, and head box and actuator position feedback with the durability needed to withstand hostile conditions. Its open bore design works well in factories where debris such as lubricant and chemical mists, airborne grit and dust, and typical industrial washdown can flow through the bore.

SUBMISSIONS

Submit electronic files of new products and images by e-mail to **memag@asme.org**. Use subject line "New Products." *ME* does not test or endorse the products described here.

GUIDE TROUGH SYSTEM

IGUS, COLOGNE, GERMANY

The Guidelite vertical guide trough system is quick and easy to install, and comprised of igus' plastic components. The design is open and ensures fast-moving and noise-free vertical energy chains for highly dynamic applications. It also reduces resonance, and cable system speeds can exceed 7 meters per second. This product is an improvement over typical guide troughs, which have closed channels and enclosed designs that create more noise in an echoing body. The open design of the igus Guidelite has a noise-dampening system which is also an improvement over conventional systems. The chemical resistant plastic is a replacement for guide trough systems made of sheet metal, which can be vulnerable in industrial environments. Assembly is also easy, and the plastic system is also safer and more cost-effective.

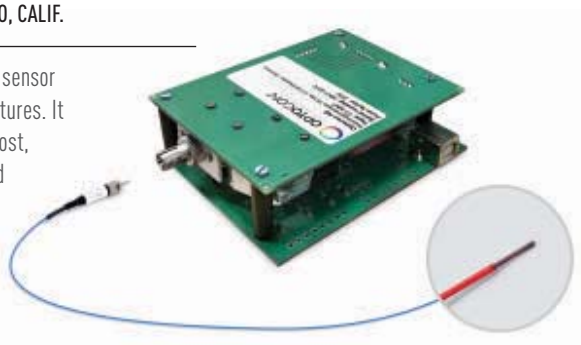
HARDNESS MEASUREMENT

PAUL N. GARDNER COMPANY, POMPANO BEACH, FLA.

Two handheld electronic PosiTector SHD Shore Hardnesss Durometer models—Shore A and Shore D—measure the indentation hardness of nonmetallic materials. Easy-to-read digital display has a reset feature to instantly restore factory settings. The durable case repels solvents, acid, oil, and water and is dust-resistant. A shock-absorbing, protective rubber holster with belt clip is included along with a two-year warranty on body and probe. Designed for accuracy, a Certificate of Calibration showing traceability to NIST is provided and Auto Ignore mode disregards readings below 20 and above 90 per international standards. The durometer continually displays/updates average, standard deviation, min/max hardness, and number of readings while measuring, and saves screen images for record-keeping and review.

FIBER OPTIC TEMPERATURE SENSOR (X)

MICRONOR, CAMARILLO, CALIF.



Micronor's fiber optic sensor can measure temperatures. It is available in a low cost, small form factor, and integrates into other systems that may require temperature measurement such as industrial control and medical instruments. Called the FOTEMP1-OEM-MNT sensor, it can measure temperatures ranging from -200 degrees Celsius to +300 degrees Celsius. It also has built-in USB, RS232 and SPI interfaces, which provides the connectivity to instruments and devices. The fiber optic sensor is more accurate and reliable than electronics-based temperature sensors, which could be affected by magnetic fields, radio frequency interference, and chemical atmospheres.

HARDWARE

FAILSAFE CONTROLLER

SIEMENS, MUNICH, GERMANY

Siemens new Simatic S7-1518-4 PN/DP ODK control system is an automation system for mechatronic tasks in a factory. Its key attribute is the ability to stay up and running with fast response times, which keeps a factory humming without any downtime. It has 13MB of memory, with an additional 32GB of storage available via a memory card slot. The control system works with standard C/C++ code, and programs can be written via an open-source Windows-based development kit. It offers one nanosecond bit performance, and six nanosecond performance for floating point calculations. The controller has four communication interfaces, including a two-port switch for field-level communication, two Profinet interfaces and a Profibus DP interface. It is part of Siemens' Digital Factory offering that combines hardware and software in one package to manufacturers.

WATER ACTIVITY HANDHELD KIT

PAUL N. GARDNER CO., POMPANO BEACH, FLA.

The HP23-AW-A Water Activity Handheld Kits is a digital probe that measures humidity, temperature and other water-related measurements to check for product stability and shelf life. It is a portable device running on a battery. The measurements are precise, and an alarm sounds off when the measurements are complete. It can save up to 10,000 records with time stamps. It is made of stainless steel in critical surfaces. This is a good device to use in small and large setups.

DIGITAL PRESSURE SENSORS

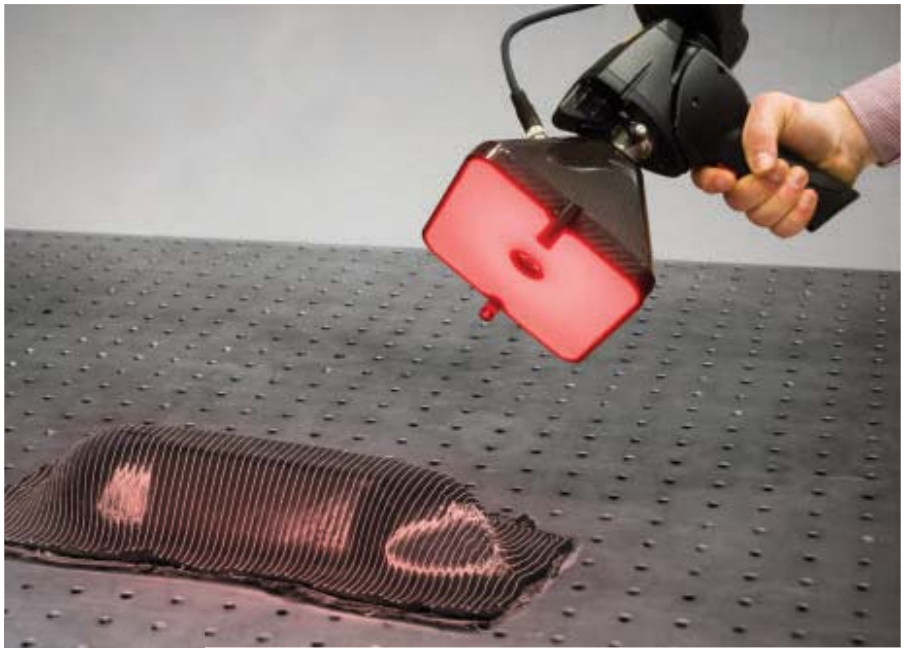
AUTOMATIONDIRECT, CUMMING, GA.

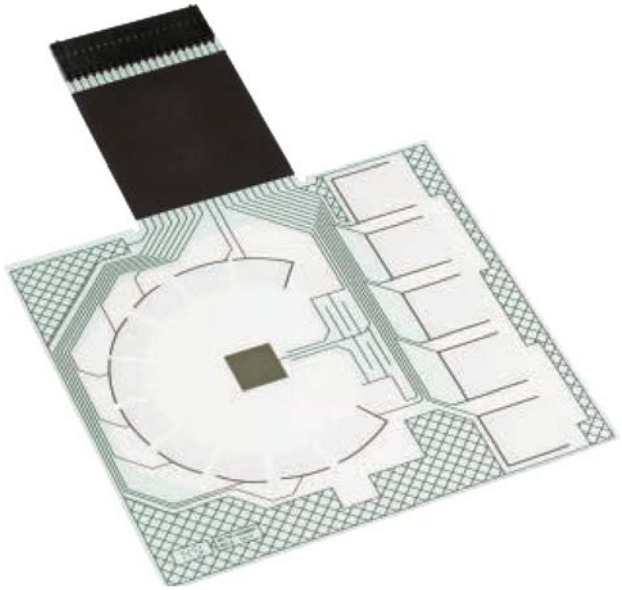
A new EPS series of digital pressure sensors have been added to AutomationDirect's ProSense sensing product line. The new pressure sensors are designed to measure pressure in industrial settings, and has both gas and liquid applications. The compact sensors are designed to withstand the rough and tumble environments in industries, and is accurate with readings in measuring ranges. It has a digital display that can measure units such as bar, mbar, kPa, MPa, inches of water column, and inches of mercury. The pressure sensors comes encased in solid steel, and a standard 1/4-inch NPT male process connection enables it to be easily installed. It has no moving parts. The pressure sensor has been set up so the results and outputs are easy to read either via indicators or on the two-color display screen.

CARBON COMPOSITE DETECTOR

HEXAGON MANUFACTURING INTELLIGENCE, LISLE, ILL.

A Carbon Composite Inspection System from Hexagon inspects and analyzes lightweight carbon fiber components. Carbon fiber is most famously used in planes and laptops with the goal to make them robust and lighter. The system has three main components: a portable ROMER Absolute Arm with Integrated Scanner, the HP-C-V3D Apodius Vision Sensor scanner, and Apodius 3D software package. The system picks up, scans and then analyzes carbon fiber with the help of the software. The system is a key part of process automation, especially in making products using carbon fiber. It is targeted at the aerospace, automotive, transportation, marine, electronics, infrastructure and other markets.





CURVED KEYPAD BACKLIGHTING

MOLEX TECHNOLOGY, LISLE, ILL.

It has been a challenge to put backlighting on curved surfaces, but PEDOT Clear Conductive Sensors from MOLEX solve that problem. The product is a flexible circuit printed on a polyester substrate that can be used in three-dimensional surfaces, so more designs can be implemented in touchpads or keypads requiring backlights. These products could include keypads on smart meters, or even keyboards. The new technology replaces indium tin oxide (ITO), which is not considered flexible. The Molex sensors last through more than 50,000 bend cycles, and is also low-cost to implement. Shipments of such products are growing as humans increasingly interact with computing and digital products using touch.

QUICK JAW CHANGE SYSTEM

SCHUNK, MORRISVILLE, N.C.

The ROTA NCX power lathe chuck with a quick jaw change system helps load parts quicker in sophisticated machines. It is designed as a replacement for conventional lathe chucks, and can load on machines with short stroke cylinders easily. It helps keep manufacturing costs down by making set up easier, and reducing downtime of machines. A jaw set can be switched with a repeat accuracy of 0.02 mm. The set up time decreases by up to 80 percent, which helps improve the efficiency of machine operations. The chuck has a large through-hole and is lighter. The goal is also to make the machines easier to upgrade.

HARDWARE

DIRECT DRIVE SERVO MOTOR

YASKAWA AMERICA, WAUKEGAN, ILL.

The Yaskawa SGM7F line of direct drive servo motors is targeted at machines on plant floors. It can deliver 4 to 35 Nm of torque in devices as small as 2.1-inches high and 5.3 inches in diameter. With the size advantage, the servo motors can be used to make machinery compact and save space on plant floors. That allows room to put other machinery on the plant, or to downsize an operation. It also has an open design that can adapt to shaft mounting. Wiring can also pass through the SGM7F servo motors easily. The servo motors generate less heat, and a focus is on precision engineering and reducing the damage of components. The line has eight models for different industrial applications such as dial tables, transfer lines, die actuators, electronic parts assembly and print registration.

LOAD MONITORING

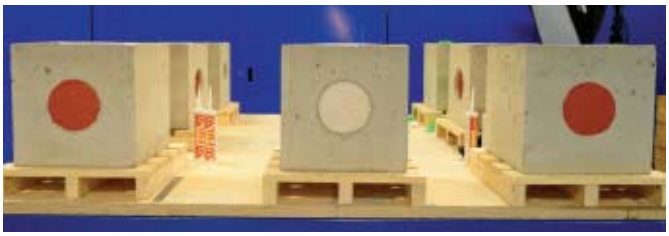
MODULIFT, POOLE, U.K.

The Active Link is an innovative end-unit system with an integrated load cell, compatible with the existing range of Modulift spreader beams. It provides wireless real-time data by measuring the load at either end of the spreader beam, making it useful in both weighing and dynamic load monitoring. Data is transmitted wirelessly to a USB transceiver that must be connected to a Windows computer or tablet with a spare USB port. The system, which replaces the standard drop link component, saves time, cost, and weight because the measurement technology doesn't have to be sourced as an additional rigging tool. It also significantly reduces the height of rigging, especially beneficial in low-headroom applications.

WEIGHT CHECKS

HARDY PROCESS SOLUTIONS, SAN DIEGO, CALIF.

As the name indicates, the Dynamic Checkweigher checks the weight of products such as bottles, cans and cartons. It does so at high speeds, and fits into the automation process of factories. The device is also highly accurate, which is important in packaging applications. It can weigh via chains or multiple sizes of belts via its open design. It also communicates with PLCs via network outlets, and can weigh up to 350 pieces a minute. It has a Hardy HI 4050CW check weighing controller, and is built on the Rockwell Automation platform. It can integrate into a factory and its software systems, and plug into analytics systems where data can be instantly analyzed and tagged to other information systems.



NUCLEAR SAFETY SEAL

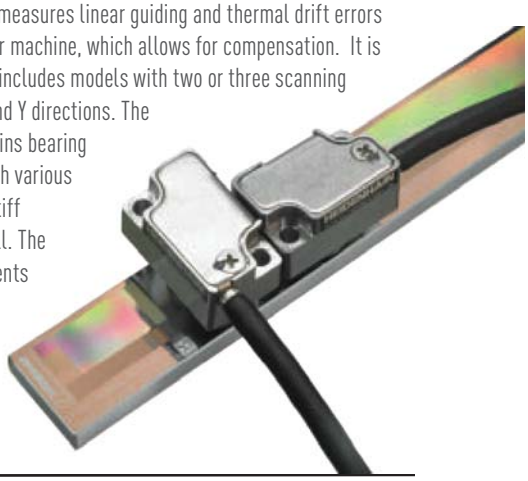
BEELE ENGINEERING, AALTEN, THE NETHERLANDS

The XATTAX sealing system from Beele Engineering can plug leaks in walls of nuclear sites. The seal is resistant to radioactive gamma rays, which could easily leak through walls of nuclear sites. It also shields against radioactive radiation. The company claims the protection of the seals is so effective that people can now work closer to the reactor. XATTAX has seals of many sizes, and the central product in the line is the Radiatt system, which can be plugged into an 80-centimeter wall. Radiatt has an 80-year lifespan. Studies have been conducted on the effectiveness of XATTAX. Outside of Radiatt, other seals for nuclear sites offered by the company have up to 99 percent effectiveness.

PRECISION MEASUREMENT TOOLS

HEIDENHAIN, TRAUNREUT, GERMANY

HEIDENHAIN's products provide accurate measurements for components in the photonics space, which is increasingly being used in the semiconductor industry, machining and other sectors. The LIF 400 1Dplus scale is an innovative two-dimensional encoder that measures linear guiding and thermal drift errors during movements of a stage or machine, which allows for compensation. It is frictionless with gratings, and includes models with two or three scanning units for measurements of X and Y directions. The MRP 5000 angle encoder contains bearing sets, and can be integrated with various encoder types to yield highly stiff modules that are easy to install. The components address requirements for precision rotary axes used in metrology, calibration devices, automation, micro-machining, and semiconductor manufacturing.



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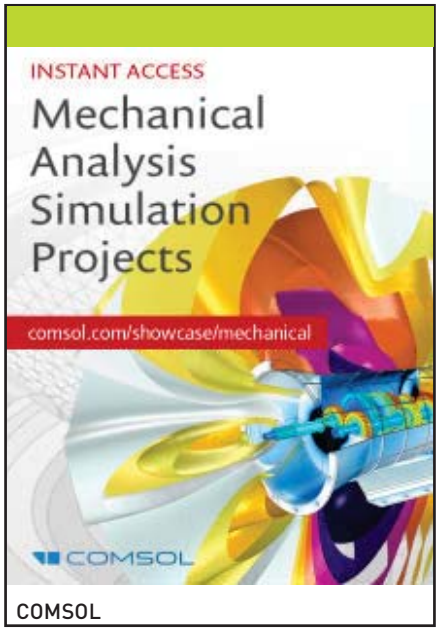

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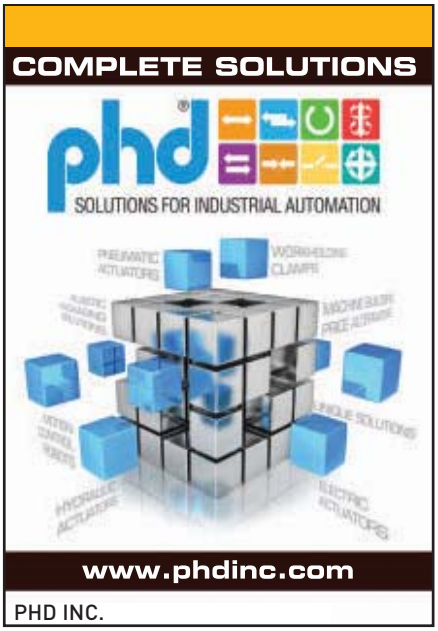
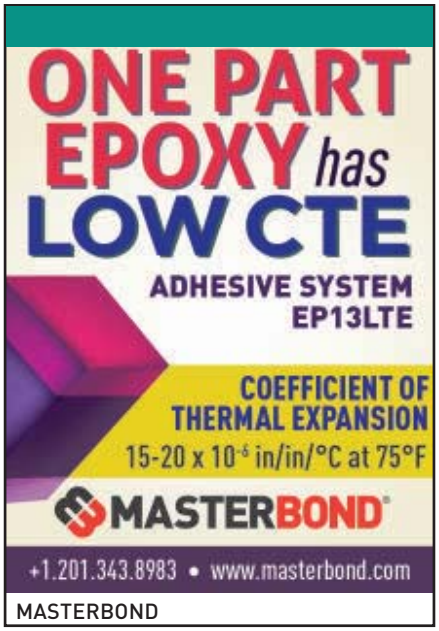


PHD INC.



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CAMPBELL UNIVERSITY
School of Engineering

Campbell University, Associate, Assistant Or Full Professors, School Of Engineering

The School of Engineering at Campbell University (http://www.campbell.edu/engineering/) seeks two Engineering Faculty for full-time, tenure-track positions at the rank of Assistant, Associate or Full Professor. One position in Mechanical Engineering begins Fall 2018 and is focused on teaching the thermal, energy and fluid sciences. One position in Mechanical Engineering, focused on teaching a common senior design sequence, begins in January 2019. Campbell's BS in Engineering program (with concentrations in mechanical engineering, chemical engineering and electrical engineering) welcomed its inaugural first-year class in fall 2016. These positions present faculty with a unique opportunity to provide leadership in building an innovative engineering program and the prominence of the new School and University.

Responsibilities: Duties will include: develop, implement and teach project-based engineering curricula; actively participate in the scholarship of teaching and learning; engage in student advising, student organizations, assessment, accreditation activities, and committee responsibilities. Applicants should be interested in contributing leadership toward the development of the engineering program. Candidates must be committed to innovative engineering undergraduate education; dedicated to excellence in undergraduate teaching, mentoring students, and scholarship; and committed to the University's mission.

Qualifications: Candidates are required to have a PhD in Mechanical Engineering or a closely related engineering discipline from an accredited institution of higher education; experience developing and teaching project-based engineering curricula; and knowledge of the current practices and research pertaining to innovative undergraduate engineering curricula.

Applications: Interested applicants should apply online at **http://www.campbell.edu/about/employment/** and include a cover letter of introduction, a curriculum vitae, and contact information for five professional references. Questions may be directed to Dr. Jenna Carpenter, Dean, School of Engineering [**carpenter@campbell.edu**].

Campbell University maintains a continuing policy of nondiscrimination in employment. It is our policy to provide equal opportunity in all phases of the employment process and in compliance with applicable federal, state, and local laws and regulations. Accordingly, the University is committed to administering all educational and employment activities without discrimination as to race, color, sex, sexual orientation, gender identity, age, ethnicity or national origin, religion, disability, genetic information, protected veteran status and any other characteristic protected by law, except where appropriate and authorized by law.

EEO/AA/Minorities/Females/Disabled/Protected Veterans

The Department of Mechanical Engineering at the University of Massachusetts Lowell invites applications for: several Visiting professors (who teach 3 courses per semester, the position is for 1 year) and Adjunct professors (who teach 1-2 courses per adjunct). The successful candidates will be expected to begin work in September, 2018 and assist in teaching a range of classes that may include: ENGN 2050 Statics; MECH2010 Computer Aided Design; MECH 3110 Applied Strengths of Materials; MECH 3020 I&M Laboratory; MECH 3220 Control of Mechanical Systems; MECH 4030 Thermal Fluids Laboratory; MECH 4230 Capstone; MECH 4250 Design of Machine Elements; MECH 4410 Thermo-Fluid Applications; MECH 4510 Dynamic Systems Analysis; MECH 4730 Design Theory and Constraints. Applicants must have earned an MS degree in mechanical engineering, or closely related disciplines to be considered. For a more detailed description of the courses, please visit: http://www.uml.edu/Catalog/Undergraduate/Engineering/Departments/Mechanical/Course-listing.aspx. To apply, visit: http://explorejobs.uml.edu. Applications received by June 15, 2018 will be considered in the first review of candidates. Each position will close after an adequate number of qualified applications are received. UMass Lowell is committed to increasing diversity in its faculty, staff, and student populations, as well as curriculum and support programs, while promoting an inclusive environment. We seek candidates who can contribute to that goal and encourage candidates to apply and to identify their strengths in these areas.
The University of Massachusetts Lowell is an Equal Opportunity/Affirmative Action, Title IX employer. All qualified applicants will receive consideration for employment without regard to race, sex, color, religion, national origin, ancestry, age over 40, protected veteran status, disability, sexual orientation, gender identity/expression, marital status, or other protected class.

Sr. Software Product Design Engineer – Req #221644
Position Overview: The Senior Software Product Designer will be responsible for defining how products in the Solid Edge Portfolio should work from an end-user point of view. This position is on the Solid Edge Product Required Knowledge/Skills, Education, and Experience:

- Qualified candidates will possess a bachelor's degree in Electrical, Electronic or Computer Engineering, or a degree in technology with equivalent work experience.
- Working knowledge of the Windows operating system, Microsoft Office products is required.
- 7+ years relevant industry experience including use of electrical, electronic or PCB design software products is necessary. Examples are products from companies such as Mentor Graphics, Altium, Zuken, Synopsys, Cadence etc

Advanced Front-End Software Engineer - Req #223433
Position Overview: The Advanced Software Engineer will work with cross-functional teams to develop products, business processes and online commercialization of cloud applications and migration of current applications to cloud.
Required Knowledge/Skills, Education, and Experience:

- Bachelor's degree in computer science or related discipline, or equivalent study or experience.
- 3+ years of professional experience in software development.
- Experience with developing and maintaining applications written for Amazon S3, DynamoDB, SQS, SNS, Simple Workflow Service, AWS Elastic Beanstalk, and AWS Cloud Formation.

Advanced Software Engineer – Req #22460
Position Overview: The Advanced Software Engineer will work on a large commercial CAD application in the area of Solid Edge CAD. The position requires performing all of the SDLC steps of software design for one area of a product.
Required Skills:

- Bachelors or Master's degree in Computer Science, Engineering, or related discipline.
- 3+ years of professional experience in CAD product development.
- Must have strong knowledge of C or C++ and the Microsoft Windows programming environment.
  To apply, visit https://jobs.siemens-info.com/jobs?page=1&keywords=plm, and reference respective job requisition number.

Advanced Back-End Software Engineer - Req #223347
Position Overview: The Software Engineer-Advanced will work with cross-functional teams to develop products, business processes and online commercialization of cloud applications and migration of current applications to cloud. Perform research and development on new cloud technologies and methodologies.
Required Knowledge/Skills, Education, and Experience:

- Bachelor's degree in computer science or related discipline, or equivalent study or experience
- 3+ years of professional experience in software development
- Proficiency in at least one modern programming language such as: C++, C#, Java, Python, PHP, Ruby on Rails, NodeJS
- Experience utilizing automation technologies and restful web services –JSON, Chef, XML, Ruby, Python - or other scripting languages.To apply, visit https://jobs.siemens-info.com/jobs?page=1&keywords=plm, and reference respective job requisition number.

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SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

Faculty Positions in Mechanical and Energy Engineering

The Department of Mechanical and Energy Engineering (MEE) at Southern University of Science and Technology (SUSTech) in Shenzhen, China is pleased to invite applications for tenure-track or tenured faculty positions at all ranks. The department is newly established with three main research directions: robotics and automation, innovative design and advanced manufacturing, and energy engineering. Successful applicants will have the opportunities to develop an innovative research program and collaborate with academic/industrial organizations worldwide. The department will consider all areas in the mechanical engineering discipline; however, a particular emphasis will be placed on robotics, additive manufacturing, innovative design, bioscience and medical science associated mechanical engineering, energy engineering with an emphasis on batteries.

SUSTech is a publically funded institution located in Shenzhen, next to Hong Kong. Since its inception, SUSTech's mission has been to reform higher education in China and become a world-class institution with a strong emphasis on innovation and entrepreneurship. Due to its location, SUSTech is exposed to some of the leading high-tech and manufacturing industries in China and is part of Shenzhen's plan to create a world-class economic and innovation center. Shenzhen is the top four most prosperous cities in China and has been consistently referred to as the leader in technological developments.

Candidates must hold a doctoral degree and strong research and teaching credentials. Successful candidates will be expected to establish independent research programs in line with the aforementioned research directions; Interdisciplinary research programs that can bridge the gap between traditional mechanical engineering areas with other STEM fields will be encouraged. To establish an international standard, candidates will be encouraged to participate in international communities and to establish transnational research collaborations. Senior candidates are expected to play leadership roles in research and education. Globally competitive salaries and start-up packages will be provided.

Application Instructions:

Those who are interested are invited to apply through the website at **http://mee.sustc.edu.cn/en/employment/zhaopin1/** or submit the following information electronically to **meehire@sustc.edu.cn:** 1) Curriculum Vitae (with a complete list of publications); 2) Statement of research interests; 3) Statement of teaching philosophy; 4) Selected reprints of three recent papers; and 5) Names and contact information of five references. Review of applications will begin immediately and continue until the positions are filled.

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CELEBRATING ENGINEERING AT E-FESTS

ASME's second year of Engineering Festivals (E-Fests) celebrated engineering at three events—E-Fest Asia Pacific in Delhi, India; E-Fest West in Pomona, Calif.; and E-Fest East at State College, Pa. The festivals featured panel discussions, workshops, networking and social activities, and student competitions such as the Human Powered Vehicle Challenge (HPVC), the Student Design Competition, and the Old Guard Competitions.

With more than 1,000 attendees, ASME E-Fest Asia Pacific, was held March 16 to 18 at Delhi Technological University. The team from Vellore Institute of Technology emerged as the overall HPVC winner and also placed first in the design category and third in the men's speed event. The team from B. H. Gardi College of Engineering and Technology placed second overall, as well as third in the women's speed event and the endurance race. Finishing third overall was the HPVC team from the E-Fest's host, Delhi Technological University. The team also took first place in the women's and men's speed events and third in the design category.

Other big winners at E-Fest Asia Pacific included Shiv Nadar University's team, which took home the first prize at the Student Design Competition "Robot Football" challenge; Aliva Dash from National Institute of Technology Rourkela, who received top honors at the Old Guard Oral Competition; Samarpan Deb Majumder from the Institute of Engineering & Management Kolkata who finished first in the Old Guard Poster Competition, and Sai Ganesh of Chaitanya Bharathi Institute of Technology Hyderabad, who won the event's Impromptu CAD Battle.

The second E-Fest of the season, E-Fest West, took place from March 23 to 25 at the Fairplex in Pomona, Calif. Students from the state of South Dakota performed impressively in most of the competitions held at the festival, which drew a crowd of nearly 650 people.

South Dakota State University's team placed first overall at the E-Fest West HPVC, as well as in the women's speed event and the innovation category. In addition, the team finished second in both the men's speed event and the endurance race and third in the design category. The team from California State University, Northridge, the overall runner-up in the competition, took top honors in the endurance race, and second place in both the women's speed event and the innovation category. The University of California, Berkeley, team rounded out the top three teams overall and picked up a second-place award for their vehicle design.

The South Dakota State University's HPVC team emerged as the first overall winner at the E-Fest West and East Human Powered Vehicle Challenge. *Image: ASME*

In addition to its overall win at the E-Fest West HPVC, South Dakota State fared well in the Old Guard Oral Competition, with students Claire Eggleston and Christian Hogan taking home second and third-place prizes, respectively. A student from another South Dakota university, Josiah Horner of South Dakota School of Mines and Technology, received the first prize at a different Old Guard-sponsored contest, the Old Guard Poster Competition.

The University of Nevada, Las Vegas, took top honors and received a prize at the festival's other major student contest, the Student Design Competition challenge. California State University, Northridge's team placed second in the competition, while the team from Utah State University won the third prize.

The third in the series of E-Fests took place from April 13 to 15 at Pennsylvania State University with over 1,000 attendees.

The overall HPVC winner was the team from South Dakota State University that also won the first prize in the design submission and for the women's speed event. The team from the University of Akron took home the overall HPVC second prize and first prize in the men's speed category. A team of students from the University of Florida took home the first prize for the Student Design Competition.

Joseph Koch of the University of Delaware and Peder Solberg of South Dakota State University, each placed first in their respective Old Guard Oral Presentation Competitions. A student from Western New England University, Caroline Teti, took top honors at the Old Guard Technical Poster Competition. Daniel Fahy of Oxford University won the first prize at another E-Fest event, the GrabCAD Challenge, which focused on "Engineering a 3D Printed Drone Attachment for Agriculture." ME

ASME LAUNCHES NEW PROGRAM FOR GROUP LEADERS

As an organization whose success depends upon the dedicated service of its committed volunteers, ASME truly values the contributions of these volunteers who champion the Society's current endeavors and ensure its future vitality.

The work of ASME volunteers benefits the Society's general membership, making possible not only major events such as the International Mechanical Engineering Congress and Exposition, the Annual Meeting and the Society's new Engineering Festival program, but also local ASME activities including section meetings, dinners, workshops, and technical tours. ASME's volunteers are also the driving force behind the development of the Society's internationally recognized codes and standards.

To that end, ASME recently launched a new conference program that is intended to provide guidance and assistance for leaders of ASME's various groups. Nearly 200 Society volunteers convened in March for the first ASME Group Leadership Development Conference, during which members of ASME's Group Engagement Committee and staff from the Group Pathways and Support provided volunteers at the group level with advice on how to ensure the success of their respective ASME groups. The conference also provided attendees—who were leaders from ASME sections, technical divisions, and research committees—with a venue where they could meet and network with their colleagues and peers.

The event, which was held March 2-4 in Orlando, Fla., was devised as a place where group leaders could feel engaged with each other and ASME, become better informed about the workings of the Society, and better understand their role within the organization and how they can help move their groups and the organization forward.

The conference kicked off with a forum where attendees learned about the Society's strategic planning efforts, followed by sessions that focused on best practices for ASME group operations, assessing and increasing the success of technical divisions and sections, and ways that ASME sections, divisions, and committees could improve diversity within their membership. Volunteers also had the chance to ask representatives from ASME staff about the reorganization of the Society's group structure that has been taking place over the past few years and find out how these changes within the Society will affect their respective groups.

Speakers taking part in the conference included Said Jahanmir, president-elect of ASME; John Mulvihill, chair of the Group Engagement Committee; Richard Marboe, senior vice president of the Technical Events and Content Sector; Paul Stevenson, senior vice president of the Student and Early Career Development Sector; Jeff Patterson, chief operating officer of ASME; Elena Gerstmann, deputy, Executive Operations, ASME; Timothy Graves, managing director, Technical Conferences and Events; and Elio Manes, director, Group Pathways and Support, among others. ME

ASME volunteers, like those shown here, attended the ASME Group Leadership Development Conference in Orlando, Fla.
Image: Wilfred Haywood, ASME

SPECIAL ISSUE OF APPLIED MECHANICS REVIEWS EXPLORES MACHINES AND ROBOTS

The ASME journal *Applied Mechanics Reviews* recently published a special issue for educators, researchers and practitioners who are interested in mechanisms, machines, and robots. Developed in conjunction with the ASME *Journal of Mechanisms and Robotics*, the issue features five comprehensive review articles highlighting basic and applied research and offer commentary on the existing literature related to robot dynamics, mechanism design, and human-robot interaction.

The articles in this special issue include "A Review of Propulsion, Power, and Control Architectures for Insect-Scale Flapping-Wing Vehicles" by E. Farrell Helbling and Robert J. Wood, focusing on actuation, energy, and power requirements for the control of flapping-wing micro-aerial vehicles, and "Redundancy in Parallel Mechanisms: A Review" by Clément Gosselin and Louis-Thomas Schreiber, which presents an introduction to redundancy in the synthesis of parallel mechanisms.

The issue also features "Geometric Algorithms for Robot Dynamics: A Tutorial Review" by Frank C. Park, Beobkyoon Kim, Cheongjae Jang, and Jisoo Hong, examining how the coordinate-free approaches of differential geometry can be used to formulate equations of motion for multibody systems; "A Review of Intent Detection, Arbitration, and Communication Aspects of Shared Control for Physical Human-Robot Interaction" by Dylan P. Losey, Craig G. McDonald, Edoardo Battaglia, and Marcia K. O'Malley, a look at applications in areas where humans and robots must work together; and "A Review of Thickness-Accommodation Techniques in Origami-Inspired Engineering" by Robert J. Lang, Kyler A. Tolman, Erica B. Crampton, Spencer P. Magleby, and Larry L. Howell, a visual review of recent advances in origami-inspired mechanism design. ME

The Leveraxe requires less power than traditional axes.
Images: Leveraxe

NEW TWIST ON AN OLD TOOL

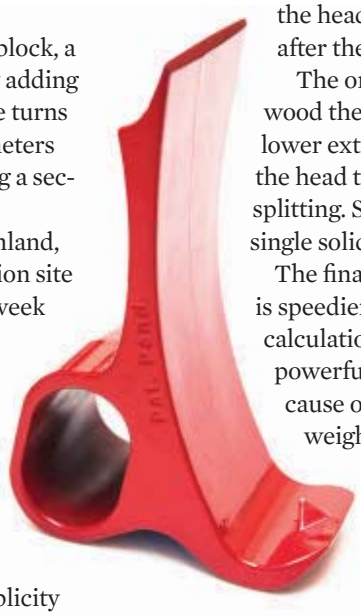
Unique axe uses lever action to make splitting wood easier.

The axe is arguably one of the world's oldest engineered objects. And yet, despite its early provenance, its essential design and operation have not changed much in its many millennia of use: whack a log with a heavy wedge and it splits the wood along the grain.

But now there's a new kid on the chopping block, a lopsided claw of a tool called the Leveraxe. By adding weight to one side of the axehead, the new axe turns after it has penetrated the wood by five millimeters or so, changing from wedge to lever and prying a section away from the greater log.

Mechanical engineer Joel George was in Finland, working on a nuclear power station construction site when he first heard of the new axe. Within a week he was visiting inventor Heikki Kärnä.

"When I first used the Leveraxe I was so surprised by how little force is needed for the axe to lever the wood apart," George said. Before he returned to Blue Mountain Lake, N.Y., he'd agreed to become Leveraxe's North American distributor.



The Leveraxe went through a few incarnations before it reached its current state of simplicity and elegance. The axe was born shortly after Kärnä retired from his job as an air traffic controller and moved to a new house in the middle of the woods. He'd been splitting wood his whole life, but he was tired of the problems that came with a traditional maul—the head often gets stuck in the wood, it also has a propensity to bounce and fly off to toward the feet, and that makes for hard work.

Kärnä's first attempt at remedying the situation was to bolt hockey pucks to both sides of a maul head. This effectively kept the tool away from the feet by bouncing it back up off the log. It also effectively killed the force needed to split the wood apart. Next he tried bolting heavy washers to one side of the head. This introduced the prying action that occurs after the head has struck wood. It worked.

The only problem was that after popping off a piece of wood the axehead would slide off, again endangering the lower extremities. So he welded studs to the thick end of the head to catch the wood and keep it atop the log it was splitting. Since then the Leveraxe's head has become a single solid piece of cast or forged metal.

The final product is safer, requires less power, and is speedier at getting the job done. "Rough theoretical calculations conclude that the Leveraxe is 30 times more powerful than a traditional axe as it hits the wood, because of the added torque that is created by the counter weight," George said. "The Leveraxe does not lose kinetic energy to friction as do traditional axes, because it penetrates into the wood on an optimum strike only a quarter of an inch."

An axeman hard at work on a log can split it up to five times as fast and with lower risk of bodily harm. "During the existence of the Leveraxe there have been no accidents," he said. Knock on wood.

"I do use it to split all my wood here in upstate New York," George added. "I'm blown away with its functionality, and its simplicity. It's very refined in the eyes of a mechanical engineer." ME

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*Source for statistics: "Cyber Security Statistics—Numbers Small Businesses Need to Know," Matt Mansfield, January 3, 2017.

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