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No. 10
138
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SOLAR ROADS

TECHNOLOGISTS LOOKING FOR a readily available open space to install solar cells have batted around the idea of placing them on our sun-soaked ribbons of highway. One downside to that concept, however, is the high cost of repaving roads with photovoltaic polygons. Now a French company called Colas has come up with a new product for creating solar roads that they hope eliminates some of that cost. Their product—Wattway—is made to be road-strong and easy to apply. There's no need to rip up asphalt and repave. Instead, Wattway is slapped onto existing road with glue.

A MODEL TO KEEP PACE

A TEAM OF ENGINEERS AT Iowa State University in Ames is using computer modeling to discover why many pacemakers fail—and how to improve future performance and achieve better patient outcomes.

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

HONING ADDITIVE MANUFACTURING SKILLS

A NEW ADDITIVE MANUFACTURING center at Arizona State University in Tempe teams industry with student- and faculty-led research to pioneer 3-D printing techniques and troubleshoot printing issues.

SUSTAINABILITY IN GLOBAL CONSTRUCTION

CATHERINE McKALIP-THOMPSON, manager of sustainability for Bechtel Infrastructure, describes trends in sustainable building design, smart cities, and the integration of engineering, architecture, and planning.

NEXT MONTH ON ASME.ORG

SELF-SAILING BOATS IN THE ATLANTIC

Boats can be autonomous too. Researchers at the United States Naval Academy have tried for several years now to get boats to sail themselves across the Atlantic.

THE EVOLUTION OF POWER PLANT CONSTRUCTION

Chris Tye, president of global engineer/constructor Fluor Corp., talks about trends in the power market and design and construction of power plants.

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ASME
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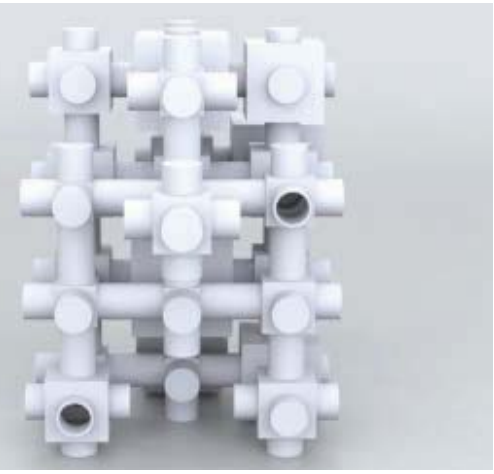

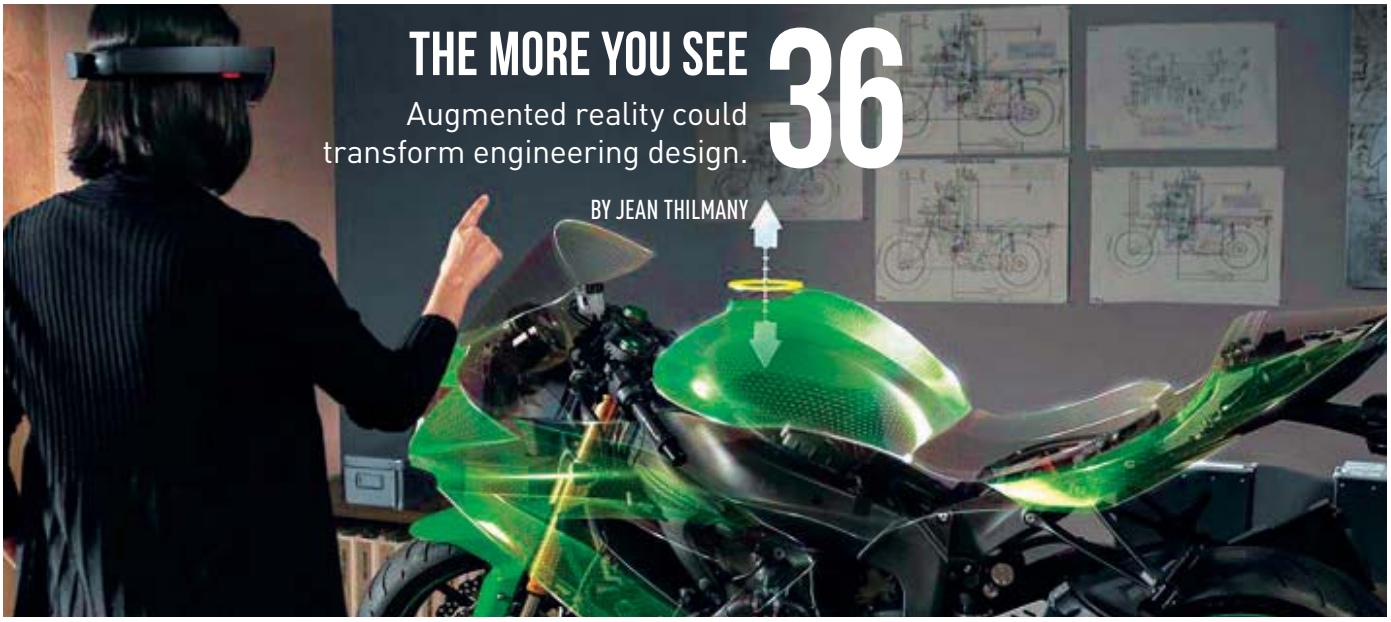

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Give me the place to stand, and I shall move the earth
—Archimedes

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John G. Falcioni
Editor-in-Chief

REWRITING THE RULES OF PRODUCT DEVELOPMENT

It was last November when those of us who still subscribe to the print edition of *The New York Times* received a relatively uninspiring cardboard insert with our Sunday papers. The instructions provided—"fold here, bend there"—were hardly different from those printed on a U-Haul cardboard packing box. But *The Times* promised the reward would be worth the effort.

After assembling it, downloading the smartphone app, and inserting my phone in the box, the payoff was unexpected. Before my eyes, the box and smartphone were transformed into a 21st century View-Master. But this wasn't my mother's stereoscope, it was an addictive immersive experience.

The virtual-reality initiative is a collaboration between *The Times* and Google on a project called NYT VR. More than one million Google Cardboard viewers were shipped to *Times* readers last year, showcasing a unique way to experience powerful storytelling.

The first story *The Times* delivered, "The Displaced," captured the plight of children from South Sudan, eastern Ukraine, and Syria who were caught in the global refugee crisis. It immersed the viewer virtually inside the striking video images. You could look up to see the sky on the video or look down to see the soil. You could look back behind you or to the sides.

Other films followed, including a visual account of the candlelight vigils following the November 2015 terrorist attack on Paris. Today, NYT VR is also being used in many classrooms to help students learn about the world in visually powerful ways.

By collaborating with Google and other virtual-reality developers on this unique project, the 165-year-old newspaper, often referred to as The Gray Lady, leapfrogged online and digital storytellers. This is one of the ways, outside of the electronic gaming industry, in which the benefits of the immersive power of virtual reality has reached consumers.

For years, engineers have saved time and money using simulation and optimization software tools. These tools have brought virtual models to the screen and have fostered powerful multidisciplinary and collaborative product-development processes for designers.

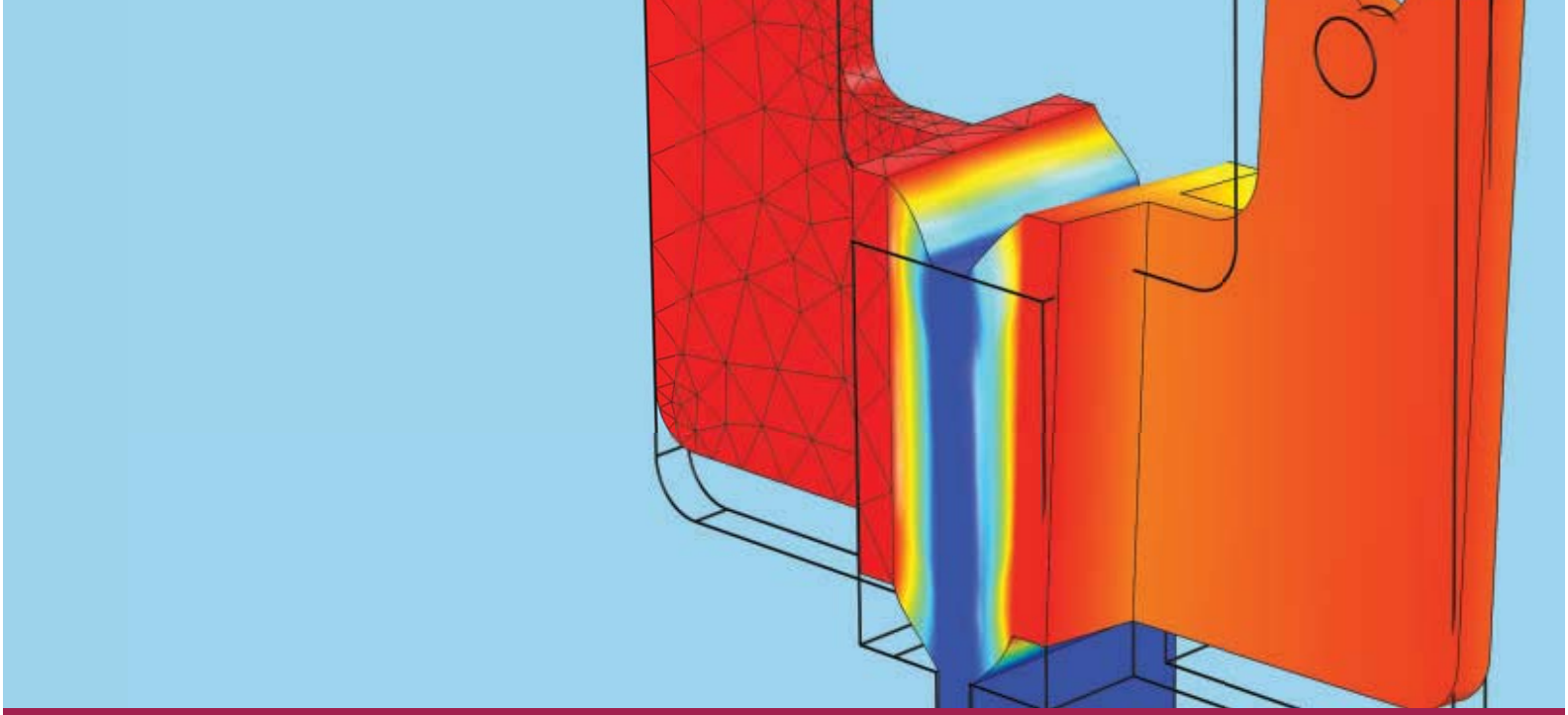
The use of virtual-reality technologies, however, has been an elusive goal. But now there is a clearer understanding of what that technology can deliver. Major backing from NASA, Autodesk and Microsoft on industry research—combined with support from Apple, Facebook, and Sony on the development of lower-cost mixed reality systems—is helping to bring design and visualization closer together.

The technologies that comprise these advanced computing platforms, ranging from virtual reality to augmented or mixed reality, are beginning to rewrite the rules of product development. As our cover promises this month, we are sharing with you some of the leading developments of this transformative trend. And even if we're not providing you with a do-it-yourself VR viewer with the magazine, the word pictures that our writers and editors have painted are sure to stimulate all your senses. ME

FEEDBACK

Do you think design and visualization tools will be as ubiquitous in the next decade as FEA and PLM are today? Email me.

falcionij@asme.org



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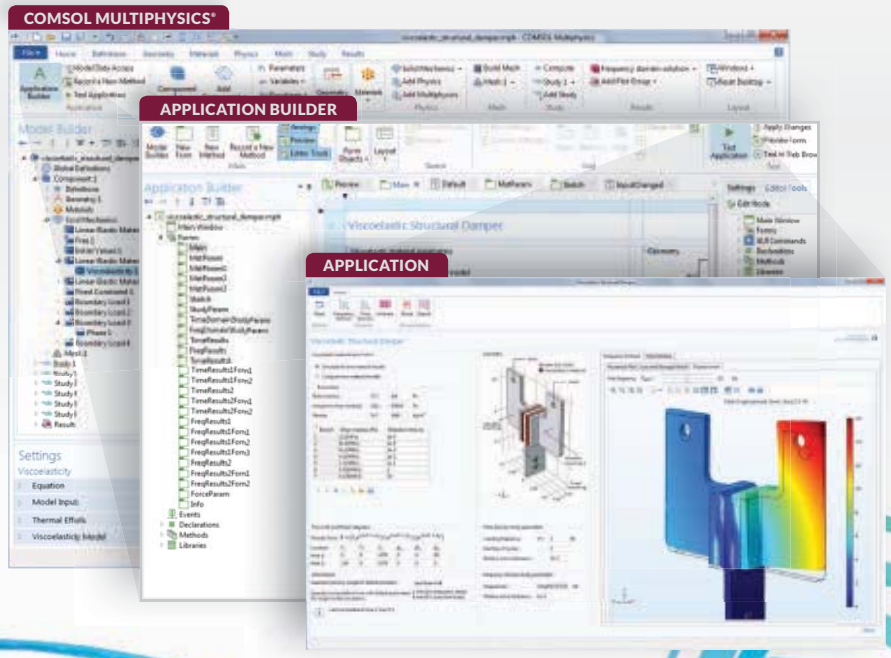

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LETTERS & COMMENTS

MAY 2016

Reader Leet suspects self-driving cars will be marketed before they are ready.

« Two readers suspect automation will cause more headaches than relief. Another catches an old error.

PREDICTIONS WITHIN BOUNDS

To the Editor: The planet is an immense system which changes with time, and we are too insignificant to matter in the greater scheme of things. Granted, we can mess with the small part of the environment over which we have control, and it is probably a matter of good housekeeping to keep it in as decent a shape as we can.

I think it is an excellent idea to tackle those problems that make life difficult, that we can tackle. I only ask that this inevitably piecemeal cleaning up chore not be elevated to indisputable proof that we are either "ruining the planet" or that, on the other side of the aisle, there is nothing wrong.

We have real experiments ongoing which illustrate the risks of predicting too much from too little knowledge. Chernobyl is a case in point. When this accident occurred in 1986, the predictions of disaster abounded. Today, the wildlife in the affected area is teeming. If anything, the environment is better now than before the accident. A lot of the environmental damage inflicted by Stalin's era has been reclaimed.

But the fear lingers on. Scientists regularly enter this area kitted up with suits and Geiger counters to take radiation readings of the skeletons of catfish that have grown to an enormous size in the cooling ponds of the reactor and are caught and dragged ashore to be eaten by wolves and foxes. Readings are off the charts, confirming the scientists' belief that background radiation is still dangerously high. These same radiating catfish had been meals for the wolf population for nearly 30 years, and there is no evidence whatever of the wolves having any detrimental effects from nuclear radiation, either directly or through the ingestion of irradiated food.

I offer you this story as evidence of how scientists, just like the common man in the street, can, and do, ignore evidence when it does not fit with their preconceived notions.

I would not argue that "climate change" is not occurring, and some of the stupid things human beings do help it along. But please keep the predictions within the bounds of the available evidence and science's ability to use it.

Douglas Marriott, *Mason, Ohio*

SELF-DRIVING, NOT SELF-EVIDENT

To the Editor: I read with interest the article on testing of autonomous vehicles (TechBuzz, May 2016). The question that immediately comes to mind is: Who wants these things driving around?

No good reason for it has been offered yet, except an unproven promise of increased safety. There are some reasons why we should be very careful about unleashing this technology.

The first is this step increase in system complexity leads to system fragility and potential for catastrophic failure, analogous to the 2008 debacle in the finance world. Another concern is massive driver job elimination. We already see technology throwing people out of work and the negative social effect of that.

A third problem is the trend to automate everything. The danger with that is people become increasingly helpless and dependent. The last is the sheer difficulty of amassing enough sensors coupled with artificial intelligence to manage the system.

I suspect that once it's tested "successfully" and then forced on the public, the system will not perform as originally promised. Additional measures will then be implemented, such as prohibiting people from roadways completely or the compulsory use of a transponder if you do.

Most of the safety claim for self-driving cars is likely due to lowered peak speeds by flattening average speeds. That could be done more simply (but perhaps less profitably) by a wireless speed governor system, variable as to zone.

We already have the recent examples of Volkswagen and Takata pressured to market technology that was not ready. Self-driving vehicles appear the same, but at a much bigger scale.

Dave Leet, P.E., *Alpine, Texas*

RECOGNITION

To the Editor: I would like to thank you for the absolutely wonderful publication that *Mechanical Engineering* magazine has become. I look forward to every issue. The articles are very interesting and cover every aspect of our field.

Lee Mount, *West Monroe, N.Y.*

ROBOTS AT WORK

To the Editor: Thanks for Alan S. Brown's very interesting article, "Robots at Work: Where Do We Fit" (April 2016).

It seems to me on the plus side that robots draw no wages; work three shifts a day, resting only for reprogramming and maintenance; require no expensive education or training; take no vacations or sick leave; and never go on strike interrupting production, while possibly reducing the costs of certain produced goods. On the negative side robots do not buy any of their own finished products or the output of any other robots or human

workers; do not support families and their sundry expenses that create many jobs; do not pay local, state or federal taxes, nor buy houses and cars, etc.; and do not even help support the welfare system for humans displaced from their jobs.

Between the export of labor-intensive jobs and the displacement of human workers by robots, it may become increasingly difficult for youths to find meaningful and financially rewarding employment, especially that which justifies an expensive college education.

We may someday have automated buses. Could we even eventually expect to replace the editor of *Mechanical Engineering* with a robot? Nothing could possibly go wrong ... go wrong ... go wrong ....

Albert Winroth, *Saratoga Spring, N.Y.*

CONSIDER CAPITALISM

To the Editor: One factor Adrian Bejan apparently overlooked in the development of airplanes ("Accelerated Evolution," April 2016) is American capitalism—the desire and need to make money to put food on the table and get ahead in life.

Donald W. Douglas was driven to design and fill orders for his new DC-3 so his struggling company would stay in business. That was the driving force behind that historic advance in aviation.

Gene Graber, *Basking Ridge, N.J.*

OLYMPIC ERROR

To the Editor: I was reading an article in *Mechanical Engineering* on the mechanics of swimming ("Stepping on the Water," October 2013) and noticed what seems to be an inaccurate caption for one photo. The image shows Michael Phelps swimming in competition. The caption identifies the other swimmer in the image as American Davis Tarwater, who competed against Phelps in the 2012 Olympic trials.

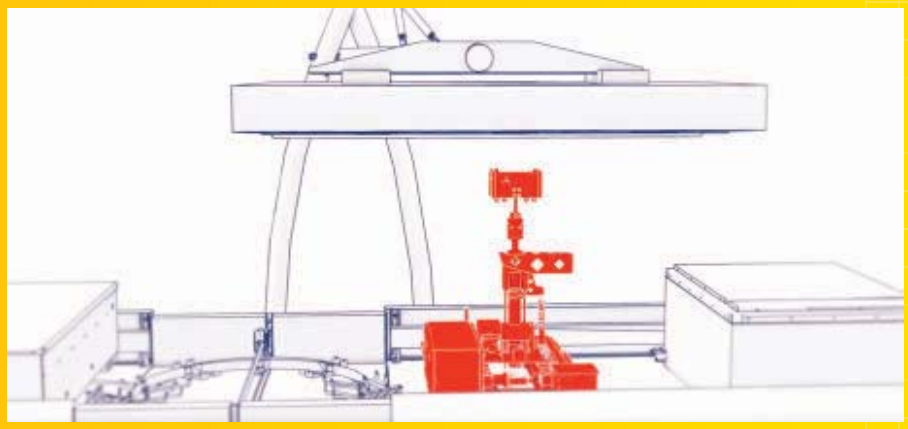
However, the cap of the other man appears to have a Serbian flag on it, suggesting this might be Milorad Cavic who competed against Phelps in the 2008 Olympic Games.

While this is a small error I believe it might be wrong nonetheless and wanted to bring it to attention.

Great publication by the way—always interesting to read!

Jivan Purutyan, *Concord, Mass. Purutyan is a student at Worcester Polytechnic Institute.*

FEEDBACK Send us your letters and comments via hard copy or e-mail memag@asme.org (subject line "Letters and Comments"). Please include full name, address and phone number. We reserve the right to edit for clarity, style, and length. We regret that unpublished letters cannot be acknowledged or returned.



CHARGE UP IN A ZAP

BATTERY-POWERED BUSES ARE READY TO ROLL IN JUST 15 SECONDS.

Electric mass transportation has no tailpipe emissions, but it often produces another kind of pollution: the unsightly clutter of overhead power lines. Battery power eliminates those wires, but at the cost of increased bulk and limited range. A new quick-charging system being built in Geneva, Switzerland, looks to remove those limitations by topping off the batteries on transit buses every few stops.

The technology was developed by ABB, which designed it to cope with the rapid pace of major urban routes and rush-hour traffic. ABB will team with Hess, a Swiss bus manufacturer, on a $16 million contract to build and maintain 12 all-electric buses.

ABB's trolleybus power optimization system (which goes by the French acronym TOSA) places electric charging equipment on the roofs of the buses. At a station equipped to recharge the batteries, the electric bus will pull under an AC-to-DC converter. A laser-guided telescoping connector mounted on the bus will take only a second or two to make the connection. Recharging will last only 15 seconds at 600 W.

The bus stations are "simply feeding stations, providing a voltage to the on-board charger which controls the actual charging. There is no communication between the infrastructure and buses," said Conrad Jansen, ABB Switzerland's global application manager for rail and urban transport.

Jansen said the plan is to recharge the buses at 13 of the 50 stations along their 13-km route connecting suburban Praille-Acacias-Vernet to Geneva's airport. The buses will also use regenerative braking to recharge as they slow down and will receive an additional 4-to-5-minute boost at the end of the line.

Because the buses recharge so frequently, they can employ smaller batteries and use the extra space to carry more passengers.

When fully commissioned in 2018, the buses will carry 10,000 people per day and run every 10 minutes at peak times.

A new electric bus will not need to draw power from overhead wires. Instead, selected stations with electric docking stations (below and left) will provide a quick charge to the bus's batteries.

Switching from diesel to electric buses will lower noise by 10 decibels and slash carbon dioxide emissions by 1,000 tons annually.

While the quick-charge buses are more expensive than conventional trolleys, the total cost of ownership is lower because cities do not have to build or maintain overhead electrical lines, Jansen said. He also expects the system to grow more competitive as fuel prices and carbon dioxide taxes rise and battery costs fall.

"The TOSA model provides insights into where urban transport is going—electrically powered, emission-free and sustainable, with minimal infrastructure," Jansen said. **ME**

ALAN S. BROWN

SOLAR IMPULSE CLOSES THE CIRCLE

SOLAR IMPULSE 2, THE LONG-RANGE solar-powered airplane completed its round-the-world flight on July 24—many months late, sure, but its developers, who are also its pilots, weren't in a hurry.

Bertrand Piccard and André Borschberg led the development of the airplane and spelled each other piloting the aircraft, sometimes flying continuously for days at a time.

They flew the plane approximately 40,000 km in 17 months. The original estimate was a journey of five months, but the plane was delayed for repairs in Honolulu for several months.

Piccard has previous experience with unconventional flight around the globe. He and Brian Jones completed the first nonstop round-the-world flight in a hot air balloon, the *Breitling Orbiter 3*, in March 1999. At takeoff the balloon carried 3.7 tons of liquid propane. At the end of the flight there were 40 kg left.

According to Piccard, the mission would have failed if the last bit of fuel had run out, and that experience triggered the idea of flight without fuel.

Piccard presented his idea for a solar airplane to a Swiss committee, which conducted a feasibility study. Borschberg headed the committee and was so impressed by the idea that he joined the project.

Solar Impulse 2 flies over the Great Pyramids as it completes leg 16 (Seville to Cairo) of its 17-leg mission.
J. Revillard / REZO

The current plane's predecessor, *Solar Impulse 1*, was a prototype that was tested in Europe, flown to Africa, and later flown across the United States.

Solar Impulse 2 is equipped for much longer flights. The plane's total mass is 2,300 kg. It carries 17,248 solar cells and 633 kg of batteries capable of storing 65.5 kWh of energy. The plane's cruising speed is 70 km per hour.

During one leg—a five-day nonstop marathon from Nagoya, Japan, to Honolulu—the plane's batteries overheated and were damaged. Replacing them delayed the aircraft in Honolulu until the end of the flying season. Flights resumed this May.

The entire trip was accomplished in 17 legs—starting and ending in Abu Dhabi in the United Arab Emirates, but with no set flying schedule. The ultralightweight aircraft had to wait for appropriate weather and sometimes to alter its flight route.

A spin-off organization, the International Committee for Clean Technology, was announced while *SI2* was crossing the Atlantic. According to the group, there are plans to develop solar-powered drones. **ME**

HARRY HUTCHINSON is the former executive editor of *Mechanical Engineering* magazine.

THE SIDEWALK AUTOMATON

The Jackrabbot, an autonomous robot capable of following the unwritten rules of the sidewalk, is dressed up for a "stroll."

A Stanford University team has created a robot that can navigate crowded sidewalks.

The autonomous car is easy. To get a driverless vehicle to safely guide itself through the nation's streets and highways, there's a baseline to go by: the rules of the road. And computer algorithms are very good at following rules.

There is another arena of transportation, however, that's more treacherous, where the rules are not spelled out—the sidewalk. Navigating the strips of concrete along the sides of city streets is a subtle affair, dependent on body language, unconscious conventions, and social and cultural norms. Google Chauffeur installed on a smaller machine wouldn't do well on a pedestrian pathway.

Now a team of researchers at Stanford has taken up the challenge of creating a self-navigating machine for the sidewalk, an R2-D2-sized automaton named Jackrabbot.

The goal is to have a robot that moves like a pedestrian. To do so, it has to understand a lot more than human-to-human interactions.

The sidewalk, after all, hosts skateboarders, bicyclists, hoverboarders, wheelchairs, dog walkers, and squirrels, in addition to simple pedestrians out for a stroll.

"You can see that the complexity of interaction is much richer than that between humans," said Silvio Salvarese, a professor of computer science and the director of Stanford's Computational Vision and Geometry Lab. "For example, pedestrians and bikes use a lot of conventions and subtle cues, in close proximity, without accidents—well, sometimes accidents, but mostly not."

> **"PEDESTRIANS AND BIKES USE A LOT OF CONVENTIONS AND SUBTLE CUES WITHOUT ACCIDENTS."**
> **SILVIO SALVARESE, DIRECTOR OF STANFORD'S COMPUTATIONAL VISION AND GEOMETRY LAB**

To understand this complexity, and get it into the Jackrabbot, the team collected a massive data set of interactions on collegiate walkways.

"What we did is fly a drone over the Stanford campus," Savarese said, "and we recorded hours and hours of footage of all possible actors that populate the campus: pedestrians, bikes, skateboards, strollers. All these agents and trajectories are for learning interclass relationships."

The data also includes non-

continued on p.14 »

JOINT VENTURE IN INDIA FOR DEEPWATER PROJECT

The multinational General Electric and the Mumbai-based engineering firm Larsen and Toubro have signed an agreement to manufacture subsea manifolds destined for future deepwater projects in the Krishna-Godavari Basin on the east coast of India.

The partnership aims to leverage the manufacturing and technological capabilities of the two companies in the oil and gas space. It will mark India's entry into local subsea equipment manufacturing.

The agreement was reported in August in the *Economic Times of India*.

Larsen and Toubro's modular fabrication facility in Tamil Nadu was chosen as the production site.

The Larsen and Toubro plant is equipped with advanced welding and fabrication capabilities along with a 150 m jetty for loading the finished product on ships.

No financial details of the agreement were released.

The Krishna-Godavari Basin is spread across 50,000 square km along and off the shore of the Indian state of Andhra Pradesh.

The region is believed to possess India's largest natural gas reserves. **ME**

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continued from page 12 »

SIDEWALK AUTOMATON

agents such as sidewalk, grass, trees, fountains, and staircases.

A side effect of the project is that, in learning how to best teach Jackrabbot about navigating among humans, they've learned a lot about how humans navigate among humans. Their data could be used by civil engineers and sociologists hoping to better understand the flow of humanity.

Their method needn't be limited to understanding human interactions, either. In fact, one Stanford colleague has put the team's practices to use in an attempt to track the relationships of hens in large colonies.

Autonomous cars could use that approach as well. There's more to the rules of the road than the rules, after all. At urban intersections with stop signs, self-driving cars will have to understand when a pedestrian's hesitation is just a safety check, and when it's a sign that the right of way has been surrendered.

More immediate applications for the Jackrabbot could include assisting shoppers, patrolling the campus as a mobile information booth, and solving the "last mile problem"—the final delivery of parcels transported by self-driving trucks.

So far, Jackrabbot has done the majority of its meandering indoors. It will spend more time outside on the pathways of the Stanford campus this fall, when the team is sure all safety issues have been worked out. Then finally, perhaps, robots will become the autonomous things they were first imagined to be.

"It's an exciting time for AI," Savarese said. "My group is really trying to help make an ecosystem where humans and robots are interacting in successful and imaginative ways."

MICHAEL ABRAMS is a technology writer based in New York City.

ONLINE RESOURCES FOR DEVELOPMENT ENGINEERS

When global development professionals need to decide about which technologies to use in their work, the Solutions Library at Engineering For Change ought to be the first stop. The E4C Research Fellows have investigated hundreds of products and compared them across numerous performance parameters.

But for information about raw materials such as bamboo or for construction techniques such as mixing concrete by hand, we didn't want to reinvent the wheel. So the fellows reviewed resources that other organizations have already compiled and created an internal list of Internet libraries for building professionals working in resource constrained-environments.

The following resource libraries vary in depth and structure, but have proven to be useful references for questions on everything from plastering to plumbing.

Materials such as bamboo can be viable alternatives to steel and concrete.

PRACTICAL ANSWERS

http://answers.practicalaction.org/our-resources

The Practical Answers resource library (also available in a useful mobile application) combines good organization with an enormous quantity of material. Divided into broad categories, topics range from transportation and infrastructure to livestock and economic development. The construction subcategory covers masonry, earthen construction, and more. Documents are available in a handful of languages which the user can filter.

APPROPRIATE BUILDING MATERIALS

http://collections.infocollections.org/ukedu/en/d/Jsk01ae/1.html

This list is consolidated from a printed catalog published in 1988, and is linked through its table of contents. More comprehensive than in-depth, the links take you through fundamentals of materials and measures, followed by informative chapters on roofs, walls, floors, and foundations. The site's design is minimalist and looks like it may not have changed much since the year the catalog was digitized, though it is easy enough to navigate.

CD3WD

http://www.fastonline.org/CD3WD_40/CD3WD/INDEX.HTM

This relic from the 1990s may be the most obscure of the resources we have found. It is an enormous list of PDFs in a rough, disjointed alphabetical order, ranging from agriculture to woodworking, passing through topics such as food processing, construction, concrete, and much more. In some cases, there are even complete books available. The list is somewhat difficult to navigate, but there are a few gems hidden within the cascade of links and text.

ENGINEERS WITHOUT BORDERS – USA

http://www.ewb-usa.org/resources/

The Engineers Without Borders library is easily searchable and user-friendly, with hundreds of PDFs available for free download. Its search feature allows users to quickly filter out relevant documents for review. These links cover a number of technical aspects of development as well as guidance on procedural steps such as assessments, operations, and maintenance.

BUILD CHANGE

http://www.buildchange.org/

Build Change's repository (under the "Resources" tab) is divided into building materials, new construction, retrofitting, visual media, and post-disaster assessments. Each are sub-categorized into regions such as China, Haiti, Indonesia, and Nepal. The list is well organized, though the content relates primarily to the projects that their team is working on in the field.

WIKIHOUSE

http://www.wikihouse.cc/about/

Wikihouse is a collaborative research and development project seeking to revolutionize the way homes are built. The website is still under construction, but the first technology it will feature will be "Wren," a kind of digital Lego. Wren is the first building system designed for open digital manufacturing. It can be shared and written as code. Parametric design uses open data to calculate cost, time, performance, and impact and to produce manufacturing information. ME

CHARLES NEWMAN is an E4C Research Fellow and an architect who has designed and built hundreds of structures across East Africa. For more development engineering resources, visit engineeringforchange.org.

HOW DEPENDABLE IS THE TRADITIONAL GRID?

Utility managers worry that **renewables may hurt grid reliability.** In fact, all energy forms and technologies suffer from some sort of **reliability challenge.**

One of Aesop's Fables tells of the hearty oak tree that mocks the reeds for weakly bending with the wind. The strong oak resists the wind for many decades, but one day it snaps in a windstorm, falling apart in spectacular fashion. The reeds, meanwhile, live on, flexible and responsive to change.

Many observers of our electric utilities mock renewables for their weakness, in the form of their variability and intermittency, and confidently praise large baseload power plants for their steady reliability. I believe that confidence is misplaced. In my next column, I will look at how serious the problem of renewable intermittency is for the grid. For now, I want to challenge the idea that only renewables suffer from reliability issues.

In fact, all energy forms and technologies suffer from some sort of reliability challenge.

Coal suffers from distribution problems. One train wreck or bad section of track 1,000 miles away can delay a coal train for weeks. When a polar vortex froze over lakes and rivers in 2014, the barges delivering coal couldn't get through the ice, threatening a coal-fired power plant along Lake Superior with a fuel supply disruption. Coal-carrying barges also have trouble delivering fuel along the Mississippi River when major droughts strike.

These factors are why coal plant operators store 60 days' worth of coal on-site. They've built the likelihood for disruption into their operational schemes.

Of course, foul weather can cause other problems, too. A major cold snap in 2011 in Texas caused some water pipes at coal plants to freeze, forcing the plants off and triggering statewide blackouts.

Other forms of baseload have reliability issues.

Historically, the biggest concern for grid operators was the risk that a nuclear power plant would trip offline, erasing 1 GW or more of capacity in a second or less. In Texas, the reserve margin—the amount of power from backup plants that needs to be on and ready to generate electricity on a moment's notice—is set based on the risk that two nuclear reactors, or 2.6 GW of generating capacity, would go offline simultaneously. That grid operators have baked nuclear variability into their planning is very telling.

Natural gas can suffer from low pressure in the pipelines when demand is unusually high for home heating and power plants simultaneously. The same 2011 Texas cold snap that tripped off coal plants also prevented dozens of natural gas plants from coming on to back up the coal plants, triggering statewide rolling blackouts. And as the major gas storage leak at Porter Ranch in Aliso Canyon, Calif., recently demonstrated, natural gas has a tendency to float away if you're not careful. That leak prompted the state's grid operators to warn of potential blackouts.

There are countless examples, but the key point is that every fuel and technology has its failure mode. Some fade often but elegantly, like solar and wind whose output gracefully moves up and down through the day and year, while others drop-off seldom but suddenly, like coal, nuclear, and natural gas.

Rather than obsessing over the variability of renewables, let's acknowledge that all power sources have tradeoffs, with some benefits and risks.

Because of these challenges, grid managers should pursue a suite of options, much the way financial advisors recommend a range of investments rather than putting your life savings in just one stock.

"LET'S ACKNOWLEDGE THAT ALL POWER SOURCES HAVE TRADE-OFFS, WITH SOME BENEFITS AND RISKS."

We started with a fable, so perhaps we should draw a lesson in this: After the 2011 blackouts in Texas when coal plants went offline and natural gas plants couldn't pick up the slack, the CEO of the Texas grid operator wrote a public letter to the wind industry, thanking it for feeding enough electricity to the grid to help prevent an even bigger fiasco. The strong oaks of traditional power failed, but the weak reeds of renewables carried on. ME

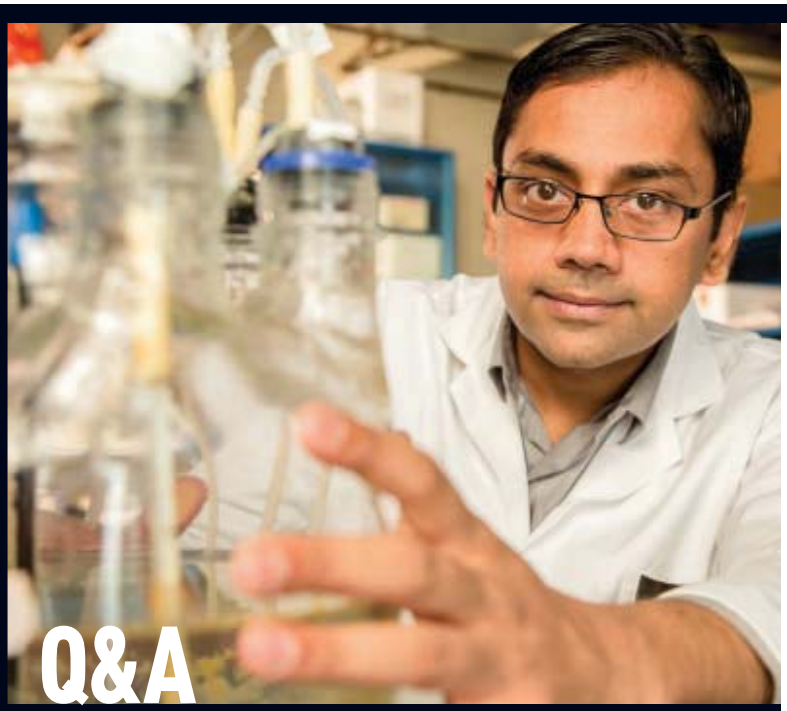
MICHAEL E. WEBBER is deputy director of the Energy Institute at the University of Texas at Austin.

ME: What do you say to naysayers?
K.C.: I hear comments like "this will never work." But they are not very accurate. This whole approach of recovering resources would work far better than the centralized model, the energy-intensive model, or the resource-intensive model. It would allow clean water and sanitation to be accessible to many billions of people. This is a formidable challenge, but I think we need to just keep going. There's no other way.

ME: If you had things the way you want, what would wastewater treatment look like in 50 years?
K.C.: Ideally we'd stop even viewing sewage as a waste stream. You can think beyond sewage, even. Food waste, fecal sludge, animal waste, agricultural waste—all these things, we call them waste. To me wastewater is really enriched water, because it's enriched in chemicals and nutrients and even energy. Once you start treating these as feed stocks or substrates, the whole conversation changes. We are not putting in wastewater treatment systems for the sake of clean wastewater, we are actually putting in, let's say, biorefineries to mine the resources in these so-called waste streams. Clean water becomes the bonus. That's really my vision.

ME: Your focus has been on the developing world. Would your system work in the U.S.?
K.C.: Things work well here—things work very well here—but they could work even better. So we take the same centralized model and perhaps change that a little bit. To give you an example: for us in New York, let's say we take many or all the high rises, and we have treatment units, or energy recovery units, inside these buildings. We can do this because we have a dense concentration of people here. The centralized plants are then relieved of a lot of their loading and they can do other things, for instance, handling precipitation events.

ME: How much energy can we actually extract from such waste?
K.C.: If we just take the organic mater contained in sewage and convert that carbon into methane and then methane into electricity, the energy comes out to about 2,500 kilowatt hours per million gallons. The energy needed for conventional wastewater treatment would be about the same, so we could potentially break even.



Q&A KARTIK CHANDRAN

ENVIRONMENTAL ENGINEER Kartik Chandran's lab at Columbia University employs a diverse team of researchers: microbiologists, molecular biologists, and process engineers. They are at work developing a system for using microbes to clean filthy water—a process that also harvests chemicals dissolved in the water and generates methane that can be used as fuel. Chandran has successfully demonstrated his process in Ghana, and last year he received a MacArthur Foundation grant to help develop it further.

ME: Do you have to produce the microbes?
K.C.: They feed off the so-called waste stream, so we don't have to. In fact, to start a brand new waste plant we basically flow wastewater through the tanks for a month or so and allow the organisms to proliferate. We rely on the activity of the organisms—that's what drives everything.

ME: Do you find the application side of things to be a cinch after the hard science has been done?
K.C.: Real systems are not dumbed down versions, or simplistic. In fact, they are often more noisy, more chaotic, and more uncertain than lab scale systems. Sometimes the real questions arise from the field systems.

ME: What would you tell young engineers about your area of research?
K.C.: I know it's not a very glamorous field, but there's such a need. As engineers, we like to ask questions, for sure, but also to solve real problems. I don't think there are any more real problems than access to clean water, sanitation, energy, and food. ME

MICHAEL ABRAMS is a technology writer based in New York City.

SOFT ROBOTS GROW UP

Despite the strides researchers have made in developing robots made from soft materials, there was always a stiff or rigid component—mainly the actuation and control systems—that limited their applications.

A team of Harvard engineers recently overcame those hurdles, unveiling what's being called the first fully soft and autonomous robot. The eight-armed robot, dubbed the "octobot," is made from deformable materials and can operate without being tethered to a control cable.

Similar types of robots are expected to eventually perform tasks unsuitable for rigid robots, such as internal medical procedures, search-and-rescue operations, and machine diagnostics and repair.

"The field is wide open," said Michael Wehner, a research associate in materials science and mechanical engineering at Harvard's Wyss Institute for Biologically Inspired Engineering and co-first author of the paper, published last month in *Nature*. "Other applications will come up that will shock us."

The Harvard team, led by Robert Wood, a microrobotics specialist, and Jennifer Lewis, an expert in soft materials 3-D printing, created a soft actuation unit, control system, and power source, all integrated into the octobot's 6-gram silicone body.

The robot is powered by liquid fuel. The fuel is made when aqueous hydrogen peroxide solution passes over a platinum catalyst in a reaction chamber that's part of the bot's integrated fluidic-pneumatic network. This decomposes the hydrogen peroxide, producing pressurized oxygen. The oxygen inflates compartments that resemble small balloons, moving the octobot's arms. In the current proof-of-concept build, the bot has to be refueled after six to eight minutes, Wehner said.

To control the octobot's arm movements, the team designed a fluidic circuit based on a system of valves. The circuit, which is mechanically programed to trigger up-and-down arm movements, oscillates to force the fuel into the reaction chambers. The material for the octobot, which is entirely 3-D printed, costs $2.25, with $1.50 of that going toward the platinum.

The team hopes to create a more sophisticated circuit system to move the arms in a variety of directions and sequences, Wehner said. It also plans to print different body shapes and add sensors to help the body move more intelligently. ME

CHINESE GOVERNMENT WANTS MORE STEEL CUTS

China is the world's largest producer of steel, but the industry was massively overbuilt in the past 20 years. The government has ordered the industry to reduce capacity, and in August a top Chinese official called for accelerating capacity reduction work in the steel and coal industries.

Lian Weiliang, deputy head of the National Development and Reform Commission, described 2016 as the key period for advancing the country's capacity-reduction target, which is to cut steel and coal capacity by about 10 percent in the next few years.

Lian said that in a demonstration of government resolve on the issue, the State Council would carry out a nationwide inspection of local efforts. According to the Xinhua News Agency, the regions of Inner Mongolia, Fujian, Guangxi, Ningxia, and Xinjiang have been slow to close redundant steel mills.

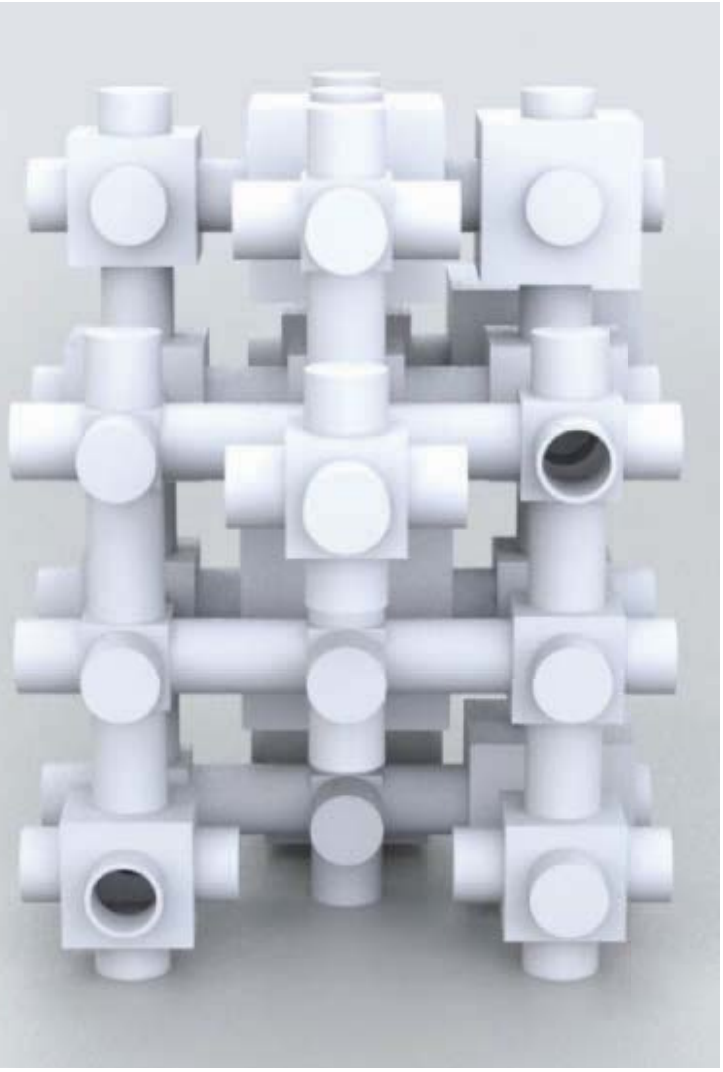
By the end of July, Xinhua reported, China had achieved only 38 percent of its goal for coal-production cuts and 47 percent of its steel-reduction target for the year. ME

BIG NUMBER

366,000

NUMBER OF PREMATURE DEATHS IN CHINA IN 2013 LINKED TO AIR POLLUTION FROM COAL COMBUSTION.

THE AIR QUALITY IN CHINESE CITIES is notoriously poor—and increasingly seen as unhealthy. According to an analysis published in the British medical journal *The Lancet* last year, "Outdoor air pollution was the 5th leading cause of premature death in China in 2013." A recent report by the non-profit Health Effects Institute looked more closely at the components of Chinese air pollution using enhanced satellite data and a network of air-pollution monitors. That data showed that coal combustion—from industrial, electricity, and domestic sources—was the largest contributor to fine particulate matter exposure. Of the roughly 916,000 premature deaths attributable to so-called PM2.5, 40 percent were due to coal burning.



The lab combines acoustic voxels into a variety of complex structures that shapes sound to fit particular applications.
Photo: Dingzeyu Li and Changxi Zheng

SHAPING SOUND

ACOUSTIC ENGINEERING IS ALL ABOUT controlling, using, and enhancing sound. This month we feature two labs that take different approaches in manipulating sound for new types of products and tools. One lab has created almost unlimited design possibilities for filtering sound and developing acoustic signatures. The other modified a common product to create uncommonly high resolution for acoustic imaging tools and other uses.

It usually takes dozens of iterations to create sound filters that achieve a good balance between reducing harmful sound frequencies and preserving desired ones. But a team of researchers has developed a computational model that removes much of the guesswork and expense from the process and allows them to build the resulting filters using 3-D printing.

Changxi Zheng, a computer science professor at Columbia Engineering, and researchers from MIT and Disney Research, call the system "acoustic voxels."

A voxel represents a location in three-dimensional space, and is often used to describe 3-D models. Zheng's voxels are a series of hollow cubes that come in different sizes and are connected by cylinders of equal length. Sound moves through the cylinders, reverberates in the cubes, then exits through one or more tubes to the next cube. Zheng says he can incorporate them in almost any 3-D printed or manufactured object.

The design is based on an algorithm that starts with a goal, such as the characteristics of the exiting sound, then randomly combines voxels to find an optimal match. The process takes only a few seconds, and is cheaper, more accurate, and up to 1000 times faster than previous methods, Zheng said. "We rely on the computer to quickly do different types of simulations and experiments until the best design is found," he added.

No matter how they're designed, acoustic filters work pretty

SOUND DATA

THE LAB Computer Graphics Group, Columbia University, New York City; Changxi Zheng, co-director.

OBJECTIVES Use a computational approach to design acoustic filters for creating new types of wind instruments, automotive mufflers, protective earphones, and acoustic signatures.

DEVELOPMENT A new algorithm that enables designers to create and 3-D print acoustic voxels to modify the sound of objects of almost any shape and size.

much the same way: as sound waves pass through a cavity, some waves bounce back and forth, either increasing or decreasing certain frequencies, depending on cavity shape.

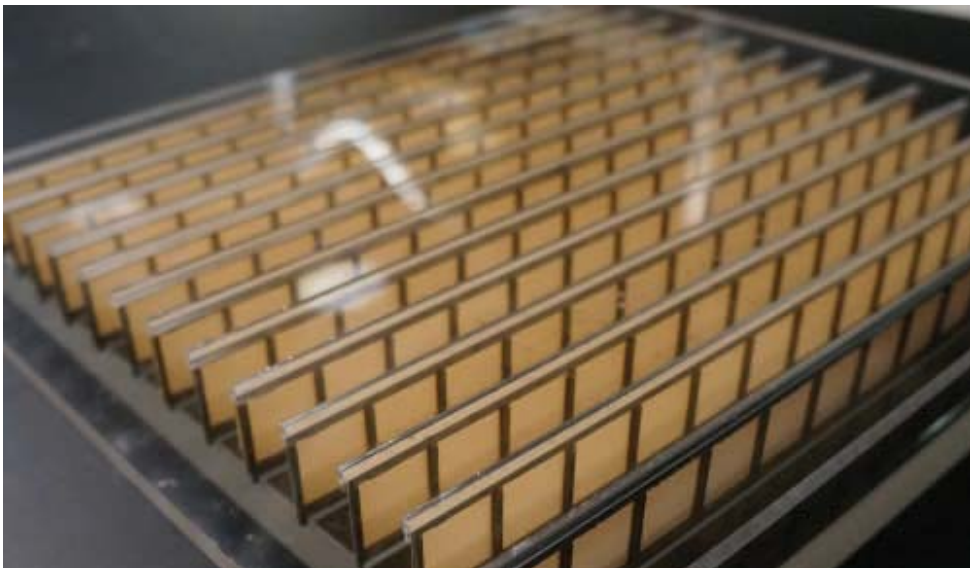
The researchers have used the voxel system to 3-D print customized mufflers, protective earphones, and wind instruments that produce several different notes depending on the force of the airflow.

Zheng believes his team is the first to create "sound tags," a unique set of frequencies generated when air passes through the voxels.

Users can read these frequencies as a string of binary numbers and transcribe them into text with a smartphone app. They could use the text to create serial numbers to prevent counterfeiting.

The team is now experimenting with very small voxels that can be embedded in a wider variety of products. ME

Through his past research in acoustics engineering and ultrasound technology, Yun Jing realized that a new metamaterial—a material with an engineered microstructure that has properties not found in nature—could greatly improve the resolution of ultrasound images. But nobody had developed anything that achieved the sought-after results. So the assistant professor of mechanical and aerospace engineering at North Carolina State University decided to take a stab at it.



This metamaterial manipulates acoustic waves that can double the resolution of traditional ultrasound systems. *Photo: Chen Shen*

The result is a metamaterial that manipulates sound waves and doubles the resolution of traditional ultrasound systems. It can also improve the focus and controllability of soundwaves in other medical diagnostic tools and applications.

"There was a gap between the theory and the realization of the material," Jing said, adding that he and his team, which includes researchers from Duke University (a center of metamaterials research), will expand their work in 2-D imaging to create more detailed and accurate 3-D images and measurements.

To create their metamaterial, the researchers started with cardboard cut from manila folders. They cut the cardboard into strips and sandwiched them between 13 aluminum frames, each divided into 14 cells.

The structure sits between the imaging device and object being imaged and interacts with acoustic waves in ways that manipulate the pressure of the waves. This causes soundwaves to propagate for longer periods of time. This gives ultrasound devices, such as sonograms, more time to capture information from the waves, resulting in higher resolution and greater accuracy.

The metamaterial also causes negative refraction, meaning that the soundwaves passing through the material bend in an opposite direction from which they're traveling. This gives Jing a way to direct and focus the wave. It should enable others to focus acoustic energy to produce high temperatures that can kill cancer cells or direct incoming sounds at a microphone to reproduce or amplify sound more precisely.

"The metamaterial can be used to focus sound waves in ways that make it a very flexible tool," Jing said. ME

JEFF O'HEIR

FOCUS ON ACOUSTING IMAGING

THE LAB Yun Jing Research Group, North Carolina State University in Raleigh; Yun Jing, principle investigator.

OBJECTIVE Improve acoustic imaging and create new tools and applications.

DEVELOPMENT Producing a metamaterial that doubles the resolution of acoustic images.

ADDING TEXTURES TO TOUCHSCREENS

Glass panes, the kind that form the fronts of most smart phones and tablets, are noted for being smooth. That smoothness can be a problem, though, for users trying to operate virtual buttons or knobs projected on the device's display. Now, researchers at Northwestern University believe they understand how to provide tactile feedback on a sheet of glass, so that a computer screen could not only show what something looks like, but provide a sense of how it feels.

Haptic displays are not new. About 10 years ago, researchers at Northwestern's mechanical engineering department developed a device that could display virtual shapes and textures—like buttons, bumps, depressions, or stickiness—over a touchscreen. The device, called TPaD, applied ultrasonic waves to a thin glass plate placed over the screen and decreased the friction between the fingertip and the plate, making the glass feel slippery.

But to make the device generally useful, the researchers had to understand why it worked.

There were two competing hypotheses. One stated that the vibrating plate caused the thin film of air under the fingertip to compress and create pressure that levitates the skin of the finger off of the screen. The second proposed that ultrasonic vibrations simply cause the skin to bounce off the glass surface.

Northwestern's Michael Wiertlewski created a test device to settle the matter. Wiertlewski built a fingerprint imager, similar to the kind used for security, and attached it to a TPaD. Using a special strobe light and high-speed camera, he measured the friction felt by a finger as it slid across the glass plate.

His results, which were published in the *Proceedings of the National Academy of Sciences*, supported both theories, in part. The measurements showed the reduction of friction, or the slipperiness, is caused by the skin bouncing—not on the glass plate, but on a layer of air trapped between the plate and the surface of the finger.

"This paper proves the fingertip is actually bouncing on air," Wiertlewski said.

Wiertlewski's team will use the research to develop new algorithms to create additional and more accurate textures, and to improve the energy consumption of new types of haptic devices.

The team also hopes to use the vibrations to push or guide fingertips across the screen. That could be used to align the fingers of the vision-impaired over a keyboard, said mechanical engineering professor Ed Colgate, a haptics pioneer who supervised the team.

Last year, two of Colgate's grad students created and began shipping the TPad Phone, a customized smartphone that researchers and designers can use to create their own textures and shapes. Similar applications building on Wiertlewski's work could be used by online retailers to display the texture of a new pair of leather shoes or a wool sweater, or by car manufactures to create virtual buttons and knobs on the large touchscreens that are gradually taking over car dashboards.

Those textures and shapes won't necessarily feel like an exact copy of what they're trying to replicate. But that's okay, Colgate said, because the human brain can fill in the gaps with what it's already familiar with.

"It's never going to be perfect," Colgate said. "But if we can get close, your brain will make its own conclusions." ME

JEFF O'HEIR

OLD BATTERIES FOR GRID STORAGE

One missing piece for integrating renewable energy into the power grid is a way to store electricity generated when it's not needed for later use.

A recent report from Bloomberg New Energy Finance suggests that grid-scale storage may arise from an unlikely place: old hybrid car batteries that would otherwise be discarded.

The demand for compact and powerful lithium-ion batteries for hybrid and plug-in hybrid electric vehicles has created a surge in battery production. According to the U.S. Department of Energy, in 2015 some 384,000 battery packs were sold for hybrid electric vehicles, with a total capacity of 500,000 kWh. Far fewer battery packs were sold for plug-in hybrids—only 115,000—but the total capacity was 3.8 million kWh because plug-in hybrids have much larger storage needs.

The plug-in hybrid market is relatively new—annual installed battery capacity has increased by a factor of 10 since 2011—and hybrid and plug-in hybrid sales are expected to keep growing. But as those cars age and are retired over the next decade, their batteries could have a second life ahead of them.

According to projections from Bloomberg's Claire Curry, 29 GWh of used EV batteries will be removed from cars between now and 2025.

That's the equivalent capacity of a day's output from a nuclear power plant and exceeds the present-day stationary energy storage market.

Curry projects that as much as 10 GWh of those used batteries could be repurposed for stationary use.

The reason is cost. Converting a used EV battery to stationary energy storage can be done for as little as half the price of a new stationary storage system.

Bloomberg reports that automakers BMW, Nissan, and Mercedes Benz already have second-life stationary storage projects in place. **ME**

"WHEN YOU PUT ON THE GOGGLES, you're going 80 miles per hour at 100 feet and wondering if you're going to crash. When you pull off the goggles, people are sweating and twitching because the adrenaline rush is like you're up there. That's what virtual reality is all about, and that's what drone racing is all about."

— Scot Refsland, co-founder and chairman of the Drone Sports Association, quoted by ESPN.com on August 10, 2016.

SYSTEMS ENGINEERING

LOOKING BACK

The Apollo moon landings were still almost three years away when this article was published in October 1966.

E. BONAN AND F.A. DOENNEBRINK
GRUMMAN AIRCRAFT ENGINEERING CORPORATION, BETHPAGE, N.Y.

Two engineers from the aerospace company that built the Lunar Excursion Module wrote about the importance of optimizing the way subsystems work together.

One extensive application of Systems Engineering is the Apollo program. The goals of this program were to develop the ability to operate manned vehicles in space and to achieve a manned landing on the moon in this decade. The profound complexities involved in achieving these goals required a good number of decisions to be made with no benefit of prior experience.

For example, three proposed modes considered in detail were: The direct-flight mode using a Nova launch vehicle; the earth-orbit rendezvous mode requiring separate launches of a tanker and a manned spacecraft; and the lunar-orbit rendezvous mode requiring Saturn launch of the manned spacecraft with a lunar excursion module (LEM). In arriving at a technical determination, critical evaluation was made by measuring the three modes against carefully selected performance criteria such as the following:

1. Number of men to be placed on the moon, length of stay, scope, and extent of lunar-surface operations.
2. Guidance accuracy of each mode.
3. Communication and tracking requirements.
4. Development complexity of each mode and assets necessary in terms of manpower, industrial facilities, and launch complex.
5. Probability of mission success and crew safety.
6. Overall mission schedule for system development and operation.

When these were considered in composite, the lunar-orbit rendezvous mode was selected because it afforded the greatest potential advantages.

Since ours is an integrated manned-space-flight research effort, allowance had to be made for knowledge gained from other programs—such as Mercury, Gemini, Ranger, and Surveyor. The pool of widening scientific data relating to knowledge of the space environment, lunar topography, and man's capability in actively participating in the mission could (and did) play a significant role in subsequent LEM design.

Due consideration was also given to flexibility that might be achieved by using the Apollo design for Earth orbiting laboratory missions to conduct manned and unmanned experiments leading to useful application of space technology. For example, it is now possible to define realistic experiments of scientific, biomedical, technological, and operational nature by a judicious mix of missions bringing together the Apollo/Saturn space vehicles, experiments, and crews. Such missions might include extended lunar-surface exploration, mapping of hitherto inaccessible regions of the moon from lunar orbit, and acquiring extensive data on the near-earth environment beneficial to man—such as agricultural planning, natural resource management, accurate long-range weather forecasts, and oceanographic surveys.

It is significant to point out that over a dozen functional subsystems must be integrated to produce a spacecraft for a given mission. These include guidance and navigation, attitude control, communications, propulsion, tracking telemetry, life support, environmental control, reentry protection, and recovery systems. They must all be compatibly accommodated in an overall structure. **ME**

TO BOLDLY GO

Only weeks before this article was published, the space program—and the engineering profession—received a boost from a fictional source. NBC aired the first episode of *Star Trek* on September 8, 1966, to mixed reviews and often low ratings. Even so, the 79 episodes aired over three seasons (and recycled in countless reruns since) captured the minds of young people—the character "Scotty" is perhaps the world's most famous engineer. The series was named a major influence by many engineers in a February 2015 article in *Mechanical Engineering* magazine.

Chief Engineer "Scotty" from NBC's *Star Trek*, played by James Doohan.

Image: NBC

BY THE NUMBERS: JOBS AND MANUFACTURING

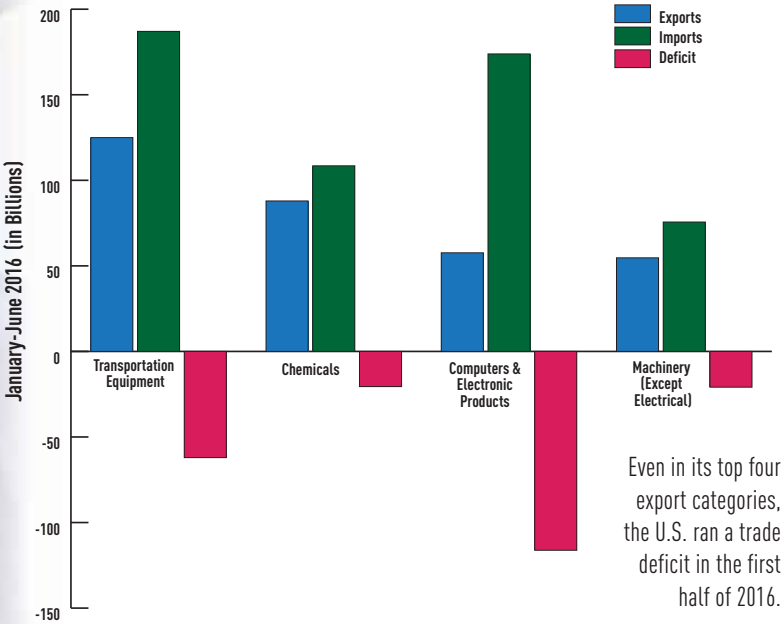
Imports have become an easy target for Americans in both major political parties. But the country's high-productivity factories simply don't need as many workers as they used to.

Trade has become a hot political issue in the United States, with many people on both ends of the political spectrum wanting to slow or restrict imports to bring back manufacturing jobs. Scenes of abandoned factories and interviews with unemployed industrial workers underscore the point.

But how much do imports actually matter?

It's true that the United States imports many more goods than it exports to the rest of the world. According to the U.S. Census Bureau, $931.2 billion in manufactured goods were imported in the first six months of 2016, compared to $522.6 billion in exports. Even in the industries where the U.S. manufacturers export the most—transportation, chemicals, computers and electronics, and non-electrical machinery—there was a net trade deficit.

U.S. TRADE IN MANUFACTURED GOODS



Even in its top four export categories, the U.S. ran a trade deficit in the first half of 2016.

But the annual trade deficit in manufactured goods (roughly $800 billion) is a small fraction of the $5.9 trillion worth of goods produced by the U.S. manufacturing sector. In terms of "bringing back" manufacturing jobs to the levels of 40 and 50 years ago, eliminating trade isn't going to do the trick.

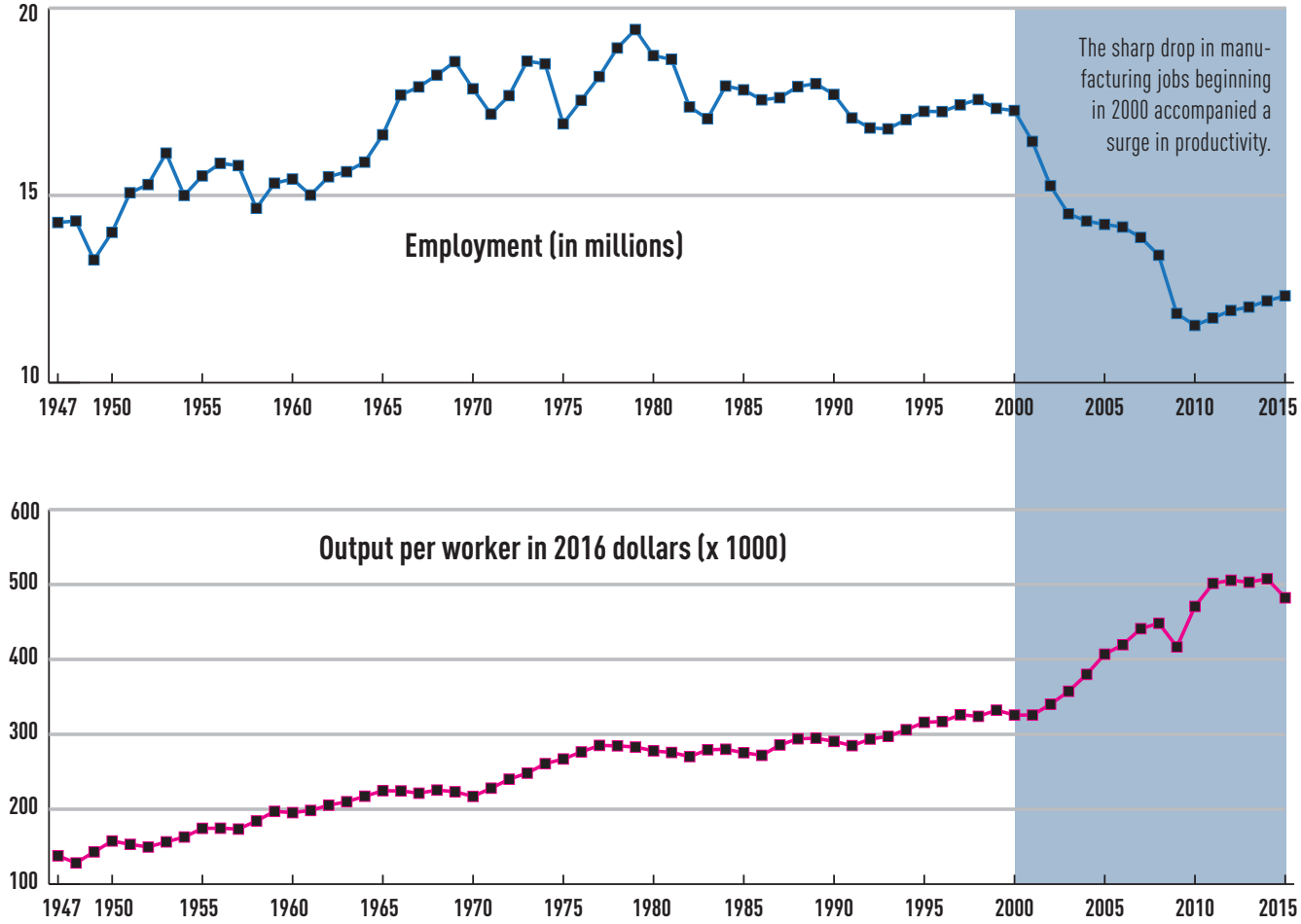
Comparing the number of manufacturing jobs, as measured by the U.S. Bureau of Labor Statistics, to manufacturing output from 1947 to the present reveals that American factories make much more stuff per worker than ever before. Most of that increase in productivity has occurred since 2000, as factory automation has reduced the demand for workers at the same time that low-value manufacturing began to leave the United States. While the workforce has been reduced by nearly 5 million since 2000—a 29 percent cut—manufacturing output has grown steadily, if slowly.

That means the factory workers who remain are adding more value than ever before. In 2015, manufacturing output per manufacturing worker was $482,242, just a bit off of the peak; by contrast, each manufacturing worker in 2000 produced $336,847 in 2015 dollars. In 1976, the inflation-adjusted production was just $276,525.

Indeed, using a simple calculation based on the present rate of productivity, the manufacturing jobs that would be added by eliminating the entire $800 billion annual trade deficit in goods would number around 1.6 million—not enough to restore the manufacturing jobs lost since 2000, let alone return manufacturing to the central place it once had in the American economy. ME

JEFFREY WINTERS

U.S. MANUFACTURING SECTOR: JOBS VS. PRODUCTIVITY



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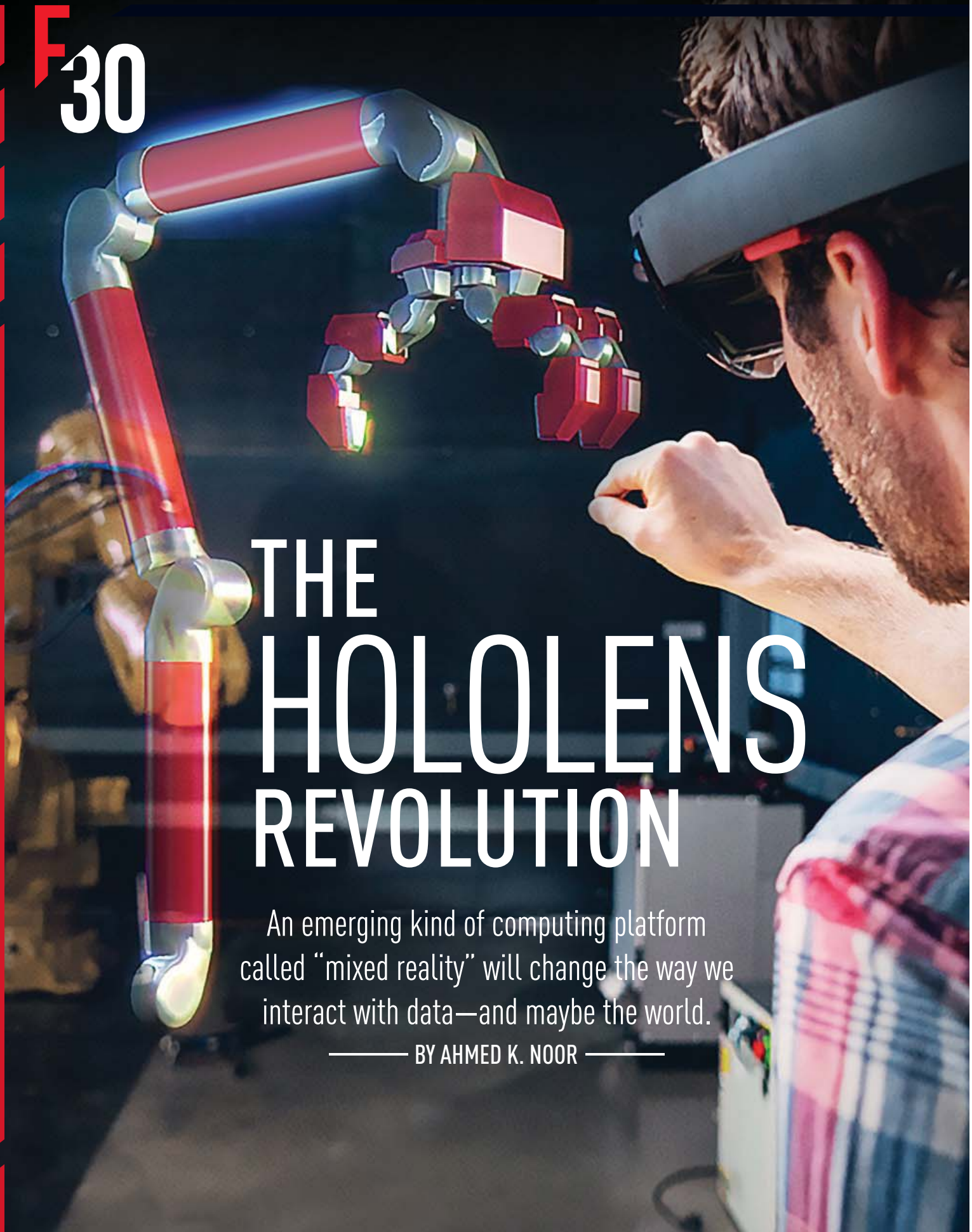


THE HOLOLENS REVOLUTION

An emerging kind of computing platform called "mixed reality" will change the way we interact with data—and maybe the world.

BY AHMED K. NOOR

The HoloLens headset enables users to see and manipulate holograms embedded in their environment.

As recently as 2014, when scientists at NASA Jet Propulsion Laboratory in Pasadena plotted the course of one of their Mars rovers, they consulted maps and satellite images, as well as images uploaded from the rover itself. There was an element of guesswork in integrating all those overlapping data sources, but guessing wrong could send the rover along an impassable path or get it intractably stuck.

Now, JPL scientists have a new tool for studying possible routes. That tool, called OnSight, enables users to explore 3-D stereo views of the Martian environment and to get a natural sense of depth and understanding of spatial relationships. They are able to examine the rover's worksite from a first-person perspective, plan new activities, and preview the results of their work firsthand.

A pilot group of mission scientists has been testing the application, using it for such tasks as identifying rock formations that merit further study by the *Curiosity* rover.

That NASA tool is just one of the applications of a new type of computer hardware and software combination called "mixed reality" or MR. It's a variant of virtual reality systems, which have been around for decades and have edged toward the mainstream through new headsets, smart mobile devices with 3-D capabilities, and improvement in display resolution. Mixed reality uses some of the same technology, but instead of an immersive experience cut off from the outside world, it blends or merges holograms into the physical environment.

Mixed reality in combination with technologies that enable interaction with holograms, called holographic computing, is poised to be the next big disruptive technology. Major technology companies such as Microsoft, Google, Samsung, Apple, Sony, and Facebook are investing significant funding in the development of low-cost virtual and mixed reality systems, and Microsoft's HoloLens is already being used in some applications, such as NASA's OnSight system mentioned above.

These devices promise to break down the barriers between virtual and physical reality, and enable the physical and virtual worlds to intersect in new ways. And they have some very real engineering applications that could well transform the profession as profoundly as the personal computer did a generation ago.

THE HOLOGRAPHIC COMPUTER

Holograms may seem futuristic, but most of us carry around objects—such as credit cards or driver's licenses—embedded with them. The recording of the light field necessary to make a hologram requires a laser, a beam splitter, and a photographic medium that enables the light scattered from an object to be recorded and later reconstructed. The

The HoloLens allows users to see the same holograms and collaborate on projects from distant locations.

resulting image changes as the position and orientation of the viewing system changes in the same way as if the object were still present, thus making the image appear three-dimensional.

Up to now, the most common photographic recording medium has been film. Holograms, by comparison, have been 3-D snapshots rather than moving, interactive images. Technologists have been working for decades to find a way to project dynamic, holographic images into the spaces where we live and work. The goal has been to create something that works similar to the depictions of holography in science fiction, from the recorded plea of Princess Leia in *Star Wars* to the immersive holodeck of *Star Trek*.

The Microsoft HoloLens doesn't do that. Instead, it is a self-contained system running a special version of Windows 10 that generates and projects stereographic images onto the lenses of a headset. In addition to the central processing unit and graphics processing unit of a conventional computer, the HoloLens possesses a separate holographic processing unit. That HPU calculates where 3-D graphics exist in the physical space of the user and keeps track of such input as voice commands and gestures.

All that computing power—along with built-in speakers, advanced sensors, buttons, a camera, and vent—have been miniaturized to fit in an untethered visor. Compared to virtual reality headsets such as the Oculus Rift, the HoloLens projects its images onto a fairly narrow field—about the area of a sheet of copy paper held 18 inches in front of your face. That limited field of view is acceptable because unlike virtual reality, mixed reality does not try to be fully immersive. Instead, the HoloLens projects its images onto the lenses in a way so that the holograms are perceived to exist together with physical real-world elements in a shared environment.

That's immensely difficult. If a hologram is supposed to sit on a table, the holographic computing system must calculate how that virtual object should appear to the HoloLens user as he turns his head, stands up or sits down, or if he leaves and then reenters the room. Indeed, if a real-world object passes through the space between the user and the hologram, the holographic computing system can in real time calculate which parts of the hologram would be eclipsed by that object and make those portions disappear.

What's more, these holographic objects are interactive. Virtual buttons can be "clicked" and holographic objects can be transformed with tools or by touch, much the way that objects on a conventional computer screen can be altered. By virtually transforming the physical world into a tangible representation of programs and controls, HoloLens represents a dramatic reduction in the distance between the user and the interface.

ENGINEERING APPLICATIONS

Microsoft introduced the system in January 2015 and since March 2016 has been shipping the system to developers and academic groups. Engineers, designers, architects, and animation teams at these organizations are using the HoloLens technology to discover the best practices and most powerful application for this new computing platform.

NASA, for instance, has been working with Microsoft on developing software tools to exploit the HoloLens. Another NASA application called ProtoSpace uses holograms for spacecraft design. The system superimposes a computer-generated version of space hardware over the field of view of the user's headset. That enables NASA scientists to naturally walk around a full-scale version of a spacecraft (such as the *Mars 2020* rover currently under development at the NASA's Jet Propulsion Laboratory), and examine different components. That capability provides a feeling of how large each component is or how tight the tolerance might be—two measures that might be difficult to assess from looking at a model on a computer screen. The goal is to avoid design conflicts as the new six-wheeled robot is assembled.

This isn't theoretical: NASA engineers are using ProtoSpace today. Engineers recenlty used ProtoSpace to check the size of the rover's nuclear batteries, which is one of the last tasks done before launch, and to make sure they would fit inside the rocket that would launch the spacecraft to Mars. ProtoSpace allows engineers to test fit all the components and practice the installation procedure at full scale with the actual tools they will need to ensure there is enough clearance. And they can do all this early in the design phase before a single part has been manufactured.

Another application being developed is called Sidekick. That tool is intended to provide crews aboard the International Space Station with assistance for complicated tasks. In one mode, Sidekick uses Skype voice and video chat to enable ground operators to see what crew members see, provide real-time guidance, and draw real-time annotations into the crew members' environment to coach them through the task. Sidekick can also augment standalone procedures with animated holographic illustrations displayed on top of the objects the crewmember is working with. This capability could provide refresher training and guidance for station crews while they are in space, much closer to the time they will be performing a task. In addition, Sidekick's standalone mode could be a resource during future deep space missions, where communication delays complicate difficult operations.

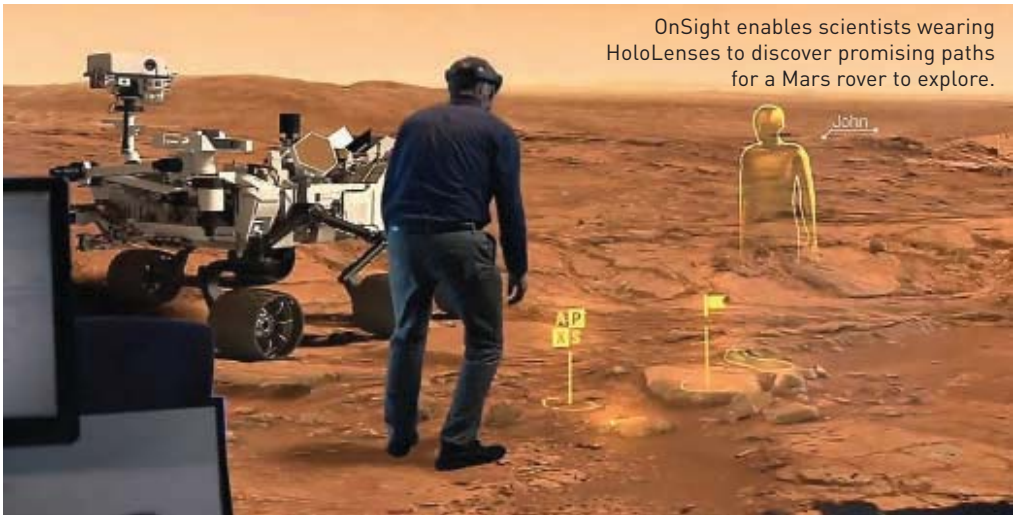
Private companies are developing applications for the HoloLens as well. The Swedish defense and security company Saab has created a holographic training system for the HoloLens, and automakers Volvo and Volkswagen are working with Microsoft to demonstrate the use of Holo-

VIRTUAL, AUGMENTED, AND MIXED REALITY

Virtual Reality (VR) is a computer generated environment that can simulate physical presence in places in the real world or imagined worlds. The user wears a headset and through specialized software and sensors is immersed in 360-degree views of simulated worlds.

Augmented Reality (AR) supplements the physical environment with computer-generated sensory input such as sound, video, graphics, or other useful information—essentially overlaying digital information on top of the physical world. Some consider the smartphone popular game "Pokémon Go" a form of consumer AR: It enables gamers to find digital characters in the real world.

Mixed Reality (MR) attempts to combine aspects of both VR and AR. Through merging the real and virtual worlds, new environments and visualizations are generated wherein physical and digital objects co-exist and interact in real time. The virtual objects (holograms) are anchored to points in real space, making it possible for the user to treat them as real.



OnSight enables scientists wearing HoloLenses to discover promising paths for a Mars rover to explore.

Lens in lieu of CAD software for seeing life-size 3-D design schematics.

The engineering and construction firm CDM Smith, Boston, Mass., is discovering how to apply the HoloLens technology through the entire product life cycle. During the planning phase of building plant upgrades or extensions, for instance, engineers are uploading CAD files into the HoloLens to visualize how additional pumps or pipes will fit into the existing space. During the design phase, the entire project team dons HoloLenses to "walk through" the final project and experience the project via holograms within the physical environment of the existing site. A safety issue in the layout that would not be obvious in the blueprints can be seen in the holographic representation and team members can suggest changes to the design before construction begins.

During construction, CDM Smith engineers walk through the project wearing HoloLenses to compare the holographic models to the actual work, to make sure the job is being done as designed. After the project is complete, facility managers can continue to use holographic models to collect and manage operations data, as well as manage the site remotely.

Education may also see some important applications for the HoloLens. My lab at Old Dominion is studying how to use the power of holographic computing to provide learners with a multisensory interactive immersive learning environment. One possibility involves providing remote access—linking several remote classrooms to the same lecture hall, or sending students on a virtual tour of places like the International Space Station, or connecting them to experts who can illustrate processes live, in person, and in 3-D.

Clackamas Community College in Oregon also is using HoloLens to develop a hands-on trade-based curriculum for automotive students. For example, students use the mixed reality application to disassemble engines, or to identify, using the headset, all the parts of an engine they are working on.

BEYOND THE TECHNOLOGY

It was less than 10 years ago that society was introduced to a new computing paradigm: handheld devices that sensed and responded to touch and motion. What was a novel and, to some, baffling interface in 2007 has become so second nature that today small children are given their parents' iPhones to play with—and those children have no problem operating them.

After seeing the HoloLens in action and talking to professionals who are excited about its possibilities, I believe holographic computing will follow a similar path. As the technology improves, holographic computers will be capable of rendering high-resolution 3-D digital content that blends seamlessly with our environment. Manipulating that content will become as easy and natural as picking up a box or sitting at a table. High-definition holograms will look as real as physical objects and will become practical tools of daily life.


New engineering software enables CAD files to be projected as holograms viewable on the HoloLens.

What's more, holographic computing platforms and headsets will be light and small enough to wear all the time, and will be able to spatially map the user's environment wherever he is. An engineer wearing a holographic computer will be able to use his actual hands to manipulate holograms representing parts of a new engineering system and virtually teleport (or "holoport," perhaps) himself and his team members into meetings.

The now-ubiquitous handheld screens will be replaced by headsets and wearable devices that provide digital and projected interfaces everywhere.

Some technological breakthroughs still need to occur before we get to that point. For one, more natural ways of interacting with holograms and the holographic computing platform need to be developed. Private companies are working to crack that problem. For instance, Milpitas, Calif.-based Eyefluence is working on eye tracking technology intended to enable one's gaze to navigate and explore holographic displays. Another company, Gest, Austin, Texas, is building a device that wraps around the palm and fingers to better capture gestures that a person could use to intuitively create, shape, and size holograms. And advanced voice

recognition is being developed by Amazon, Google, Apple, Microsoft, and other tech giants.

Advances in scanning technology may enable engineers to scan, capture, create, and render 3-D models based on the user's first-person visual perspective, eliminating the need for common scanning tools such as spinning tables for depth sensing devices or large scanning booths that require a hundred cameras. Magic Leap, a Dania Beach, Fla., company that is developing its own holographic computing system and headset, is just one of the groups working on that first-person scanning technology.

The biggest breakthroughs, I believe, will come with the coupling of holographic computing and two other emerging AI and information technologies: next-generation cognitive cybernetics capable of deep learning and even anticipatory capabilities, and the Internet of Things comprised of widespread connected embedded sensors.

Combined, those three technologies could create something like an Internet of Presence and Experiences, where smart wearable devices and appliances tap into advanced cognition systems to deliver information and services to you via holograms—often before you even know you want it. Those advanced technologies could transform mixed reality into an all-pervasive digital reality that is based on extraordinary levels of data, context, and insight.

Beyond the technology, however, there are likely some social aspects to the use of mixed reality headsets that need to be worked out. The headsets are more imposing than the Google Glass, and it may turn out that they are going to be tools best suited for use in designated workspaces and classrooms rather than in coffee shops or stores. On the other hand, society has adapted to mobile computing much more quickly than might have been expected.

The possibilities for holographic computing are truly exciting, and the endless applications go as far as the human mind can imagine. Holographic computing is one of the major engineering tools for the 21st century, and we are only beginning to understand how it will change the profession. **ME**

BEYOND HOLOLENS

In addition to Microsoft, several other companies are developing mixed-reality devices.

Magic Leap
The company is currently developing mixed-reality technology with a smaller headset than the HoloLens using a proprietary technology to make the blend between real and virtual almost undetectable. Lucasfilm's ILMxLabs and Magic Leap are working to reinvent how stories are told using mixed reality.

Sulon Q
This developer platform offers console-quality graphics and powerful processing (using AMD FX-8800P processor). Like the HoloLens, the untethered headset is powered by Windows 10.

Meta 2
This headset is tethered, but it compensates by accessing greater computing power to provide higher resolution images over a broader field of view than HoloLens. It is also 28 percent lighter than the HoloLens.

Daqri
The company's Smart Helmet is an industrial-grade human machine interface powered by an Intel Core m7 processor, and includes depth sensors and a thermal camera. It is intended for use in industrial settings such as energy worksites and factories.

ODG (Osterhout Design Group)
ODG is teaming with a company producing photorealistic graphics to develop a 170 g MR headset that projects high-resolution images at 120 frames a second.

AHMED K. NOOR is eminent scholar emeritus and professor emeritus of modeling, simulation and visualization engineering at Old Dominion University in Virginia.

TO LEARN MORE

For more information on holographic computing and mixed reality, go to a website created as a companion to this *Mechanical Engineering* magazine feature: **http://www.aee.odu.edu/holocomputing/**. The site contains links to online material related to variety of aspects of both holographic computing and mixed reality. The site includes a daily news feed for up to date information on related subjects.

Augmented reality lets designers visualize parts like the motorcycle cladding, fuel-tank cover, and seat shown in green here.

THE MORE

From virtual service manuals to holograms you can touch, augmented reality could transform engineering design.

BY JEAN THILMANY

The industrial designer and the engineer stand before their individual workstations, both wearing wraparound headsets that shade their eyes. They're collaborating on a project and standing side by side, yet they don't speak and don't interact. They're immersed in their work. And no wonder.

The designer presses his mouse. An image of the handheld video game controller he's been creating lifts off the screen and appears to hover between the two.

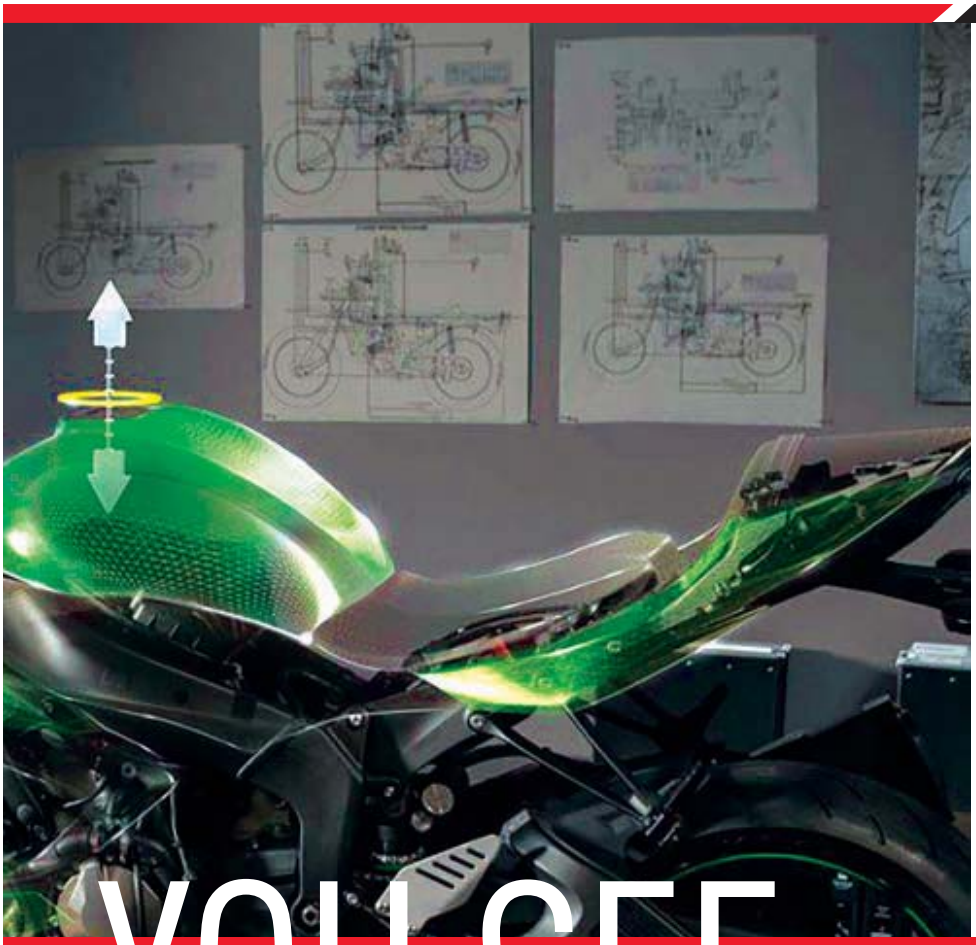
Then the engineer clicks. The assembly of internal parts he's designed lifts off his computer screen, hovers in mid-air for a second, then glides inside the image of the controller. At first the controller's internal assembly and the designers shell don't quite fit together, but after a small tweak, they do.

The two, depicted in a promotional video from Autodesk, have paired Microsoft's HoloLens headset with Autodesk's Fusion 360 engineering design software. And although the two are actors playing out a yet-unrealized scenario, the video may offer a glimpse into the future of engineering design.

That future? Just two words: augmented reality.

AUGMENTED OPPORTUNITIES

After years of anticipation by gamers and technology aficionados, in 2016 virtual reality



YOU SEE

took center stage as companies rolled out several high-profile VR devices, including the Oculus Rift, PlayStation VR, and HTC Vive.

The new headsets offer a wide field of view and high resolution, as well as positional tracking that closely follows a user's eye movement to prevent motion sickness. They advance VR beyond large displays and CAVES, the high-end, specially equipped rooms that scientists have used since the 1990s to immerse themselves in 3-D environments.

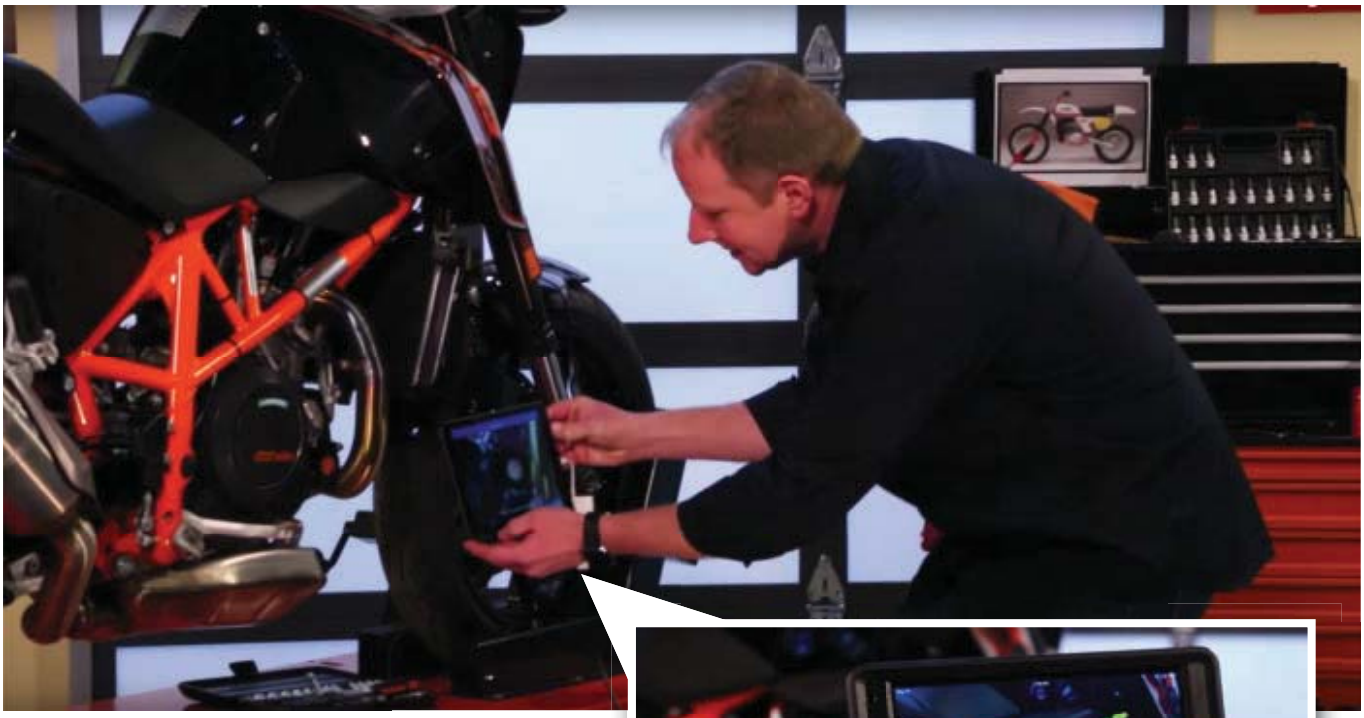
This year also saw the beta release or full release for several pivotal augmented-reality (AR) technologies, including Microsoft's HoloLens and the Meta 2 headset from the Meta Company.

Unlike VR, AR dangles text, graphics, or video into a person's visual field that describes, or augments, what they're looking at. (See sidebar, p. 33.) Think Google Glass, now taking a break as it retools, which displayed information or images just above the user's line of sight. Or think the AR game Pokémon Go, which created a sensation after its July 2016 release, persuading players by the millions to capture, train, and battle virtual cartoon creatures called Pokémons in the real world.

AR's possibilities have spurred major engineering software companies such as Bentley Systems, Siemens PLM, and Autodesk, and even the software behemoth Microsoft to invest in AR for engineering, manufacturing, and plant design.

Siemens PLM, for example, has created AR brochures with images that spring into view. Bentley has created a homegrown AR system that helps architects and construction engineers convert 2-D blueprints into 3-D representations of buildings.

Merging engineering software and AR could let engineers suspend 3-D models in mid-air and tweak them in real time, said Garin Gardiner, business development manager for Autodesk's Fusion 360 design software. This would make for fewer physical prototypes. Engineers who aren't in the same room—or even the same country—could talk through changes to the model, and watch each



A KTM technician demonstrates how to visualize a malfunctioning motorcycle part on a tablet—and view AR instructions (green, in inset) on how to fix it.

other's hands as they make them, Gardiner added.

AR's is just getting started in engineering, but the potential is such that the AR app market for the field will grow 10-fold between 2014 and 2019, from $247 million to $2.4 billion, according to market-research report from Juniper Research.

"AR is unavoidable for engineers," Jon Peddie, a graphics industry veteran and market analyst who specializes in digital, online, and mobile apps. "The opportunities it presents are just astounding."

REALITY PLUS

Augmented reality got its start in 1990, when Boeing researchers Thomas Caudell and David Mizell proposed a new and simpler way to convey aircraft wiring instructions to workers assembling the aircraft. By overlaying computer-represented text and graphics on real-world images, they'd create a virtual service manual of sorts that could be updated easily, eliminating the need to lug around voluminous paper manuals.

In the years that followed, Caudell and Mizell developed such virtual service manuals, and in 2008 a Boeing engineer and a technician developed a method to help technicians perform building tasks in AR before carrying them out while building satellites, said Peddie, whose book, tentatively titled *Augmented Reality: Where We Will All Live*, is due out next spring.

Meanwhile, others new AR applications let auto mechanics gaze through headsets for visual guidance as they repaired car engines.

"The problem is the people using it were al-

ready experts," Peddie said. "They didn't need to know the nuts and bolts or the torques, so it didn't serve as a training device for them." As a result, people stopped using the virtual service manuals, and they languished.

But in AR's new era, wearable headsets are smaller, less bulky, and far more user-friendly than older AR devices. They're also reliable, affordable, and don't tie their wearers by cord to a computer system.

In 2014 Autodesk, the engineering software giant, and Microsoft decided to team up and give AR for engineers, designers and technicians another go.

Autodesk's Gardiner, who spearheaded the collaboration, and his colleagues first surveyed engineers who used Autodesk software on how they worked best. How did they collaborate on projects? How did they work with teammates in far-off offices?

It turned out that engineers struggle to visualize how on-screen images translate into 3-D products. To understand how to design parts and keep them from interfering with one another, "they'll walk to someone's desk and ask questions or they'll send an email," Gardiner said. This often leads to long conversations that can take days or weeks to work through.

To speed the design process, Autodesk and Microsoft launched a project called "Freeform." They built prototypes and tested scenarios of how engineers and designers could work with holographic objects, alone and in collaboration.

"We've found you can make quicker and better decisions by having the AR model right in front of you," Gardiner said.

TECHNICIAN'S GUIDE

Jens Tuma held an iPad up to the kickstand of one of his company's motorcycles, and an image of the kickstand appeared on the tablet, neatly framed and ready for a picture. Then he moved his fingertips on the tablet to zoom in, and a green animation appeared on the screen atop the image of the actual kickstand.

As head of customer service for the KTM Group, which makes off-road and street motorcycles, Tuma must ensure that customers whose KTM bikes need repair can find a technician who can fix them. But many motorcycle repair technicians within the group's growth markets lack experience fixing KTM bikes. Tuma figured an AR-based service manual would give these technicians some much-needed visual guidance.

Years after the first virtual service manuals fizzled out, companies have begun reviving them. And now Tuma, whose team used PTC software to build a virtual service manual, was demonstrating to a gathering of analysts, investors, and PTC software users how a motorcycle technician would use it.

> "We've found you can make quicker and better decisions by having the AR model right in front of you."
>
> — GARIN GARDINER, AUTODESK

After running a diagnostics test that determined issues with the bike, Tuma held his iPad with the AR application running over a broken kickstand. An AR image appeared overlaying the real-life ones—along with drop-down instructions to walk technicians step by step through a repair.

To create a virtual service manual like KTM's, you first need to capture real-world measurements using a sophisticated imaging system that employs cameras and sensors.

For a motorcycle, sensors would gather data such as engine temperature, suspension velocity, and spring rate (the amount of weight needed to compress a spring one inch). Those numbers plug into a referential database—a database that can be referred to by the AR software, Peddie said.

Then, in real time, the system must cross-reference information from this database with real-world information from cameras and inertial measurement units on the AR goggles that track the wearer's movements and orientation in space. Then the system uses creates a 3-D model that appears to float in space, overlaid with text or graphics that guide the technician through a repair.

Tuma believes that with AR manuals like these,

The real-time benefits of AR

In this scenario, an engineer (left) and an industrial designer (right) use AR to design a video game controller.

With a click of a mouse, a hologram of the controller lifts off the screen and hovers.

technicians can make repairs faster than ever before. "We want to get rid of a room full of technician's books," he said.

TWENTY-THOUSAND APPS

To create its AR service manual, KTM used the Vuforia Studio platform, which engineering-software maker PTC purchased in November 2015 from Qualcomm Connected Experiences. Vuforia includes the VuMark, an open-source AR ap development platform. App creators have responded by building more than 20,000 AR apps for phones, tablets, and digital eyewear such as Sony SmartEyeglass and Vuzix M-100 from Vuzix.

Many new AR apps being created with the VuMark platform and by private companies are meant for gaming, including apps for Pokémon Go, a Mattel ViewMaster, and a Skylanders card game. Others are meant for marketing, including Siemens PLM's AR brochure.

> With this ability to control your PC using everyday gestures, "we're all going to be throwing away our external monitors."
>
> — MERON GRIBETZ, CHIEF EXECUTIVE OFFICER, META

Yet until Pokemon Go, few AR apps caught on with the public, and even fewer were targeted to the engineers and manufacturers who stand to benefit most. What's more, no standards exist yet for AR, which forces users to continue with the same headset vendor or risk losing their applications and information.

"Customers are trapped," said Mike Campbell, PTC's executive vice president for Vuforia Studio. "When you neutralize that with standards, many AR companies will go away or get acquired."

For these reasons, executives in many industries have hesitated to adopt AR technologies. It's also unclear how doing so can help boost their bottom line. But as AR capabilities advance, the technology may be hard to resist.

New capabilities have begun creating innovative ways for engineers and designers to interact with AR images. In the future, they might collaborate as the designer and engineer do in the Autodesk promotional video do, by clicking on images on their computer screen to make them hover above them, then testing whether those images merge smoothly.

It's not clear yet how they'll manipulate AR images, but it could be by using gestures, fingertips, a mouse click or a joystick jog. But developers are also creating new methods that allow users to interact with AR objects, Peddie said.

The Meta 2 AR headset, developed by a New York-based startup called Meta, lets a user fix an image on a computer monitor in mid-air, then browse the web by moving his or her hands around the virtual screen. He could also grab and drag a window around the suspended virtual desktop simply by making a fist and moving it through the air.

Meron Gribetz, Meta's chief executive officer,

The engineer's internal parts assembly slides inside the controller hologram.

It doesn't quite fit. An AR caution sign and other indicators shows where.

After a few tweaks to the parts assembly, the holograms fit. Voila!

demonstrated these capabilities at TED2016. He wore the company's signature headset and cradled a larger-than-life 3-D image of a brain, as an image on a large screen showed the audience what Gribetz was seeing. Then he grabbed the virtual brain with his hands and rotated it.

With this ability to control your PC using everyday gestures, called a gesture-led interaction, "we're all going to be throwing away our external monitors," Gribetz told the audience.

It may be a while, though. The Meta 2 sells for $949, and it's currently aimed at software developers. A consumer version of the Meta2 headset is under development but is not yet ready.

TOUCH AND RELEASE

Collaborators may also be able to treat a hovering image more like the actual physical object, Peddie said. "For instance, say I want a flange to be a little larger, so I made it bigger on the design. And you move it a little to the left. You could always have rotated the image [on a monitor], but now you can walk around it, to see from all angles how the changes would affect the design," he explained.

If a part couldn't be manufactured as designed, a manufacturing and a mechanical engineer with a tablet and headsets could redesign it right on the manufacturing floor—in seconds. This would eliminate the need for companies to send a part back to be redesigned, which would save them a lot of money, Peddie added.

Engineers may also be able to reach out and touch AR designs to get a feel for how they fit together. Autodesk and Microsoft have begun work toward a joint haptic system that would allow engineers to do this, though no release date has been set.

AR will also be useful for the Internet of Things and the Industrial Internet of Things, Jay Wright, PTC general manager for the Vuforia brand, has said. By visualizing data streaming back from sensors and controllers in real time, a farmer could get an instant look at crop moisture levels, or a shipping company could monitor and control a fleet of delivery drones and get instant feedback on delivery problems, maintenance issues and parts that need replacing.

At this point PTC and other companies are mostly brainstorming how to put AR to use in the Internet of Things, and they're hoping app developers will pick up the baton. In June the company released Vuforia Studio Enterprise (previously announced as Project ThingX), to help app developers integrate AR with the company's Creo 3-D CAD visualization and illustration software and its ThingWorx Internet of Things application.

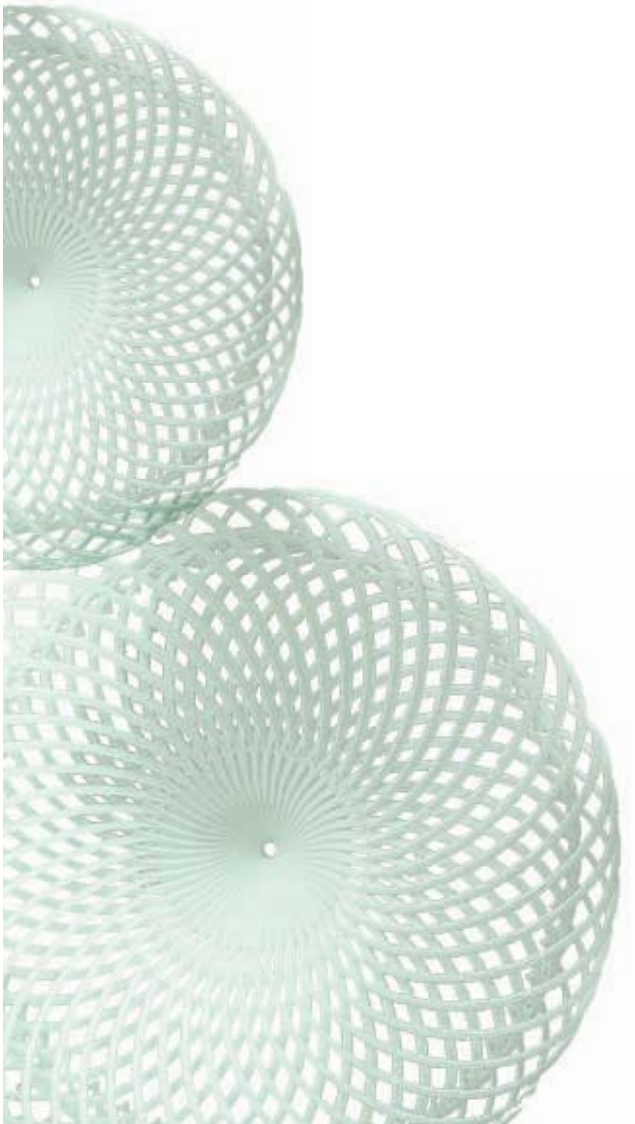
AR today is like the Internet in its early days, when companies puzzled over how to leverage it to grow, Peddie said. But as engineers and manufacturers imagine new ways to use AR in their work, it could become almost old hat, just as television or CAD have today, Peddie said. "I predict that by 2020, we'll just stop talking about it." ME

JEAN THILMANY is a technology writer based in St. Paul, Minn.

Can 3-D Printing Go Green?

By R. P. Siegel

3-D printing's downsides include hazardous chemicals, plastic waste and prodigious energy consumption. Following nature's blueprints could make it cleaner.



Two years ago the design software giant Autodesk made an unconventional move.

The company's CAD software, which once could assemble only blocky, geometric shapes, had evolved to let engineers design new kinds of intricate micron-scale geometries. These could only be fabricated using 3-D printing. The company wanted to understand its customers' needs and the additive manufacturing workflow as intimately as possible. "The best way to understand this was to make our own hardware," said Shalom Ormsby, a designer at Autodesk.

The company took the leap and built its first production-quality 3-D printer, the Ember.

But building this 3-D printer was not enough. Autodesk prides itself on its sustainability efforts. It has ramped up recycling; it uses only renewable energy to run its business; and it maintains a website

3-D printers can create an endless variety of intricate plastic parts, but where will those parts go when it's time to dispose of them?

with examples of sustainable solutions for buildings, manufacturing, and infrastructure. It has embedded ecological intelligence, including life cycle analysis—a cradle-to-grave analysis of a product's impact—directly into its software to help designers make sustainable choices regarding energy, materials, and water.

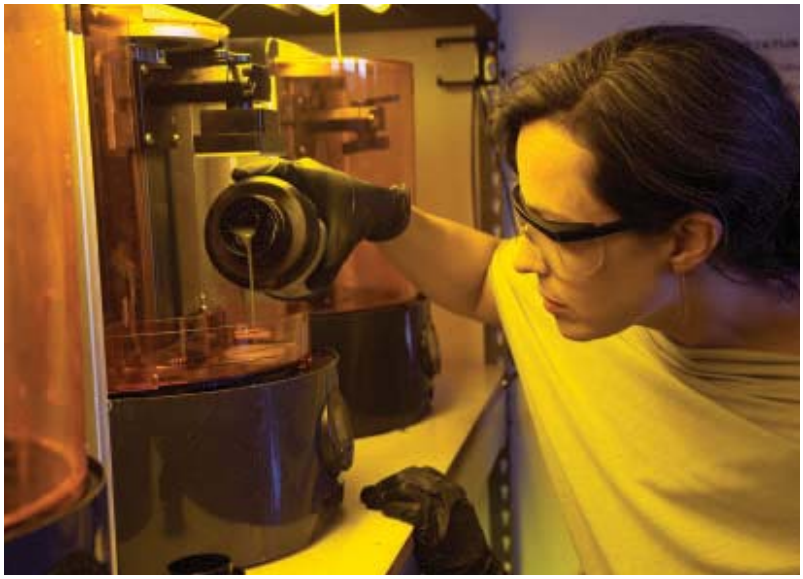
Autodesk recognized that 3-D printing posed an opportunity, but also a problem.

As 3-D printers have become smaller, less expensive, and easier to use, they've become increasingly popular. A growing maker movement, including online groups and meetups at local maker spaces, has enthusiastically adopted the technology. Commercial applications are taking off. Soon, proponents say, everyone will be able to manufacture just about anything, anywhere.

Additive manufacturing could make manufacturing more sustainable because it creates far less waste than traditional subtractive methods and because making products locally would shorten supply chains, reducing fuel use and carbon pollution from shipping. But additive manufacturing could also cause new problems.

3-D printing could "accelerate consumerism of nonbiodegradable throwaway plastic objects," Janine Benyus, author of the landmark book *Biomimicry* and founder of the Biomimicry Institute, has written. Because 3-D printers work at high temperatures, they consume a lot of energy: a home 3-D printer uses about as much power as a desktop computer. This could have major implications for local energy grids. What's more, toxins in the 3-D printing supply chain, including the chemicals in polymer resins, could jeopardize both human health and the environment, she said.

When Autodesk released the Ember in 2014, the company therefore found itself producing a device designed to produce plastic objects that could be implanted in hips, knees, or hearts, make their way



Autodesk's Dawn Danby aims to develop nontoxic printer-resin chemicals. *Photo: Blue Bergen*

"As we began to invest a lot in the world of additive manufacturing, lots of questions came up about how we might support that industry in being more sustainable, especially at this early stage."

— Dawn Danby, Autodesk sustainable design program

into the hands or mouths of toddlers, or get discarded in ditches bordering streams.

"As we began to invest a lot in the world of additive manufacturing, lots of questions came up about how we might support that industry in being more sustainable, especially at this early stage," Dawn Danby, who manages Autodesk's sustainable design program, recalled.

Could Autodesk really make 3-D printing more sustainable—and in time to keep plastic waste and toxic material from proliferating?

Danby and her colleagues decided to try.

Greener Solutions

Autodesk had staff who knew how to help cut its 3-D printer's energy consumption and reduce its packaging to prevent waste. But it lacked the expertise in chemistry and toxicology to properly evaluate and improve the various resins the printer might use as feedstocks.

For help, Danby reached out to Tom McKeag, who directs the Berkeley Center for Green Chemistry (BCGC). McKeag is a landscape architect by training and considers himself neither a scientist nor an engineer. But he's managed to train himself in product design and manufacturing, and he has become an expert and strong proponent of bioinspired design, in which designers use nature as a model when coming up with solutions.

Since 2008, McKeag has taught courses in bioinspired design and other topics at University of California, Berkeley, where the center is based. He served for three years on the board of the Biomimicry Institute, and edits *Zygote Quarterly*, a bioinspired design magazine.

By 2015, McKeag was co-teaching an interdisciplinary, project-oriented class called Greener Solutions, which trains students to draw from chemistry, engineering, and environmental health science to come up with sustainable solutions for real-world problems. Each year the class, co-taught by Megan Schwartz-

man of U.C. Berkeley's School of Public Health, addresses a problem presented by a sponsoring company. General Coatings has tapped the class to find safer formulations for spray foam insulation; Seventh Generation requested improved preservatives for personal care products; and Levi's asked them to investigate cleaner alternatives to the finishing process for wrinkle-free Dockers.

Autodesk was "trying to inspire more innovation around materials while setting a higher bar for safety and sustainability," Danby said. "We want a greener resin, but what exactly does that mean?"

McKeag had some ideas, and he knew who else could help. He contacted Beth Rattner, executive director of the Biomimicry Institute.

Founded in 1998 by Janine Benyus, the Biomimicry Institute works on the premise that life has evolved for billions of years while solving myriad problems associated with thriving on this planet, and Benyus believed we could learn a great deal by studying what nature does and how its processes work.

In particular, nature often employs clever mechanisms, some of which designers have adapted to fashion new technologies. For instance, John Dabiri and his team at Stanford found a way to pack wind turbines more tightly together while improving performance. They did it by studying the way that schools of fish use leading vortices—the whirlpool-like masses of fluid along the leading edge of a moving object—to propel themselves. A company called EvoLogics mimicked the acoustics of dolphins' signature whistles in an underwater modem that detect signals from sea-floor pressure sensors to provide warnings of a tsunami. Many other examples exist.

"[Biomimicry] is not really technology or biology; it's the technology of biology," Benyus has written. "It's making a fiber like a spider, or lassoing the sun's energy like a leaf."

At Berkeley, McKeag was already collaborating with Rattner, who advises the Greener Solutions classes on chemistry and the relevant biological literature. The Biomimicry Institute was also helping fund the class and paying a graduate student named Justin Bours, who had previously taken the course, to develop criteria for a "green" 3-D printing resin.

Nature as a Model

McKeag kicked off the work by teaming up with Bours and Marty Mulvihill, a chemist and former director of BCGC. They searched the scientific literature to learn how a biomimetic approach could improve printer resins, and they produced a report in April 2015 that identified 11 bioinspired design principles to guide the class's investigation.

McKeag then challenged the Greener Solutions students to develop a framework to assess safety and sustainability. The class came up with four criteria.

First, the students asked if the ingredients could be sourced locally and if they could be grown. In nature, plants and animals grow on a small number of readily available nutrients, all drawn from their diet or the surrounding environment. For example, songbirds in the woods display a dazzling variety of colors. Unlike today's manufacturers, who obtain raw materials from multiple points worldwide, most birds use nutrients to synthesize a single material, which they assemble to build nanostructures that scatter specific wavelengths of light, producing the species' characteristic colors.

Second, they considered whether the material uses structure, including nanostructure, to impart function. Consider the Humboldt squid. Its rubbery body transitions smoothly to a beak whose tip is the hardest non-mineral material known to man, yet both the body and the tip are made of the same chemical components, but in

"Biomimicry is not really technology or biology; it's the technology of biology."

— Janine Benyus, Founder of the Biomimicry Institute

> "If [the 3-D printer] still requires petroleum-based inputs and still creates products that, at the end of their usable life, are not recyclable, then it has not lived up to its potential."
>
> — Dawn Danby

different proportions. If a single resin material could take on different properties based on how it was applied and cured by the printer, this could pose a significant opportunity for 3-D printing.

The class also considered whether resin was drawn from a small set of ingredients. In nature, a mere 20 amino acids combine to make more than 100,000 different proteins in the body. Was there a way to follow nature's lead and come up with a small set of safe chemical building blocks called monomers that could combine to produce a range of different materials or material properties? To find out, the Berkeley student researchers explored options such as "multi-tasking monomers," which would be programmed to produce different materials under different processing conditions.

Finally, the class considered whether 3-D printed products could be recycled, the way nature converts waste from one organism or biological process into food or feedstock for another. As Dawn Danby said, "if it still requires petroleum-based inputs and still creates products that, at the end of their usable life, are not recyclable, then it has not lived up to its potential."

Safety First

Next, the class performed a hazard assessment on current 3-D printing materials, operating on the guiding principle that the chemistry used should be benign for both human health and the environment.

The students found that 3-D printers use six common resin types: acrylates, thiols, alkenes, vinyl ethers, epoxides, and oxetanes. Acrylates, which the Ember printer uses, are the most common because they work well in a 3-D printer and are considered safest for creating solid objects from liquids. Yet acrylates are far from perfect. The monomers and oligomers that make the resin solidify into plastic are highly reactive by design, which means that uncured acrylates can be hazardous in the environment, much like liquid paint. SLA printers tend to leave 20-30 percent of the resin uncured.

The class broke into groups. Different groups recommended replacing the photoinitiator, modifying the base resin, or using a different initiation mechanism. They considered only the materials, suggesting no changes to the printer itself.

The photoinitiator, a chemical called TPO, responds to light by catalyzing acrylate monomers and oligomers to form the polymer, or plastic. But it's also a reactive chemical that's known to harm animal reproduction and the freshwater environment. For that reason, the class followed a principle that McKeag, Mulvihill, and Bours had called the optimal activator, which meant using light or another environmental factor, rather than a chemical, to catalyze the reaction.

They suggested using a blend of curcumin, the principal component of turmeric, the pungent spice used to help flavor curry, and riboflavin, otherwise known as vitamin B2. The literature the class surveyed described their use as photoinitiators in polymerization reactions. Since both are edible, they'll likely be considerably safer than the current photoinitiator.

Another group of Greener Solutions students proposed a different bioinspired approach to initiate the reaction: exposing the resin to a change in acidity. Oysters and mussels use this approach to enable the water-soluble adhesives they secrete that solidify and attach them to rocks under water. The

process, known as calcium carbonate mineralization, is already used in two-dimensional lithography, so there was a sound basis for it.

Since nature also grows its own ingredients, one group in the class proposed replacing the acrylate resin with triglycerides (fats) derived from castor oil. Another group recommended chitosan, the material insects and crustaceans use to build their shells. Earlier research had shown that these replacements were both effective and safe, with the triglycerides likely to produce softer materials.

Tom McKeag (center), who directs the Berkeley Center for Green Chemistry, watches students in the 2015 Greener Solutions class do a team-building exercise.

In the end, Autodesk decided to pursue several of the class's suggestions. These included developing a turmeric-based photoinitiator, a pH-based photoinitiator derived from oysters and mussels, and a chitosan-based resin, said Chris Venter, an Autodesk senior research scientist who leads the biomaterials development for printers like Ember and the yet-to-be-released Escher, which will use multiple robotic print heads for high-volume production. The company even hired Bours as a full-time chemist to continue developing the new resin components.

Between Autodesk, the Greener Solutions class, and other researchers, "we should get to benign feedstocks fairly quickly," said the Biomimicry Institute's Rattner.

Doing so will mitigate the degree of harm from 3-D printing as more people become involved in design and creation. But it's clear that far more can be achieved. "How do we get to where we can operate these at ambient temperature, like your body does?" Rattner asks. "Your body makes some pretty great ceramics, namely your teeth, without a kiln or a furnace, so why can't we get a 3D printer to do that?"

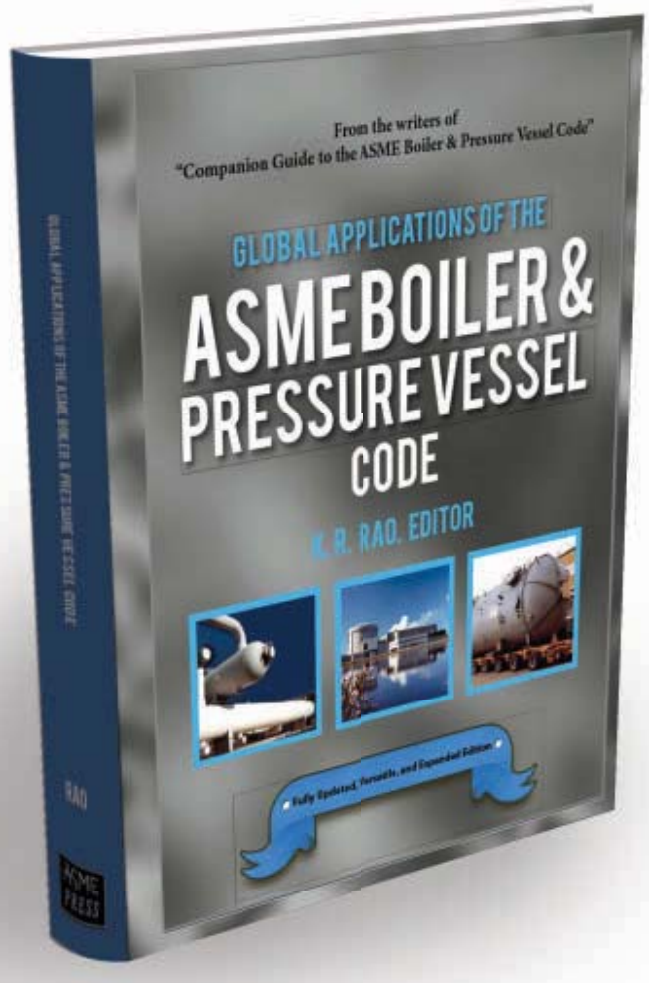
Meanwhile, at Autodesk, Bours is developing an online database of 3-D printing materials to help manufacturers, designers, and developers make sound materials choices.

Autodesk will eventually stop selling resin, but will make public what they've learned about developing safe, nontoxic resins, Venter said. The company hopes that the safer resins they develop will be cheaper than today's and will encourage more people to try 3-D printing. Down the road, the resins could be made from "simple, common ingredients that are purchased locally—perhaps even at the grocery store," Venter said.

That's a long way from the toxic resins and plastic trash 3-D printers are poised to generate today. But for 3-D printing and many other products and endeavors, "nature has already solved so many of those other dimensions of the problem," giving us renewable, non-toxic, biodegradable technologies that require less energy, water and time to make, Rattner said.

Indeed, that's what can happen when you follow nature's lead. ME

R.P. SIEGEL is a technology writer based in Rochester, N.Y.



FEATURED

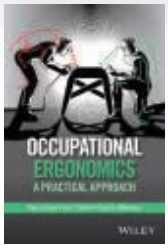
GLOBAL APPLICATIONS OF THE ASME BOILER & PRESSURE VESSEL CODE

K.R. RAO, EDITOR

ASME Press, Two Park Ave., New York, NY 10016. 2016.

This new publication follows not only the four editions of the Companion Guide to the ASME Boiler & Pressure Vessel Code but also two related updated volumes. This stand-alone book addresses international applications of the boiler code, with authors covering Europe, Asia, and Africa in addition to North America. Some of the special topics dealt with by ASME Code experts are the global harmonization of nuclear codes and standards and international perspectives on spent fuel storage. One topic of particular interest is the inclusion of the nuclear activities of China for the first time. In that chapter as every other, authors with expertise in both their country's codes and the ASME Pressure Vessel Codes and Standards have provided an update on the current Code status of their respective countries.

500 PAGES. $269; ASME MEMBERS, $215. ISBN: 978-0-7918-61073.

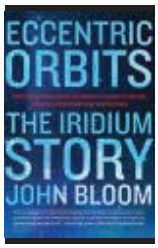


OCCUPATIONAL ERGONOMICS: A PRACTICAL APPROACH

Theresa Stack, Lee T. Ostrom, and Cheryl A. Wilhelmsen
John Wiley & Sons, 111 River Street, Hoboken, NJ 07030-5774. 2016.

Workers are often treated as parts to be plugged into pre-existing work stations without a consideration of the human factors involved. But that is not a terrible economically efficient approach. As Stack and her co-authors point out, the design of the work station can profoundly impact the ability to effectively perform the required tasks. Their book progresses from the concept of ergonomics, through the various assessment techniques, and into the more complex techniques. Each chapter presents the technique discussed in that chapter and demonstrates how it is used; readers can readily adapt these techniques to the ergonomic assessment tasks they are interested in, such as office environments, factory floors, and the special ergonomic considerations of the healthcare field.

552 PAGES. $125.00. ISBN: 978-1-118-81421-5.



ECCENTRIC ORBITS: THE IRIDIUM STORY

John Bloom
Atlantic Monthly Press, 154 West 14th Street, 12th Floor, New York, NY 10011. 2016.

Bloom, an award-winning journalist, traces the conception, development, and launching of Iridium—a satellite communications system begun by Motorola in the 1990s with the goal of providing telephone service to every spot on Earth. But within months of launch, Bloom reports, the system was burning through $100 million a month, bringing in almost no revenue, and headed toward bankruptcy. The service was saved from destruction by a retired CEO who realized that anyone who needs to make a call but is far removed from telephone lines or cell phone towers—from war correspondents and mine operators to ship captains, search and rescue teams, and special operations forces—could be cultivated into customers.

560 PAGES. $27.50. ISBN: 978-0-80212-1684.

CLOUD-BASED RENDERING

ONERENDER, PUEBLA, MEXICO.

OneRender provides a 3-D design project environment that enables a designer or product prototyper to access remote computational power to produce visualizations on a pay-per-render basis. A user can set up a scene, start a render on the cloud, and log out. Depending on the number of actual GPUs working in the cloud, a complex visualization rendering of several images or video can be finished in minutes. The entry-level version is free. The standard and professional levels allow visualizations to be rendered on faster graphical processing units and the ability to render 3-D images in complete 360 degree views. The ability to display such images on virtual reality headsets is being developed.

CAMERA DRIVER

IMAGING DEVELOPMENT SYSTEMS GMBH, OBERSULM, GERMANY.

IDS Software Suite 4.80, a driver for USB 2.0, USB 3.0, and GigE industrial cameras from IDS, is now available for free download on the camera manufacturer's website. The driver supports the upcoming USB 3 uEye CP camera series that is equipped with fast Python sensors from ON Semiconductor and it is now WHQL certified for Windows 10 in addition to earlier releases of Windows and Linux. Version 4.80 supports the so-called Vertical AOI Merge Mode, specially developed by IDS, when using models of the USB 3 uEye CP. That mode enables the user to flash per line, if desired, and therefore to apply different light sources and further applications.

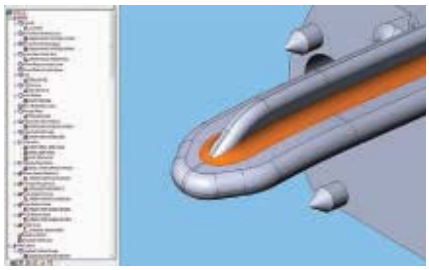
MULTICHANNEL MEASUREMENT

MICROSTAR LABORATORIES, BELLEVUE, WASH.

Accel64 for Linux version 1.00 is now available for GNU/Linux systems as a free download. Advanced data acquisition processor applications can now be supported as 32-bit applications on 32-bit or 64-bit hardware platforms, or as 64-bit applications on 64-bit hardware platforms. The application determines what kind of hardware platform is present and selects the native interface mode as the default. The delegation of complex real-time details to the DAP/DAPL systems means that data acquisition applications can use generic kernels and graphical desktop environments, even on lightweight platforms without 64-bit support.

LATHE ROUGHING STRATEGY

DP TECHNOLOGY CORP., CAMARILLO, CALIF.



DP Technology Corp. has released a new version of its flagship product, Esprit 2016. The application features a new high-speed lathe roughing strategy that implements Esprit´s new physics-based cutting engine. Traditional cutting strategies only consider the geometry of the part, while the new strategy in Esprit creates the toolpath considering multiple cutting factors and machine characteristics that impact machining performance. Esprit 2016 also features enhanced CAD recognition functions to correct and detect any acute unseen defects in imported CAD models. In addition, users can now edit or remove fillets or even extract a spine curve from fillets as a tool drive curve in machining operations. The 5-axis programming features eliminates unwanted plunge-type moves in Swarf cycles, and smooths any concealed defects in spiral finishing part surfaces.

SCANNING ARM

FARO, LAKE MARY, FLA.

The Design Scan Arm is tailored for 3-D modeling, reverse engineering, and CAD-based design applications across the product lifecycle management process. It utilizes a blue laser to produce high-resolution point cloud data, which means the device can scan challenging materials without the need for spray or targets. The Design Scan Arm is portable, lightweight, and maneuverable, and is intended for desktop mounting in the design studio or engineering lab. The simple user interface makes it easy to operate regardless of skill level or 3-D scanning experience. The scanning arm may be suitable for an organization that wishes to manufacture parts without existing CAD models, reverse engineer legacy parts for design changes or replacement, or create digital libraries to decrease inventory and warehouse costs.

MOTOR SENSOR

ABB, ZURICH.

A new sensor technology offered by ABB is intended to reduce downtimes of low-voltage motors by up to 70 percent and extend their lifetime by as much as 30 percent. The smart sensor provides information on operating condition parameters such as vibration, temperature, or overload, and calculates power consumption. The data is analyzed by a specially developed software program and provided to the plant operator in the form of graphics for maintenance planning. Motor operation can be optimized so as to reduce energy consumption by as much as 10 percent, which should enable users to recoup the additional cost of the system. The new technology is available on new motors made by ABB, but the sensors also can be retrofitted on already operating low-voltage motors within minutes.

RATCHET SET

AUTOMATIONDIRECT, CUMMING, GA.

AutomationDirect now offers Wera Zyklop metal ratchets and ratchet sets. Available in ¼ in., 3/8 in., and ½ in. drive sizes, the ratchets feature a fine 72-tooth ratchet mechanism with a low return angle of 5° to allow fast and precise work in small spaces. The ratchet head is fitted with a switch lever that allows for a rapid change of direction. A ball lock securely holds sockets and attachments ensuring safe operation; to release the socket, simply press the release button. The ratchet's slim design and forged, chrome-molybdenum steel construction has no torque limitation and is ideal for use in tight areas. The ratchet is constructed of chrome vanadium steel with a brushed chrome-plated finish for corrosion protection. The company has also added the Wera Zyklop mini bit ratchet, which features a 6° return angle, a thumbwheel for quick operation, and a switch lever for convenient direction change.

MICROFINISHING

THIELENHAUS TECHNOLOGIES GMBH, WUPPERTAL, GERMANY.

The Sphero is a high-precision microfinish machine equipped with a tool spindle unit that can swivel up to 90°, enabling the optimal machining position to be chosen for each process. Workpieces with diameters of up to 75 mm can be machined on the Sphero, and when clamped the workpiece rotates at up to 4,500 rpm. The associated tool unit is arranged vertically and is easily accessible for quick retooling. The integrated tool changer has a capacity for up to 10 tools, so that even complex machining processes can be carried out with only one clamping process.

Among the use cases the company suggests is machining of the joint heads of wheel suspension and steering components of automobiles and the smoothing of the spherical sliding surface of an axial piston pump.

TWIN-CYLINDER PUMP

GARDNER DENVER THOMAS, SHEBOYGAN, WIS.

The Thomas 2110 pump provides variable output through its brushless dc motor and motor controller design. The 2110 series has durable die-cast aluminum component parts, which enables the pump to weigh only 0.85 lbs. The pump features oil-less, non-lubricated pistons and cylinders, with permanently lubricated bearings and stainless steel valves. Its compact design makes the pump easy to install, while the twin-cylinder design provides reliability with low vibration and quiet operation. The pump has a capacity of 0.5 cfm (14 l/min) while operating at 3000 rpm, and it can produce a pressure of 30 psi. The company suggests such applications as in portable oxygen concentrators or in small, battery-operated devices that require an air compressor.

DATA ACQUISITION

ENDRESS+HAUSER, GREENWOOD, IND.

The Memograph M RSG45 Data Manager is a compact device that can serve as a data acquisition system for small process control applications. The RSG45 is a panel-mounted device that acquires up to 14 discrete and 20 universal/HART analog inputs from process sensors and displays the data on its 7-inch multicolor screen. The device also records the data internally and performs math calculations and alarm checks. Data is stored in tamper-proof internal memory, on an SD card or on a USB stick—all of which fulfill the security requirements of FDA 21 CFR part 11. The device may also transmit the data to a personal computer or any control system via Ethernet, RS232/485, Modbus, Profibus DP, or PROFINET digital communication links. Data can also be transferred to a device plugged into the USB or the SD port.

PRODUCTS

X-RAY SPECTROMETER

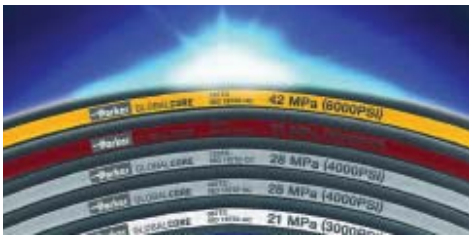
SPECTRO ANALYTICAL INSTRUMENTS GMBH,
KLEVE, GERMANY.

Spectro Analytical Instruments has upgraded its Spectro xSORT handheld X-ray fluorescence spectrometer to provide better speed and precision in the analysis of light elements. The Spectro xSORT is designed so that operators don't have to switch methods between samples or use helium flushes. An X-ray safety gasket prevents backscatter radiation from light element matrix samples. The device also features a quick-change battery, an interface with operator-defined hot keys, and simplified software with touchscreen. Other options include an integrated GPS receiver and integrated video camera. The device weighs only 1.64 kg and its compact, one-piece design is optimized for use in the field, even in tight or less accessible spots.

HYDRAULIC HOSES

PARKER HANNIFIN, MAYFIELD HEIGHTS, OHIO.

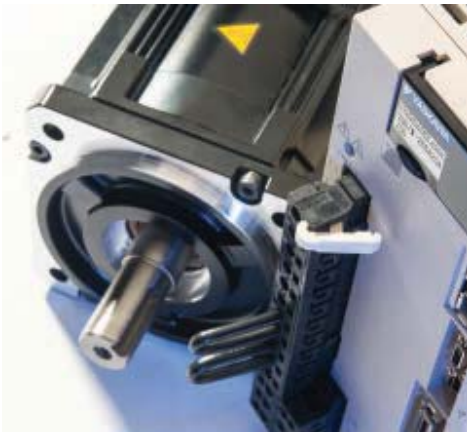
Parker Hannifin recently introduced the GlobalCore brand of hoses. Designed to meet the most common working pressures in industry, GlobalCore is built and tested to the ISO 18752 specification. The five hydraulic hoses and two fittings are specified by pressure range and not by construction and provide options for the most critical sizes and pressure ranges: 21 MPa (3,000 psi) to 42 MPa (6,000 psi) in sizes -4 through -32. The company says the intent is to reduce engineering and service complexity. The hose series is offered in three types of coverings. The standard is synthetic rubber, while the ToughCover is 80 times more abrasion resistant and the SuperTough cover is 450 times more abrasion resistant than the standard cover.



CABLE SHEATHING

SOLVAY, BOLLATE, ITALY.

Solvay has added three new grades to its Cogegum silane grafted, polyolefin-based, cross-linkable, and halogen-free flame retardant compounds portfolio. Cogegum GFR 903 is a sheathing grade compound targeted at special cables in the petroleum and the chemical industries that must meet NEK TS 606 and IEC 60092-360 requirements, such as in offshore installations. The compound is highly flame retardant. Cogegum GFR 1401 is an insulation grade compound designed to meet ISO 6722 and major automotive standards, such as T3 for engine compartment cables that require heat resistance of up to 125 °C. Cogegum GFR 1301 is an insulation and sheathing grade compound for extremely demanding electrical and electronics cables with working temperatures from -40 °C to 105 °C; it provides flame retardancy rated to UL 1581 VW-1 and meets UL standards 44 and UL 758.



DIRECT-DRIVE SERVO

YASKAWA AMERICA , WAUKEGAN, ILL.

Sigma-7 is a new line of rotary, linear and direct drive servos and amplifiers from Yaskawa. According to the company, Sigma-7 offers nearly double the bandwidth of its Sigma-5 servos, which will allow for quicker response to system commands. The servo has a 20 percent smaller footprint and a new amplifier design to save control panel space, and its dual-axis amplifiers mount in smaller spaces. The Sigma-7 provides full compatibility with the Sigma-5 servos currently in the field, which means they can replace the older model without the need for reprogramming or re-engineering existing equipment. Users can choose from two direct drive servos and four linear products, including a SigmaTrac option designed for easy bolt-on, plug-in implementation.

CARTESIAN ROBOT

ROLLON, HACKETTSTOWN, N.J.

Rollon has launched Motion Box, a new pre-engineered Cartesian robot system designed to provide six different motion profiles that can be set-up and running in hours. The initial system setup is already complete so end users can get parts moving in a reliable and repeatable manner. The pre-programmed motion profiles suit more than 80 percent of all Cartesian motion applications. After defining the available space and required motion footprint, users check the load and speed requirements. Load and speed charts make it simple to determine travel times for *x*, *y*, and *z* axes. Motion Box also offers flexible integration options via an Ethernet connection. The Cartesian robot system can connect to wider automation setups using EtherNet/IP, DeviceNet, TCP/IP, CC-Link, Profibus and PROFINET, as well as company networks and control architectures.

JOINT KIT

IGUS, EAST PROVIDENCE, R.I.

Igus has updated the Robolink D modular robotic kit that provides users the ability to assemble custom robotic systems for a range of applications. The gearing is offered either as an individual component or with an integrated NEMA motor and consists of an outer ring gear and flexible, inner ring gear made from self-lubricating, wear-resistant plastic. Separate joints, which are motor-driven directly on the axis, are available in a range of installation sizes. A new complete, 6-axis arm with strain wave gearing is also available, along with universal gripper adaptors, which allow the attachment of a range of different grippers on the Robolink D joints. Additionally, a new online configurator is available to let users configure and assemble custom Robolink D joints. Motors, encoders, cabling, and other accessories are also available.

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.

RESOURCEFILE

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UNIVERSITY OF ILLINOIS AT CHICAGO

ASSISTANT/ASSOCIATE/FULL PROFESSOR

Mechanical Engineering

The Department of Mechanical and Industrial Engineering at the University of Illinois at Chicago (UIC) invites applications for several tenure-track faculty positions in various areas of Mechanical Engineering. Individuals will also be considered at associate or full professor rank if they possess outstanding qualifications commensurate with the rank.

Successful applicants are required to have an earned PhD in Mechanical Engineering or a related field, and are expected to develop and maintain an active, externally-funded research program as well as teach courses at both the undergraduate and graduate levels.

The Department offers BS, MS, and PhD degrees in Mechanical Engineering, and Industrial Engineering and Operations Research, and currently has an undergraduate enrollment of about 770 and a graduate enrollment of about 470. More information about the Department can be found at **http://www.mie.uic.edu**. Applicants are required to send a letter of application indicating their qualifications, an up-to-date CV including the names and contact information of three references, and separate one-page statements outlining their future teaching and research plans.

For fullest consideration, applications must be submitted online at **http://jobs.uic.edu/job-board/job-details?jobID=66284** by **December 1, 2016**. Applications will be accepted until the positions are filled. Expected starting date is August 2017.

UIC is an EOE/AA/Minority/Female/Disabled/Veteran.

The University of Illinois conducts background checks on all job candidates upon acceptance of contingent offer of employment. Background checks will be performed in compliance with the Fair Credit Reporting Act.

MECHANICAL AND INDUSTRIAL ENGINEERING
COLLEGE OF ENGINEERING
UIC

CASE WESTERN RESERVE UNIVERSITY EST. 1826

Faculty Position in Thermal and Fluid Sciences

The Department of Mechanical and Aerospace Engineering at Case Western Reserve University invites applications for a tenure-track position in Thermal and Fluid sciences, with an anticipated starting date of August 1, 2017 or thereafter. The positions will be at the Assistant or Associate Professor level, although appointment to Full Professor may be considered for candidate with an excellent track record.

We seek an outstanding scholar who demonstrates a clear vision and plan to successfully establish an internationally-recognized, competitively-funded research program that is rooted in the fundamentals of thermal and fluid sciences and explores innovative applications. A doctorate in Mechanical, Aerospace or a closely related Science/Engineering field is required. In addition, the successful candidate is expected to actively contribute to the core undergraduate and graduate teaching missions of the department, and to engage in departmental, institutional, and professiol service activities.

Applicants should submit a cover letter, curriculum vitae, statements on teaching and research, copy of three representative journal papers, and the contact information of at least four professional referees to MAE-facultysearch@case.edu, in one PDF file. Evaluation of applications will begin immediately and continue until the position is filled.

Case Western Reserve University is an equal opportunity, affirmative action employer, and is committed to providing employment opportunities to all qualified applicants without regards to race, color, religion, age, gender, sexual orientation, national origin, disability, or protected veteran status.

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Position in Mechanical Systems

at the Ecole polytechnique fédérale de Lausanne (EPFL)

The Institute of Mechanical Engineering is soliciting applications for a faculty position at the level of tenure-track assistant professor or tenured associate professor in a broad range of research areas related to mechanical systems.

Of particular interest for this search are applicants with specific technical interest that includes but is not limited to: vibration and structural control, instrumentation and monitoring, distributed sensing, design and mechatronics. Applicants should have a demonstrated record of excellence in their chosen technical area.

As a faculty member of the School of Engineering, the successful candidate will be expected to initiate an independent and creative research program and participate in undergraduate and graduate teaching. Internationally competitive salaries, start-up resources and benefits are offered.

EPFL, with its main campus located in Lausanne, Switzerland, is a dynamically growing and well-funded institution fostering excellence and diversity. As a technical university covering essentially the entire palette of engineering and science, EPFL offers a fertile environment for research cooperation between different disciplines. EPFL has a highly international environment that is multi-lingual and multi-cultural, with English often serving as a common interface.

Applications should include a cover letter with a statement of motivation, curriculum vitae, list of publications and patents, concise statement of research and teaching interests. Applicants for Assistant Professor should request letters of recommendation to be sent to the committee, while applicants for Associate Professor should provide the names and addresses of at least five potential recommenders. Applications must be uploaded in PDF format to the recruitment web site:

go.epfl.ch/igm-search

Formal evaluation of candidates will begin on **December 1st, 2016** and continue until the position is filled.

Enquiries may be sent to:
Prof. John Botsis
Search Committee Chair
Email: **igm-search@epfl.ch**

For additional information on EPFL, please consult the web sites: **www.epfl.ch, sti.epfl.ch** and **igm.epfl.ch**.

EPFL is committed to increasing the diversity of its faculty, and strongly encourages women to apply.

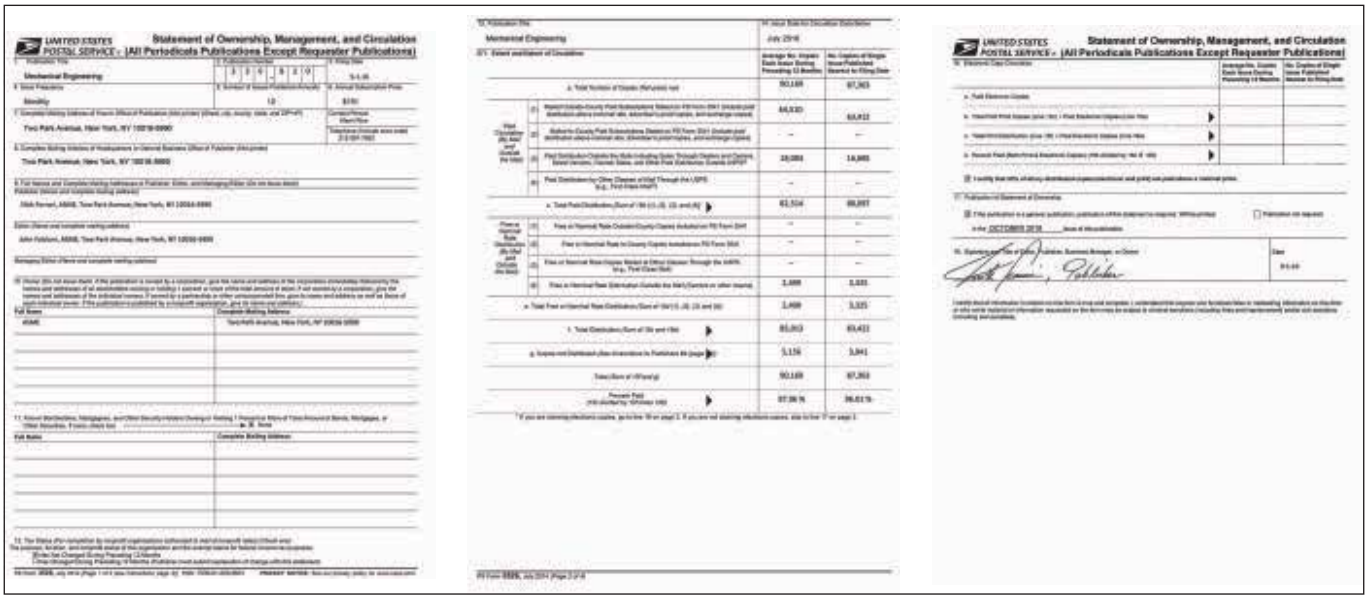
POSITIONSOPEN

ASSISTANT/ASSOCIATE/FULL PROFESSORS - MECHANICAL ENGINEERING
UNIVERSITY OF MASSACHUSETTS LOWELL

The Department of Mechanical Engineering at the University of Massachusetts Lowell is seeking to hire several **FULL-TIME TENURE-TRACK FACULTY AT THE RANKS OF ASSISTANT OR ASSOCIATE PROFESSOR;** applications for Full Professor will also be considered for exceptional candidates. Applicants must have earned Doctoral degrees in mechanical engineering, or closely related disciplines, and are required to have a record of quality teaching and scholarship. Successful applicants will collaborate with existing faculty members, teach classes to support the undergraduate and graduate programs, develop new courses, advise and recruit graduate students, and are expected to develop a robust, externally funded research program in one of the following areas: **(1) ROBOTICS AND AUTONOMOUS** Systems: biomechanics, soft robotics, compliant robots for manufacturing, advanced networked control systems, multi-agent dynamic systems, cooperative robotics, cyber-physical systems, and de-centralized path planning to support robotic programs with a strong applied complement. Faculty will have the opportunity to work with the NERVE Center, a 10,000 sq. ft. robot testing facility, as well as the NASA Valkyrie humanoid robot. **(2) STRUCTURAL DYNAMICS AND DYNAMIC SYSTEMS:** Development of advanced structural dynamic modeling techniques using analytical and experimental approaches (conventional finite element and experimental modal analysis complimented with advanced hybrid system modeling and reduced order modeling for linear and nonlinear systems). Modeling and analysis of dynamic systems with applications to wind energy, aerospace, vehicle, robotic, energy or other systems. **(3) THERMOFLUID TRANSPORT:** Computational transport phenomena including multi-physics, multi-scale, multi-phase, and/or reaction kinetics with a specific focus on energy applications such as combustion, plasma processes, solar thermal and photo-thermochemical, electrochemical, and biomass energy systems, as well those related to the food-energy-water nexus. **(4) MECHANICS & MATERIALS:** Design of advanced materials and/or structures relevant to applications of automotive, energy, robotics, flexible structures, flexible electronics, 3D printing or sustainability. Composite materials are of particular interest; expertise in other material systems will also be considered.

Note: Candidates must clearly specify a single research area (of the four listed) in bold font in the first sentence of their Cover Letter. In cases of demonstrated outstanding research productivity and scholarship, an appointment with tenure may be considered. **TO APPLY, VISIT:** http://jobs.uml.edu. Applications received by December 15, 2016 will be considered in the first review of candidates. However, later applications may be considered for these positions. Each position will close after an adequate number of qualified applications is received. UMass Lowell is a Carnegie Doctoral High Research (RU/H) university ranked in the top tier of US News' National Universities, and is strategically located 30 miles northwest of Boston in the northeast Massachusetts high-tech region. 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.

THE DEPARTMENT OF BIOENGINEERING AT GEORGE MASON UNIVERSITY, the largest public research university in Virginia, invites applications for the position of **CHAIR AND PROFESSOR.** The successful candidate will join our dynamic and rapidly growing department and lead it in achieving continued excellence and national recognition. Candidates must have an earned doctorate in bioengineering or a related field, be eligible for tenured appointment at the rank of full professor, and have appropriate administrative experience. For the full position description, please see http://bioengineering.gmu.edu/. Applicants should apply for position number F9261z at http://jobs.gmu.edu/. To ensure full consideration, applications should be received by November 15, 2016. EO/AA/Vet/Disabled Employer



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RECRUITMENT

ASME TO PUBLISH ASME B16 STANDARDS REVISIONS THIS YEAR

ASME Standards & Certification is preparing to issue revised versions of three of its ASME B16 Standards. The new versions of the standards—ASME B16.5, B16.34 and B16.47—were finalized in May and will be published concurrently this year.

ASME developed these three standards to provide industry with technical guidelines and requirements regarding the use of flanges and valves ranging from nominal pipe sizes (NPS) NPS ½ to NPS 60. The B16 Standards Committee and Subcommittees C and N provide important guidance on pressure-temperature ratings, marking, materials, dimensions, and testing for valves and flanges through these standards.

ASME B16.5 Pipe Flanges and Flanged Fittings—one of ASME's most requested product standards because it covers a large range of sizes and pressure temperature ratings—covers pipe flanges and flanged fittings for flanges with rating class designations 150, 300, 400, 600, 900 and 1500 in size categories NPS ½ through NPS 24. The standard also applies to flanges with rating class designation 2500 in sizes NPS ½ through NPS 12. Materials covered in the standard include forged, cast and plate carbon, low alloy, stainless steel, and nickel alloys.

The second of the three standards, ASME B16.34 Valves— Flanged, Threaded, and Welding End —applies to new valve construction requirements. It covers pressure-temperature ratings, nondestructive examination requirements, testing and marking for cast, forged and fabricated valves—including flanged, threaded, welding end or flangeless valves—constructed of carbon steel, low alloy steel, stainless steel or nickel-base alloys.

The ASME B16.47 Large Diameter Steel Flanges standard covers pressure-temperature ratings, materials, dimensions, tolerances, marking, and testing for welding neck and blind pipe flanges NPS 26 through NPS 60. It encompasses flanges with rating class designations 75, 150, 300, 400, 600, and 900, and includes requirements and recommendations regarding flange bolting, flange gaskets, and flange joints. Dimensions for raised face (RF) and ring joint gasket facings are addressed in the standard, as are materials including forged, cast and plate carbon, low alloy, stainless steel and nickel alloys.

ASME publishes the three standards simultaneously because they are so interrelated. In fact, they started as a single standard, B16e, handled by one B16 Subcommittee. In 1920, the American Engineering Standards Committee organized Section Committee B16 to unify and further develop standards for pipe flanges and fittings. Section Committee B16 soon formed subcommittees and, in 1923, Subcommittee 3 began developing the first edition of B16e, which was approved in 1927.

Technological developments led to the splitting of that standard into two in 1977: B16.34, which began covering all valve construction requirements including flanged valves, and B16.5, which became the stand-alone document for flanges and flanged fittings construction details.

A subgroup of B16 Subcommittee C began work on the B16.47 Large

IMECE TO FEATURE LEADERS IN ENERGY, TRANSPORTATION

ASME International Mechanical Engineering Congress and Exposition, to be held next month in Phoenix, Ariz., is expected to draw more than 4,000 attendees from a variety of industry sectors, from advanced manufacturing and aerospace to power, bioengineering, and environmental engineering.

IMECE will feature presentations from a host of thought leaders from the engineering profession, including David Sandalow (pictured, right), the Inaugural Fellow at the Columbia University Center on Global Energy Policy, who will present the opening keynote on Nov. 14, and Ilan Gur, founding director of Cyclotron Road, and Jim Holland, vice president for Ford Motor Co.'s Vehicle Component and System Engineering department, who have been selected as the speakers for two of the meeting's conference-wide plenary sessions.

In addition, David A. Howell, senior vice president for Westinghouse Electric Co.'s operating plants business, has been confirmed to appear as one of the conference's invited industry presentations. The invited industry presentation program was launched at IMECE two years ago to encourage more participation by engineers from industry.

Other highlights of IMECE 2016 will include the Student Design Competition, the President's Luncheon, the Old Guard Oral Competition, the Undergraduate Student Expo, the Member's and Student's Luncheon, the NSF Student Competition, the FutureMe Mini-Talks program, and the Micro-Nano Forum and Career Workshop for early career engineers.

This year, another IMECE special event, the Honors Assembly, will move up a day on the schedule to Sunday evening, Nov. 13.

To learn more about IMECE 2016, or to register, visit www.asme.org/events/imece. To view the conference's schedule of events, visit www.asme.org/events/imece/program/schedule-at-a-glance.

Diameter Steel Flanges standard in November 1980 in an effort to standardize dimensions within the industry for materials covered by B16.5 for NPS 26 to NPS 60 flanges. The B16.47 Standard was approved as an American National Standard in June 1990 following approval by ASME and the ASME B16 Standards Committee (formerly the American National Standards Committee B16).

The new editions of ASME B16.5, B16.34, and B16.47 will incorporate several important revisions, such as the inclusion of NPS 22 in B16.5; the alignment of the pressure-temperature tables in B16.5 and B16.34; the inclusion of low temperature valves and expansion of coverage up to NPS 60 in B16.34; and the addition of pressure-temperature table modifications to B16.47.

For more information on the forthcoming 2016 editions of ASME B16.5, B16.34, and B16.47, contact Richard Lucas, Standards & Certification at lucasr@asme.org. For more information on ASME Standards & Certification, visit https://www.asme.org/topics/standardscertification. ME

RICHARD LUCAS, Standards & Certification

(This article was written with advice and review by Guy Jolly, member of B16 Subcommittee C and B16 Subcommittee N.)

FIRST TWO WILEY-ASME PRESS SERIES TITLES ISSUED

The first two titles published under the co-branded Wiley-ASME Press Series in Mechanical Engineering imprint were recently issued. The new books—*Fundamentals of Mechanical Vibrations* by Liang-Wu Cai and *Introduction to Dynamics and Control in Mechanical Engineering Systems* by Cho W.S. To—are now available in both digital and print editions.

The new books are a result of an agreement ASME signed with technical publisher John Wiley & Sons last year to jointly develop and publish a collection of mechanical engineering books. The two organizations plan to publish up to 10 new titles per year under the Wiley-ASME Press Series imprint.

The first book in the series, *Introduction to Dynamics and Control in Mechanical Engineering Systems*, is a textbook focusing on the dynamics and controls of engineering systems, with a special emphasis on mechanical engineering systems. The book is arranged in lecture note format and covers the modeling, formulation, and dynamic behaviors of various mechanical dynamic engineering systems, as well as the theory of feedback control and modern control.

Fundamentals of Mechanical Vibrations provides readers with an introduction to the fundamental aspects of linear vibration analysis for engineers and engineering students. The book covers five key topics, beginning with a chapter that familiarizes readers with the use of Lagrangian dynamics to obtain the governing equations for a system. Other chapters address mathematical tools for vibration analyses of single degree-of-freedom systems, lumped-parameter models for simple engineering structures, vibrations of multiple-degree-of-freedom systems, and vibration analyses using finite element analysis.

Print copies of both books can be ordered through the Wiley website. The titles are also available in e-book format via the ASME Digital Collection.

For more information on ASME Press publications, visit ASME.org/shop/books. ME

To access videos and podcasts of highlights from past conferences, visit www.asme.org/events/imece/about/past-imece-highlights.

ASME MASTERCLASS HEADS TO BARCELONA

ASME Training & Development will offer its MasterClass Training Week on Pressure Vessels, Piping, and Pipelines for the first time in Barcelona, Spain, this month.

The training event courses, taught by prominent experts and ASME codes and standards leaders, will be held from Oct. 17 to 21 at the Meliá Barcelona Sarrià.

The Pressure Vessels, Piping and Pipelines MasterClass Training Week in Barcelona will consist of 19 courses, including six that will be held on Oct. 17 and 18: "Advanced Application of ASME Boiler and Pressure Vessel Code Section VIII, Division 1 Construction Requirements," "Bases and Application of Design Requirements for High Pressure Vessels in ASME Code Section VIII, Division 3," "Bases and Application of Piping Flexibility Analysis to ASME B31 Codes," "Integrity Management of Natural Gas Pipelines Using the ASME B31.8S Standard," "Pipeline Stress Corrosion Cracking Management," and "Techniques and Methods Used in API 579-1/ASME FFS-1 for Advanced Fitness-For-Service (FFS) Assessments."

Some of the other MasterClasses to be offered during the Training Week event include "B31.4 & B31.8, Liquids and Gas Pipelines," "Run-or-Repair Operability Decisions for Pressure Equipment and Piping Systems," "Impact Testing and Toughness Requirements for Pressure Vessels—ASME Section VIII, Divisions 1 & 2," "Bolted Joint Assembly Principles Per PCC-1-2013," "Design by Analysis Requirements in ASME Boiler and Pressure Vessel Code Section VIII, Division 2—Alternative Rules," "Inline Inspections for Pipelines," "Piping Failures—Causes and Prevention," and "Fatigue Analysis Requirements in ASME BPV Code Section VIII, Division 2—Alternative Rules."

For more details on these Pressure Technology and Standards MasterClass Training Weeks, or to register, visit http://go.asme.org/pressuretech-training or contact Jennifer Delda, program/business manager, at deldaj@asme.org.

An illustration from a medieval manuscript depicts a mechanical wine servant from the late 12th or early 13th century. The machine served up wine in a goblet and even dabbed the drinker's mouth with a napkin.

ROBOTS OF YORE

They seem like the stuff of any Disney World attraction: lifelike songbirds, a mechanical monkey, musical fountains, roaring lions. But they're actually robots and automata whose mechanical advances amazed both the commoner and noblesse during medieval times.

These ancient automata still hold their power to amaze, said Elly Truitt, an associate professor of history at Bryn Mawr College. In her recent book, *Medieval Robots*, she explores their history and design, and uncovers how people used mechanical technology to explain and understand the laws that govern the human body and the universe.

"Mechanical engineers will find in this book an exciting and untold history of their own profession," Truitt said.

By examining descriptions of mechanical automata in written records from travel narratives and household accounts throughout Latin Christian West, which covered most of contemporary Europe, Truitt learned how they grew more sophisticated over the centuries.

One of the region's earliest known mechanical automata was a brass clepsydra, or water clock, that the caliph of Baghdad presented as a gift to Charlemagne in 807. Small brass balls would drop into a metal basin to mark the hour, while a mounted horseman emerged from one of 12 windows, like an Advent calendar.

A 13th century water clock with an advanced gear structure that interlocks with bell-striking mechanisms.

Later, medieval engineers incorporated technologies such as meshed gears, cranks, and cams.

"It shows a broader understanding of how you can use the same source of power (water and wind) for more than one thing, and how that leads to more complex machines," Truitt said.

Although the names of the men who created many of the devices are lost to history, they included sorcerers, enchanters, wise men, philosophers, artisans, and monks, Truitt said.

Prominent among them was Ismael al-Jazari (1136-1206), a mechanical engineer and artist from what is now Turkey, who built a female wine servant dressed in colorful clothing and mounted on wheels. Wine trickled from a reservoir above her head through a small opening into a basin. When tilted, the basin poured the wine into a glass goblet. The wine servant then rolled toward the guest and lifted a napkin to wipe the drinker's mouth.

Then there was the Throne of Solomon, an elaborate moving tableau that graced the great palace of Constantinople in the early 10th century. In front of the throne stood a bronze-gilded tree filled with a variety of mechanical birds, which mimicked their species' correct song. As subjects bowed before the emperor and lifted their heads, his seat elevated, as if ascending to the heavens. Two gold-covered lions flanking the throne beat their tails and exposed quivering tongues when they opened their mouths to roar.

"The Middle Ages were filled with all kinds of scientific innovations ... and a lot of weird things," Truitt said. ME

JEFF O'HEIR

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